Ana-Maria Dabija *Editor*

Energy Efficient Building Design

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Preface

The topic of energy efficiency – focusing on the contribution of the design, components, and materials that define the building – is currently approached, so why another book? What does this book bring new in the field?

One answer is that with every year (and with every book), the scientific knowledge increases and the same principles can be – and are – studied from different angles, perspectives, and points of view, as well as from different parts of the world: contributions, both theoretical and case studies, come from Romania, Bulgaria, Greece, Italy, Turkey, and the United Arab Emirates, in other words, from a territorial area that spans from the Mediterranean Sea to the Persian Gulf and from South and South Eastern Europe to the Middle East.

Different perspectives are also the step toward innovation: after all, who could have imagined, two centuries ago, where would the observations made in 1839 by French Physicist Edmund Becquerel on the photovoltaic effect lead to? Or that the romantic vines that climb on fences and walls can have, in the same time, a beneficial and a destructive effect on the building and the environment? Or that bale and mud can represent today – as they did throughout the entire history of mankind, which is also a history of the building concepts and processes – reinvented or reinterpreted building materials? Or that the sun, apart from how Architect Louis Kahn described it "does not realize how wonderful it is until after a room is made," is also an ever-lasting means of energy for the building (and not only). In fact, it is Le Corbusier's definition of architecture that is maybe the most well-known in the world of architects, which brings together two keywords: light and volume (space): "Architecture is the masterly, correct and magnificent game of the volumes brought together under the light."

This book aims also to put more *light* on the link between fundamental scientific research and practical research – considering that designing a building represents an integrated, innovative, interdisciplinary research on materials and technologies. The sun is not only the one who gives value to a space, as Kahn said, or to a volume, as Le Corbusier said, but is also used by physicists, chemists, and engineers who transformed the solar energy and encapsulated it in integrated panels that provide energy or hot water while serving as building materials as well.

The building principles are mainly the same, as they are the responses to the rules of nature. How to integrate them in order to accomplish a finalized product – the building and the space surrounding it to the scale of the territory – is what makes the difference. The concept is unique; the tools are mainly the same and deal with the local conditions. The targets in the contemporary building industry, from concept to the final product, are the same everywhere in the world: to provide a comfortable shelter while preserving the natural and built heritage to the next generations. Therefore, the case studies represent the integration of the principles in practice; from the analysis of the residential architectural program to the hospital or sports arena examples, each study case emphasizes the interdisciplinarity of the design of a building.

We often joke that the architect's worst enemy is the engineer, and vice-versa. But, architects and engineers know that when dealing with materialized ideas that cast shadows on Earth, interdisciplinarity and scientific professional dialogue are the keys to a safe and healthy environment. The building and the built environment are the joint effort of teams of professionals of different specializations. Innovative materials and products are shaped and find their place as building products, contributing to a landmark of our epoch. Therefore, today, when engineering research results are integrated into building products, Walter Gropius's definition is so fresh: "Architecture begins where engineering ends."

Last but not least, we hereby gratefully thank the scientific committee who provided the peer-review process:

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Daniel Efurosibina Attoye and Kheira Anissa Tabet Aoul

1.1 Introduction

The growth and development of solar photovoltaic (PV) technology represent one of several current fields of interest which have significant impact across multiple disciplines. From engineering, to science, to environmental advocacy and architecture, solar PV has evolved into a very dynamic topic of discourse and debate, initiating much academic research and technological innovation. This introductory section reviews the importance of building-integrated solar PV; it also underscores its challenges as areas of research opportunities and future investigation. As a working definition, 'building-integrated photovoltaics (BIPV) is a renewable, solar PV technology that is integrated into buildings. It refers to solar PV components/modules that function as conventional building materials in the building envelope, such as the roof, skylights or façade elements [1]. This implies that without the BIPV component, the building envelope is exposed to external thermal conditions and will not be able to perform certain functions. For example, a BIPV roof, if removed, opens the built space to precipitation or dust. This definition distinguishes BIPV from building-applied photovoltaics (BAPV) which applies to solar PV modules attached to an existing roof or wall. BIPV implies that the solar PV module is a functional and integral part of the building which 'generates electricity for the building to reduce the energy needs and, at the same time, bear external loads and keep the safety and integrality of the building' [2]. Figure 1.1 illustrates a possible application of BIPV on a conventional building.

The significant advantages of this technology lie in its multifunctionality, a combination of energy, architectural, aesthetic, economic and environmental advantages which will be discussed later in this chapter. As an innovative PV technology, BIPV has grown into an interdisciplinary field with aspects of innovation relating to cell

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Fig. 1.1 Application of BIPV in transition. (Source: Authors)

efficiency and performance [3], energy generation [4, 5], thermal management [5], hybrid technologies [6, 7], building integration [8, 9] and customisation [10]. One unique aspect of the technology is its adaptability and scalability to various building prototypes and forms in any geographical location. This however requires sufficient technical know-how in the design process to enhance solar capture and optimise performance for maximum energy output [11]. To achieve this, the use of mathematical models, generic algorithms, parametricism and simulations has been used by several researchers. These studies aimed at investigating and optimising BIPV performance while accounting for shading, orientation and building integration complexities [12–14].

1.1.1 Justification

The global environmental conditions of the twenty-first century are perceived to be a direct and indirect result of the nineteenth-century Industrial Revolution. Global use of fossil fuels such as coal, oil and gas for automobiles and industries, for example, has not only dominated our energy mix since the revolution but also caused a rapid increase in harmful carbon dioxide emissions [15]. Literature shows that the increase in gaseous pollution is linked to globalisation and industrialisation, with its associated energy demands [16]. Although the intention of these developments is positive, negative impacts on health [17], local vegetation [16] and air quality [18] have been reported. It has been argued that unless checked by effective mitigation, 'the risks of dangerous climate change, already significant, will soon rise to dangerously high levels' [19]. Mitigation in various dimensions is therefore a key factor to improving the environment for present and future generations [20, 21]. Alternative sources of energy have been suggested to stem the rate of pollution due to the observed links with the use of non-renewable sources [22]. The focus on BIPV as a renewable energy option which applies solar energy represents an innovative, technological, mitigation strategy. Adoption of renewables such as solar and wind has been frequently discussed as potential solutions based on their aggregated effectiveness in this regard. Indeed, if future projections hold, renewables will account for over 50% of CO_2 emission reduction by 2050 [23]. They also contribute to economic development via an increase in gross domestic product [24], energy access, secure energy supply, and the reduction of negative impacts on the environment and health [15].

In line with the above, 'renewable energy development and utilization of renewable energy in other sectors have become the priority of many governments that are reflected in relevant public policies. Building sector is no exception' [25]. Beyond its vital role as a mitigation strategy, BIPV falls into a category of building-integrated renewable technologies which have become a part of international, regulatory building rating systems. With specific reference to green building rating systems (GBRS), energy efficiency and carbon emission reduction, renewable energy credits are considered a top priority when it comes to the energy category [26]. Indeed, adopting renewable energy technological innovations is critical towards meeting green building objectives and accreditation [27]. The crucial issue is, therefore, to advocate BIPV (and other renewable strategies) by advancing both mitigation towards environmental accountability and adoption towards green accreditation as complementing goals. A study comparing LEED, BREEAM and Estidama building rating systems [26] reports the following figures: three points can be earned under LEED for 10% renewable energy generation and a maximum of three points for 30% contribution under BREEAM. Comparatively, eight points can be earned under Estidama for 20% renewable energy generation. The study notes that the point variations could be related to the local environment challenges, smart grid provisions and government subsidies. It is sufficient to say that there is an international regulatory drive to support building-integrated renewables.

Contrary to expectation, the environmental, regulatory and accountability drives did not result in a remarkable global acceptance of BIPV as a renewable energy strategy in building design as evidenced from existing literature [10]. As of 2016, the global energy capacity added by solar PV to the world energy mix was about 303 GW, and BIPV contributed only 1% of that amount, that is 3.4GW [28–30]. Literature shows that there are barriers related to information and cost, for example, which are discussed later in this chapter. However, contrasting the slow uptake in BIPV despite three decades of application, with the global uptake of renewables in general, is perplexing. Indeed, many countries have set up governmental policies, government-supported programs, tax credits and other incentives to simply advance a shift towards renewable energy sources and highly efficient green sustainable energy systems [31, 32]. One study carried out a survey of 38 countries; authors boldly assert that renewable sources can be a significant driver of national economic growth [31], with the data showing that at least 16 EU countries are on that list. Although the study reports that, in some other cases, renewable energy usage had a negative and an unidentifiable economic impact, it surmises that unique country economics and an ineffective production process may be responsible.

BIPV is a type of renewable energy system, and based on the foregoing, it stands to reason that the necessary policy and mechanism for its uptake is in place—at least at some level. The question therefore is 'what has stifled global BIPV adoption?' The position of the authors is that a clear understanding of the importance and challenges of BIPV is a crucial first step to accepting it as a mitigation strategy, to redress the status quo and increase its adoption potential.

1.2 Background

BIPV systems represent a nexus of several technological and design-related aspects which have significant relevance to the architectural practice. From a broad perspective, the following are some of the core areas of current interest: the PV technology and system design, climatic issues, performance and optimisation and energy generation. Other areas are architectural integration and customisation, market, policy and cost issues and environmental impact concerns. Figure 1.2 shows these areas and some related subareas. Several researchers have reviewed key aspects of BIPV relating to the holistic BIPV ecosystem and life-cycle assessment [33, 34]. Few other core areas have focused on recent product advancements [35, 36], passive intelligence strategies [37], double-skin BIPV façades [38], research pathways [39] and knowledge/technological transfer criteria [40]. In these reviews, the solar technology, BIPV product, architectural integration and functionality have frequently been discussed.

In a clear distinction between PV and BIPV, the building-integrated system requires an adaptation of the PV technology to meet basic architectural component design requirements such as functionality, stability and aesthetics as well as energy generation [10]. For a BIPV project design, further emphasis should be given to the set goal for each of these targets. For example, Ref. [41] suggests a parametric method for ensuring optimum PV production using tilt angle, orientation and architectural integration to achieve the goals of energy generation and aesthetics. Ref. [11] designed a dynamic BIPV shading which tracks the sun, optimises energy generation and savings and prioritises architectural integration. Earlier reference to these BIPV customisation strategies has been referenced as a key means of resolving the conflict between PV energy generation and BIPV architectural integration [10]. These multilayered considerations, driven by the design goal, are crucial considerations in BIPV design. Indeed, some researchers have argued that achieving the target and deliverables of 'PV integration' in the envelope design is required from the early design phase (EDP) [37, 38, 40]. Ref. [40] made the argument for a synergic approach which ultimately unifies building and energy knowledge with specific consideration for the PV technology, aesthetics, physical and performance, construction as well as standards and warranties.

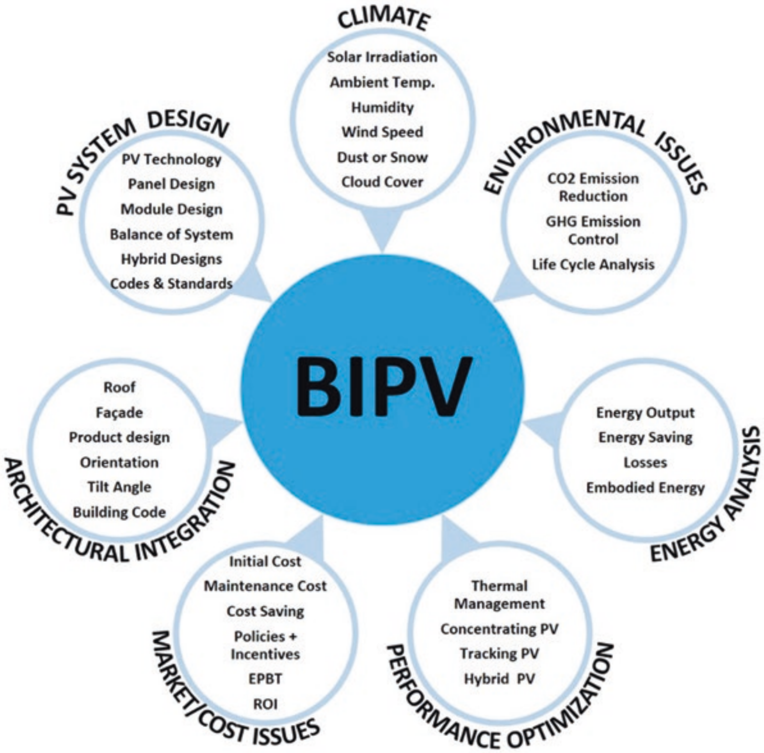

Fig. 1.2 General aspects of BIPV. (Source: by Authors)

From the client brief/program, to design conceptualisation in the schematic design stage, BIPV requires creativity and innovation. As an important response in line with this requirement, it is logical to expect that the system should maintain a high level of adaptability to suit multiple client requirements. In view of this essential requirement, some level of BIPV variety is intrinsically needed to meet the prime building objective of creating architectural designs which meet individual clients' expectations. In specific terms, this entails customisation of the BIPV system at the product and building integration levels [42], as well as the design and fabrication, and proper architectural integration of innovative products for the construction industry [10]. Potentially, BIPV customisation can achieve 2–80% improvement in power output and performance [41, 43, 44] compared with basic BAPV integration. This is however based on the kind of design as other studies have reported reduction in a range of 4–70% [45, 46]. These relationships and the resulting findings have been reviewed elsewhere in literature [10]. Table 1.1 shows multiple opportunities for customising BIPV to achieve the needed flexibility and variability for building integration; it highlights components, subcomponents and various variables for parametric design and fabrication, as well as architectural integration.

Table 1.1 BIPV customisation levels and potentials

Component	Subcomponent	First-level variable	Second-level variable
Design and fabrication	Cell technology	Mono-Si	
		Poly-Si	
		a-Si	
		CIGS	
		Organic	
	Cell shape	Square	
		Hexagonal	
	Module design	Packing factor	Option #1: Close
			Option #2: Far
		Glass/sheet material	Transparent
			Coloured
			Opaque
		Frame colour	Option #1: Dark
			Option #2: Light
		Cell arrangement	Option #1: Conventional
			Option #2: Patterns
	Module arrangement	Option #1: Conventional	
		Option #2: Unique (e.g. diagonal)	
Architectural integration	Location	Roof	Flat
			Pitched
			Curved
		Façade	Wall
			Window
		Exterior devices	Option #1: Shading
			Option #2: Balconies
		Advanced systems	Double-skin Façade
			Sun-tracking façades
	Products	Tiles	
		Foil	
		Module	
		Glazing	

Source: Adapted from [10], used with permission

Beyond customisation of BIPV, it has been argued that a necessary effort must be made to communicate its' potentials, advantages and related aspects [47]. This communication is needed by potential clients, researchers and investors, as well as policy- and decision-makers. Providing education and information to aid BIPV proposals made to clients or aid to research programmes requires a systematic communication approach [47]. Research surveys on public educational barriers state various reasons for the status quo such as a general lack of sufficient knowledge and poor understanding of cost perceptions of BIPV and financial benefit understanding

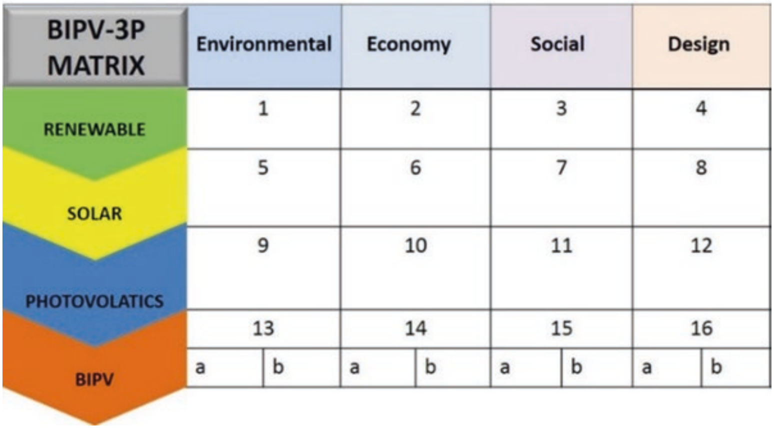

Fig. 1.3 BIPV-3P Matrix. (Source: Ref. [47], used with permission)

[48–50]. Also reported is a highly negative perception of the system price and costs associated with aesthetic BIPV options [49]. It has been reported that 'the successful design and realization of solar architecture—in general, relies upon the effective communication of its qualities in the development of a project' [49]. In a previous study [47], a communication matrix was developed to clearly present BIPV as a renewable solar PV technology, as well as its related environmental, economic, social and design-related benefits. Figure 1.3 shows the developed 'BIPV-3P Matrix' which represents this communication approach. Cells 1–16 were used to present intersecting discussion starters as a guide. For example, cells 1–4, respectively, contain environmental, economic, social and design-related benefits of renewables related to the specific project or proposal. Cells 5–8 would contain similar information but focus on solar energy, while cells 9–12 focus on PV specifically. Cells 13–16 are divided into two parts to communicate BIPV benefits as an energy source and a building component. Details of the justification, development process, matrix contents and preliminary evaluation are presented in the referenced study [47].

1.3 The Importance of BIPV

There are two broad aspects which underscore the importance of BIPV; these are the 'energy dimension' and the 'building dimension'. This section argues that in both cases, BIPV takes on a 'corrective' role for the PV and construction industries, respectively, and this emphasises its importance. BIPV is both an energy source and a building component; this means it classically combines features from these erstwhile distinct industries, in both practice and research. Interestingly, modern trends, technological development and definitely contemporary building requirements have also brought these fields closer, leading to the rise of sustainable building technologies.

1.3.1 BIPV as an Energy Source: 'The Energy Dimension'

The energy dimension considers BIPV as a technology which converts the building from an energy consumer to an energy generator [51], able to supply the local grid with clean, on-site solar energy as compared to conventional buildings which are 100% dependent on the grid. On the one hand, some researchers assert the unique benefits of solar to provide, in 1 hour, more energy than the total global energy demand for 1 year [52–54] that potentially makes BIPV a very effective sustainable energy source. On the other hand, the argument against this may raise the intermittency of solar radiation and issues with the geographical location, tilt angle and orientation. These opposing viewpoints suggest that there is ample opportunity for future research along these lines.

Over the past few decades, PV technology has emerged as a developing, yet leading, green technology which harnesses solar energy. PV cell efficiencies can reach about 26.5% for silicon-based types and 38.8% for multiple-junction terrestrial cells [55]. The cost of solar has dropped from \$76.67 per watt in 1977 to \$4.12 per watt in 2008 (Q2), to 22 cents per watt in 2018 (Q4) [56]. Unlike utility-scale PV plants, BIPV provides energy at the point of use, removing the need for the long-distance transmission of electricity with its associated transmission and distribution (T&D) costs as well as conversion/line losses [57–59]. Capital expenditure for land is also removed as the building envelope provides the needed base and support structure for the solar panels [57, 58, 60, 61].

From a social perspective, BIPV users are provided with a degree of energy autonomy as the technology potentially encourages owners'/operators' load-shifting and reduced levels of energy consumption [62, 63] by encouraging personal accountability. This is because BIPV favours a psychological reorientation of the consumer as a 'provider' of energy to their own building. Also, this may raise awareness of energy-related issues and thus trigger behavioural changes in energy usage [62]. In addition, BIPV can, in this regard, help protect consumers from power outages, and it carries the potential to significantly reduce uncertainty in power delivery [63]. The cost benefits to the client accrue in combination with grid integration where clients can supply to the grid and receive financial returns. Feed-in tariffs (FITs) thus lower cumulative costs and improve cost savings such that the equivalent cost of electricity is closer to zero [61, 64, 65]. In summary, as an energy source, BIPV has reduced environmental impact and stands as a potential improvement to existing utility-scale technology while providing social benefits and economic savings.

1.3.2 BIPV as a Building Component: 'The Building Dimension'

Ref. [66] asserts that 'the impact of buildings on the environment depends on their design, construction, use and location'. This could not be truer today two decades later: the building industry is deemed responsible for 30–40% of greenhouse gas emissions, 30–40% of solid waste generated and 20% of all water consumption [67]. Over 40% of global energy consumption and 10% of all CO_2 emissions are linked to the building industry [23, 68, 69]. The rapid expansion of construction activity can cause a variety of challenges in economic, spatial and environmental terms [70]. Some researchers boldly state that the construction sector has a 'dark side' [71] and describe this as the 'intensification of environmental deterioration through pollution, urban sprawl and destruction of vegetation' [71, 72]. These figures and assertions suggest that strategies are needed to address current trends in building design, energy demand and environmental impact. Options such as energy-efficient and green building and passive design [73, 74] have been frequently investigated. In their practical application, these strategies tend to directly or indirectly advocate or apply renewable energy.

The import of these references resonates with the argument to convert buildings from consumers of energy to producers of renewable energy. This is 'mitigationary', a substantial improvement as previously indicated, and generates good publicity for the client by earning green credit rating. In addition, it is also a corrective and responsible response to decades of 'unsustainable building designs and practices'. BIPV satisfies this triple requirement and also brings a unique plethora of opportunities to the building industry. As a building material, BIPV replaces conventional building components such as roofing, walls, glazing, cladding and fenestrations and other structures like shading devices, parapets and balconies. Each of these components provides opportunities for integrating PVs to the building and, by extension, for customisation [39, 75–79]. Here, the potential of multifunctional application is clearly emphasised. BIPV can be applied as safety glass [78], a privacy screen as a visual cover employing one-way mirroring [77, 78], or in transparent options using thin film for light transmission and visual contact with the exterior [78, 80, 81]. Other applications include sun protection/shading/lighting modulation [39, 75, 77, 78, 81] and noise protection—reaching up to 25 dB sound dumping [39, 75, 78, 81].

From a cost point of view, BIPV provides material and labour savings because it replaces other building materials that would have otherwise incurred their own assembly and mounting costs [39, 82]. In addition, BIPV can aid reduction of the ongoing costs of a building via operational cost savings and reduced embodied energy [83]. It is also a modern means of replacing conventional materials such as brickwork [75]. BIPV serves as a public demonstration of the owner's green, ecological and futurist persona [78], thus becoming a tool to make 'a statement about one's environmental consciousness'. As aesthetics is a huge consideration within the architectural parlance, innovative and customised BIPV options provide unique colour, size variations and flexibility [10, 39, 78, 84]. The BIPV market offers new products which can be curved, transparent, translucent or opaque, providing architects with a vast palette of options. Table 1.2 shows a categorised summary of BIPV benefits relating to design, cost and environmental aspects within the building dimension.

Table 1.2 Benefits of BIPV

Aspect	Reference
1. Design-related benefits	
View and daylighting—semi-transparent options allow for light transmission and contact with exterior	[78, 80]
Aesthetic quality—integration in buildings as a design element	[39, 78]
Sun protection/shadowing/shading modulation; used as fixed or movable shading devices	[39, 75]
Replacement of conventional materials such as brickwork	[75]
Public demonstration of the owner's green ecological and future-oriented image	[78]
Safety—applied as safety glass	[78]
Noise protection—reaching up to 25 dB sound dumping	[39, 75]
Heat protection/thermal insulation (heating as well as cooling)—improvement in the efficiency of cells by cooling through rear ventilation	[39, 75]
Visual cover/refraction—one-way mirroring visual cover	[77, 78]
2. Economic benefits	
Removal of the need for the transmittance of electricity over long distances from power generation stations	[57, 58]
Reduction in capital expenditure for infrastructure and maintenance	[57, 58]
Reduction in land use for the generation of electricity	[60, 61]
Material and labour savings as well as electrical cost reductions	[39]
Reduction in additional assembly and mounting costs; lowering of total building material costs and significant savings	[82]
Ongoing costs of a building are reduced via operational cost savings and reduced embodied energy	[83]
Combined with grid connection, FITs; cost savings equivalent to the rate the electricity is close to zero	[55, 61]
3. Environmental benefits	
Reduction of carbon emissions	[61]
Pollution-free benefit of solar energy	[83]
Reduction of the social cost of carbon (SCC) relating to the health of the public and the environment	[61]

Source: Ref. [85], used with permission

1.4 BIPV Development and Challenges

The technological developments in BIPV technology have established the opportunity to transform buildings into renewable energy-based generators. Consequently, this chapter has highlighted the ensuing challenge to meet both conventional architectural design objectives and optimum PV performance. This task becomes more complicated with the constantly evolving nature of both the construction and PV industries. Potentially, industry collaborations, continuous professional development and training could help bridge the knowledge and the industrial gaps. Currently the PV market consists of a wide range of material and manufacturing processes leading to the need for knowledge transfer regarding the efficiency and suitability of the available technologies [86]. Architecture on the other hand has birthed metropolitan cities with skyscrapers and multi-storey buildings—in almost every country, which have less roof space and more façade area for BIPV installations. Consequently, façade integration of PV technology is one crucial area of BIPV development. Notwithstanding, BIPV components can be integrated into façades, roofs and other building areas such as balconies, parapets and shading devices.

Product development for building integration has evolved over the years. Several companies like *Tesla* and *Onyx Solar* now provide unique products with options for aesthetic architectural integration. Various product types include BIPV tiles, BIPV film which use thin-film technology, BIPV modules which is a weathertight PV application and other PV glazing technologies [82]. As BIPV products continue to develop, the salient goal to satisfy ‘architectural design requirements’ will unequivocally include, among other things, building aesthetics. An overview of state-of-the-art BIPV products reveals that BIPV module layers (glass, polymers, PV-active layers) now have technical solutions for colour application [87]. Although there are still product limitations, BIPV products now come in a variety of colours and sizes and can match the other non-BIPV building components. This would ultimately suit design requirements and working practices in the construction industry [88].

On a broader scale, the International Energy Agency Photovoltaic Power System (IEA PVPS) Task 15 is a leading proponent for identifying the necessary mechanisms for accelerating BIPV adoption. Authors of a Subtask E 2019 report [87] have extensively discussed the certain key developments in the BIPV field which relate to dissemination, business modelling, regulatory issues, environmental aspects and demonstration sites. To address the bottlenecks in the development of architectural-friendly BIPV products, the report highlights cost as a barrier but also notes that ‘a lot of effort has been made to improve and optimize the relationship between colour and efficiency/power generation of BIPV elements’.

1.4.1 BIPV Challenges

The challenge with BIPV design is that meeting architectural design objectives is sometimes in conflict with PV design requirements for maximum energy output. For example, consider a BIPV glazing design selection to ensure view and daylight versus maximum power output; transparency is key towards meeting the former, while conventionally, the latter is achieved by opaque solar panels. In innovative cases, the characteristics of conventional BIPV façades have been modified to address such conflicts through customisation as an emerging trend in BIPV façade design. In a previous study [10], the identification of six broad categories of challenges to BIPV adoption was presented. These relate to education/information, product, examples, cost/economy, industry and management. The secondary data for the study covered ten countries and represents the opinions of close to a thousand international respondents and identified varying perspectives and issues of concern. For example, some studies highlight challenges related to various stages of

Fig. 1.4 An overview of identified BIPV challenges. (Source: Adapted from Ref. [10])

application [89], such as the design stage and installation stage. From a more general perspective, other studies identified sociotechnical, management, economic, policy-related [48] as well as knowledge and information-related challenges [90]. Still others noted insufficient presentation of BIPV product and project databases, lack of adequate business models and insufficient dissemination of BIPV information [70]. Figure 1.4 outlines several of these challenges and the key issues under each category. Beyond the scope of this chapter is the need to elucidate and categorise a qualitative, quantitative or mixed-methodological consideration, each of these challenges as future research opportunities, for students and research institutions.

1.5 Further Research

As with any innovative technology, it is expected that trends in research and development will target current and emerging challenges, driving investigations, innovations and inventions. The literature on BIPV is growing as aspects of PV efficiency and performance optimisation have driven the industry for years and will continue to do so. However, there are other areas of research which are likely to spur interest within interdisciplinary research in the near future. One specific area of interest would be the development of simple and comprehensive BIPV design and communication tools. PV tools like PVWatts and PVSyst provide information for engineers about PV output. However, these need to seamlessly integrate with existing design software and also maximise digital technologies for client-designer communication. The need is for design requirements like colour, shape and size to be available for parametric and design iteration during early-stage BIPV design decisions and interactions. As an example, the *PVSites* BIPV simulation tool [91, 92] provides some of these functions. Further work is required to create, upgrade and integrate needed plugins with existing Building Information Modelling (BIM) functions for both technical design and presentation software and tools for designers. Another area of needed investigation is to use BIPV demonstration projects in new markets to drive research, innovation adoption and market diffusion. This is indeed a direct response to studies on drivers of BIPV adoption [10]. This expands and applies the work done by the IEA PVPS Task 15 on enabling and accelerating BIPV adoption [87, 90] with focus on demonstration projects. The need is to guide qualitative and quantitative evaluation of these built cases to improve our understanding of market trends, drivers, challenges and needed improvements. For example, how do users perceive the 'interior and exterior' BIPV spaces? Which products are key 'market drivers' in each market? What concerns do prospective clients have about their local architectural identity or heritage? And how well does the system perform overtime—energy- and cost-wise, in relation with existing and changing energy policies? Yet many more technical and non-technical questions need to be regionally addressed by a construct critique of built examples.

Furthermore, curriculum development for students and continuing professional development (CPD) seminars and workshops are key needs from an educational perspective. With so much happening in the manufacturing and PV industries, there is the need to create, update and enhance course content on BIPV. Some studies have systematically identified and outlined knowledge, technological and educational needs [40, 93]. The next step may be to push for some international curricula standard with regional focus to address specific issues. On another hand, a global BIPV policy review will be crucial to facilitate professional practise. This will require the review of current policy examples across Europe and the rest of the world; research findings and lessons learnt from various models will be a necessary input in this process. The knowledge gap is the task here: connecting specialists and learners and bridging the gap between research, manufacture and practise to promote the market. These aspects mentioned will become the building blocks for online courses which have the needed flexibility and versatility needs to reach multiple learners, creating an online, one-stop platform of crucial information for the BIPV community.

Other aspects relating to grid integration, social incentives and new products, such as BIPV paint, BIPV glass blocks, BIPV plug and play components, will also need to go through design, testing, code compliance and market introduction. There are indeed so many areas of research; however, the key consideration should be to maintain a balanced techno-social approach. This means developing the technology, not as an electrical device to be attached to the building form, but as a building material which expresses the designer's creativity and meets the client's demands with respect for regional codes and regulations.

1.6 Conclusion

The future outlook for BIPV is tied to the global perception of the need to address environmental issues related to energy and building impacts. This chapter has presented a justification for BIPV from an environmental and building dimension while outlining its importance, development and associated adoption challenges. BIPV is a renewable energy-based technology which utilises solar energy applied as a decentralised, onsite energy generator while serving as a multifunctional building component. Here, where design meets technology is the future of BIPV, a consideration of the multi-criteria demands needed for the evolution of both architectural and technological innovations.

Looking forward, Ref. [31] classically sums the ideal scenario where the deployment of renewables embraces cost-effectiveness, efficiency, infrastructure and being mindful of regulatory barriers and the institutional structure of any country. With growing global research and government interest, one wonders if BIPV will remain an alternative energy source. Buildings are getting more complex, integrated and smart and more fluid and multifunctional. As such, the materials we build with must match the emerging demands of energy efficiency, design innovation, environmental consciousness and the ever-crucial dimension of a people-focused, sustainable design ideology. Literature and practise prove that BIPV provides the architect with a perfect opportunity to meet these ever-evolving twenty-first-century building design requirements.

References

1. BCC Research. Building-integrated photovoltaics (BIPV): technologies and [5] global markets. A BCC energy and resources report 2016
2. Y. Li et al., Mechanical analysis of photovoltaic panels with various boundary condition. Renew. Energy **145**, 242–260 (2020)
3. M.A. Green, S.P. Bremner, Energy conversion approaches and materials for high-efficiency photovoltaics. Nat. Mater. **16**(1), 23–34 (2016)
4. A. Elnosh et al., Field study of factors influencing performance of PV modules in buildings (BIPV/BAPV) installed in UAE, 2018. https://doi.org/10.1109/PVSC.2018.8547298
5. A. Hasan et al., Energy and cost saving of a photovoltaic-phase change materials (PV-PCM) system through temperature regulation and performance enhancement of photovoltaics. Energies **7**(3), 1318–1331 (2014)
6. L. Belussi et al., LCA study and testing of a photovoltaic ceramic tile prototype. Renew. Energy **74**, 263–270 (2015)

7. M. Morini, R. Corrao, Energy optimization of BIPV glass blocks: a multi-software study. Energy Procedia **111**, 982–992 (2017)
8. W. Bahr, A comprehensive assessment methodology of the building integrated photovoltaic blind system. Energy Buildings **82**, 703–708 (2014)
9. H. Elarga, A. Zarrella, M. De Carli, Dynamic energy evaluation and glazing layers optimization of façade building with innovative integration of PV modules. Energy Buildings **111**, 468–478 (2016)
10. D.E. Attoye et al., A review on building integrated photovoltaic façade customization potentials. Sustainability **9**(12), 2287 (2017)
11. P. Jayathissa et al., Optimising building net energy demand with dynamic BIPV shading. Appl. Energy **202**, 726–735 (2017)
12. R.A. Agathokleous, S.A. Kalogirou, Part II: thermal analysis of naturally ventilated BIPV system: modeling and simulation. Sol. Energy **169**, 682–691 (2018)
13. L. Walker, J. Hofer, A. Schlueter, High-resolution, parametric BIPV and electrical systems modeling and design. Appl. Energy **238**, 164–179 (2019)
14. L. Zhu et al., A simplified mathematical model for power output predicting of Building Integrated Photovoltaic under partial shading conditions. Energ. Conver. Manage. **180**, 831–843 (2019)
15. IPCC, Summary for policymakers, in *IPCC Special Report On Renewable Energy Sources and Climate Change Mitigation*, ed. by O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C. von Stechow, (Cambridge University Press, Cambridge, UK; New York, 2011)
16. L.D. Emberson et al., Impacts of air pollutants on vegetation in developing countries. Water Air Soil Pollut. **130**(1), 107–118 (2001)
17. J. Fenger, Urban air quality. Atmos. Environ. **33**(29), 4877–4900 (1999)
18. B. Saboori, J. Sulaiman, S. Mohd, Economic growth and CO2 emissions in Malaysia: a cointegration analysis of the environmental Kuznets curve. Energy Policy **51**, 184–191 (2012)
19. S. Lodhia, N. Martin, The Garnaut review. Sustain. Account. Manag. Policy. J. **3**(1), 33–49 (2012)
20. W. Liu et al., Minimizing the carbon footprint for the time-dependent heterogeneous-fleet vehicle routing problem with alternative paths. Sustainability **6**(7), 4658–4684 (2014)
21. D. Knera, D. Heim, Application of a BIPV to cover net energy use of the adjacent office room. Manag. Environ. Qual. Int. J. **27**(6), 649–662 (2016)
22. A.O. Adewuyi, O.B. Awodumi, Renewable and non-renewable energy-growth-emissions linkages: review of emerging trends with policy implications. Renew. Sustain. Energy Rev. **69**, 275–291 (2017)
23. IRENA 2017. Accelerating the energy transition through innovation: WORKING PAPER based on global REmap analysis, June 2017
24. A.K. Tiwari, Comparative performance of renewable and nonrenewable energy source on economic growth and CO2 emissions of Europe and Eurasian countries: a PVAR approach. Econ. Bull. **31**(3), 2356–2372 (2011)
25. J. Zuo, Z. Zhao, Green building research–current status and future agenda: a review. Renew. Sustain. Energy Rev. **30**, 271–281 (2014)
26. O. Awadh, Sustainability and green building rating systems: LEED, BREEAM, GSAS and Estidama critical analysis. J. Build. Eng. **11**, 25–29 (2017)
27. Q. Shi et al., Identifying the critical factors for green construction – an empirical study in China. Habitat Int. **40**, 1–8 (2013)
28. W. van Sark et al., Development of BIPV courseware for students and professionals: the Dem4BIPV project, in *Proceedings of the 33rd European Photovoltaic Solar Energy Conference*, Thursday, 28 Sept 2017, pp. 2895–2899. WIP-Renewable Energies, 2017
29. J. Sawin, Renewable energy policy network for the 21st century renewables 2017 global status report; REN21 secretariat: Paris, France, 2017, pp. 1–302

30. IEA PVPS. Snapshot of global photovoltaic markets; Report IEA PVPS T1-31, 2017. Available online: http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA-PVPS_-_A_Snapshot_of_Global_PV_-_1992-2016__1_.pdf. Accessed on 1 Apr 2018
31. S. Bhattacharya et al., The effect of renewable energy consumption on economic growth: evidence from top 38 countries. Appl. Energy **162**, 733–741 (2016)
32. P. Kumar et al., A review of multi criteria decision making (MCDM) towards sustainable renewable energy development. Renew. Sustain. Energy Rev. **69**, 596–609 (2017)
33. F.J.W. Osseweijer et al., A comparative review of building integrated photovoltaics ecosystems in selected European countries. Renew. Sustain. Energy Rev. **90**, 1027–1040 (2018)
34. T. Zhang, M. Wang, H. Yang, A review of the energy performance and life-cycle assessment of building-integrated photovoltaic (BIPV) systems. Energies **11**(11), 3157 (2018)
35. A.K. Shukla, K. Sudhakar, P. Baredar, Recent advancement in BIPV product technologies: a review. Energy Buildings **140**, 188–195 (2017)
36. M. Tripathy, P.K. Sadhu, S.K. Panda, A critical review on building integrated photovoltaic products and their applications. Renew. Sustain. Energy Rev. **61**, 451–465 (2016)
37. Y. Ibraheem, E.R.P. Farr, P.A.E. Piroozfar, Embedding passive intelligence into building envelopes: a review of the state-of-the-art in integrated photovoltaic shading devices. Energy Procedia **111**, 964–973 (2017)
38. R.A. Agathokleous, S.A. Kalogirou, Double skin facades (DSF) and building integrated photovoltaics (BIPV): a review of configurations and heat transfer characteristics. Renew. Energy **89**, 743–756 (2016)
39. B. Jelle, Building integrated photovoltaics: a concise description of the current state of the art and possible research pathways. Energies **9**(1), 21 (2016)
40. P. Bonomo, A. Chatzipanagi, F. Frontini, Overview and analysis of current BIPV products: new criteria for supporting the technological transfer in the building sector. VITRUVIO Int. J. Archit. Technol. Sustain. (1), 67–85 (2015)
41. C. Hachem, M. Elsayed, Patterns of façade system design for enhanced energy performance of multistory buildings. Energy Buildings **130**, 366–377 (2016)
42. D.E. Attoye et al., Innovative building integrated photovoltaic façade: parametric design, advantages and challenges, in *Proceedings of the 12th Conference On Advanced Building Skins (ABS2017)*, Bern, Switzerland, Oct 2–3 2017
43. D. Hardy et al., Improving the aesthetics of photovoltaics through use of coloured encapsulants, in *Proceedings of the PLEA 2013—29th Conference, Sustainable Architecture For A Renewable Future*, Munich, Germany, 10–12 Sept 2013
44. Z. Nagy et al., The adaptive solar facade: from concept to prototypes. Front Archit. Res. **5**, 143–156 (2016). https://doi.org/10.1016/j.foar.2016.03.002
45. S.Y. Lien, Artist photovoltaic modules. Energies **9**, 551 (2016)
46. G. Peharz et al., Application of plasmonic coloring for making building integrated PV modules comprising of green solar cells. Renew. Energy **109**, 542–550 (2017)
47. D.E. Attoye et al., A conceptual framework for a building integrated photovoltaics (BIPV) educative-communication approach. Sustainability **10**(10), 3781 (2018)
48. E. Karakaya et al., Barriers to the adoption of photovoltaic systems: the state of the art. Renew. Sustain. Energy Rev. **49**, 60–66 (2015)
49. M.M. Probst, C. Roecker, Criteria for architectural integration of active solar systems IEA Task 41, Subtask A. Energy Procedia. **30**, 1195–1204 (2012)
50. A. Prieto et al., Solar façades-main barriers for widespread façade integration of solar technologies. J. Façade Des. Eng. **5**, 51–62 (2017)
51. B. Hagemann, Examples of successful architectural integration of PV: Germany. Prog. Photovolt. Res. Appl. **12**(6), 461–470 (2004)
52. M. Thirugnanasambandam et al., A review of solar thermal technologies. Renew. Sustain. Energy Rev. **14**(1), 312–322 (2010)
53. O. Morton, Solar energy: a new day dawning?: Silicon Valley sunrise. Nature **443**, 19–23 (2006)

54. N.S. Lewis, D.G. Nocera, Powering the planet: chemical challenges in solar energy utilization. Proc. Natl. Acad. Sci. **103**(43), 15729–15735 (2006)
55. M.A. Green et al., Solar cell efficiency tables (version 52). Prog. Photovolt. Res. Appl. **26**(7), 427–436 (2018)
56. M.A. Green, How did solar cells get so cheap? Joule **3**(3), 631–633 (2019)
57. A. Sagani, J. Mihelis, V. Dedoussis, Techno-economic analysis and life-cycle environmental impacts of small-scale building-integrated PV systems in Greece. Energ. Buildings **139**, 277–290 (2017)
58. S. Sharples, H. Radhi, Assessing the technical and economic performance of building integrated photovoltaics and their value to the GCC society. Renew. Energy **55**, 150–159 (2013)
59. R. Timilsina, L. Kurdgelashvili, P.A. Narbel, Solar energy: markets, economics and policies. Renew. Sustain. Energy Rev. **16**(1), 449–465 (2012)
60. L. Byrnes et al., Australian renewable energy policy: barriers and challenges. Renew. Energy **60**, 711–721 (2013)
61. R.J. Yang, P.X. Zou, Building integrated photovoltaics (BIPV): costs, benefits, risks, barriers and improvement strategy. Int. J. Constr. Manag. **16**, 39–53 (2016)
62. R. Sauter, J. Watson, Strategies for the deployment of micro-generation: implications for social acceptance. Energy Policy **35**(5), 2770–2779 (2007)
63. D. Dunn-Rankin, E.M. Leal, D.C. Walther, Personal power systems. Prog. Energy Combust. Sci. **31**(5), 422–465 (2005)
64. A.S. Abdullah et al., Renewable energy cost-benefit analysis under malaysian feed-in-tariff. (2012). https://doi.org/10.1109/SCOReD.2012.6518631
65. P. Hammond et al., Whole systems appraisal of a UK Building Integrated Photovoltaic (BIPV) system: energy, environmental, and economic evaluations. Energy Policy **40**, 219–230 (2012)
66. D.J. Harris, A quantitative approach to the assessment of the environmental impact of building materials. Build. Environ. **34**(6), 751–758 (1999)
67. http://www.saint-gobain.co.uk/sustainability/sustainable-construction/. Date accessed 19 Jan 2018 at 19:14
68. P. Nejat et al., A global review of energy consumption, CO2 emissions and policy in the residential sector (with an overview of the top ten CO2 emitting countries). Renew. Sustain. Energy Rev. **43**, 843–862 (2015)
69. World Energy Council (WEC), *World Energy Resources 2013 Survey* (World Energy Council, London, 2013)
70. O. Balaban, The negative effects of construction boom on urban planning and environment in Turkey: unraveling the role of the public sector. Habitat Int. **36**(1), 26–35 (2012)
71. N.Z. Abidin, Investigating the awareness and application of sustainable construction concept by Malaysian developers. Habitat Int. **34**(4), 421–426 (2010)
72. V. Yorucu, R. Keles, The construction boom and environmental protection in Northern Cyprus as a consequence of the Annan Plan. Constr. Manag. Econ. **25**(1), 77–86 (2007)
73. M.A. Brown, F. Southworth, Mitigating climate change through green buildings and smart growth. Environ. Plan. A. **40**(3), 653–675 (2008)
74. C.E. Ochoa, I.G. Capeluto, Strategic decision-making for intelligent buildings: comparative impact of passive design strategies and active features in a hot climate. Build. Environ. **43**(11), 1829–1839 (2008)
75. P. Heinstein, C. Ballif, L. Perret-Aebi, Building integrated photovoltaics (BIPV): review, potentials, barriers and myths. Green **3**(2), 125–156 (2013)
76. M.C. Munari et al., Solar energy systems in architecture-integration criteria and guidelines, in *International Energy Agency Solar Heating and Cooling Programme*, ed. by M. Probst, M. Cristina, C. Roecker, (International Energy Agency, Paris, 2013)
77. K. Farkas et al., in *Designing Photovoltaic Systems for Architectural Integration*, ed. by K. Farkas, (International Energy Agency, Paris, 2013)

78. D.F. Montoro et al., Building integrated photovoltaics: an overview of the existing products and their fields of application, in *Report Prepared in the Framework of the European Funded Project*, (SUNRISE, Saskatoon, 2011)
79. R. Thomas (ed.), *Photovoltaics and Architecture* (Taylor & Francis, Didcot, 2003)
80. M. Pagliaro, R. Ciriminna, G. Palmisano, BIPV: merging the photovoltaic with the construction industry. Prog. Photovolt. Res. Appl. **18**(1), 61–72 (2010)
81. M. Oliver, T. Jackson, Energy and economic evaluation of building-integrated photovoltaics. Energy **26**(4), 431–439 (2001)
82. B. Petter Jelle, C. Breivik, H. Drolsum Røkenes, Building integrated photovoltaic products: a state-of-the-art review and future research opportunities. Sol. Energy Mater. Sol. Cells **100**, 69–96 (2012)
83. S. Morris, *Improving Energy Efficient, Sustainable Building Design and Construction in Australia—Learning from Europe* (ISS Institute, Carlton, 2013)
84. D.A. Hardy, S.C. Roaf, B.S. Richards, Integrating photovoltaic cells into decorative architectural glass using traditional glass-painting techniques and fluorescent dyes. Int. J. Sustain. Dev. Plan. **10**(6), 863 (2015)
85. D.E. Attoye et al., Innovation in construction: the case of BIPV customization in extreme climates, in *Proceedings of Comfort At The Extremes Conference (CATE) 2019*, Heriot Watt University, Dubai, Apr 10–11 2019
86. L. El Chaar, L.A. lamont, N. El Zein, Review of photovoltaic technologies. Renew. Sustain. Energy Rev. **15**(5), 2165–2175 (2011)
87. G. Eder et al., Coloured BIPV: market, research and development, 2019
88. I. Zanetti et al., Building integrated photovoltaics: product overview for solar building skins-status report, Kidlington, UK, 2017
89. R.J. Yang, Overcoming technical barriers and risks in the application of building integrated photovoltaics (BIPV): hardware and software strategies. Autom. Constr. **51**, 92–102 (2015)
90. S. Ritzen et al., IEA-PVPS Task 15: enabling framework for BIPV acceleration (IEA-PVPS)", in *Proceedings of the 48th IEA PVPS Executive Committee Meeting*, Vienna, Austria, 16 Nov 2016
91. Prototype of BIPV simulation tool – Second version – PVSites (2017) Available online at https://www.pvsites.eu/downloads/category/project-results?page=2. Accessed 14 Oct 2019
92. P. Alamy, V.K. Nguyen, PVSITES software tools for BIM-based design and simulation of BIPV systems, in *Proceedings of the Advanced Building Skins Conference*, Bern, Switzerland, pp. 1–2, 2018
93. M. Tabakovic et al., Status and outlook for building integrated photovoltaics (BIPV) in relation to educational needs in the BIPV sector. Energy Procedia **111**, 993–999 (2017)

Chapter 2
Design Opportunities and Building Integration of PV systems

Ludmil Stoyanov, Zahari Zarkov, Gilles Notton, and Vladimir Lazarov

2.1 Introduction

The building integration of PV panels was considered an exotic idea because often the panels' productivity is not optimal. However, in recent years, PV integration has become almost mandatory because of requirements for buildings with small or zero energy consumption and because of PV panel price reduction which increases the profit even if the production is not optimal [1, 2].

It is important to note that with a small compromise in a building's shape, it is possible to increase significantly the PV system productivity. It is therefore important to determine the productivity of integrated systems at the design stage to give directions to architects and civil engineers for the orientation, height, and shape of the building as well as for surfaces with PV modules. Also it is possible to resolve the inverse problem – to forecast the energy production of a given building.

Different researches over the years [3] show that most of the Earth's population is situated in the Northern Hemisphere. The largest proportion is located at a latitude of about 30° because it is in India, Indonesia, and China. A high population density is also observed in Europe and the USA, but it is located in higher latitudes. On the other hand, in the north latitudes, agriculture is very well developed – 8 countries (EU included) in the top 10 countries with the largest agricultural output are located in the Northern Hemisphere. Thus, the use of agricultural terrains for installation of PV power plants is not suitable, and the use of building-integrated PV can be an appropriate solution. For these reasons, this research is oriented to Earth's Northern Hemisphere.

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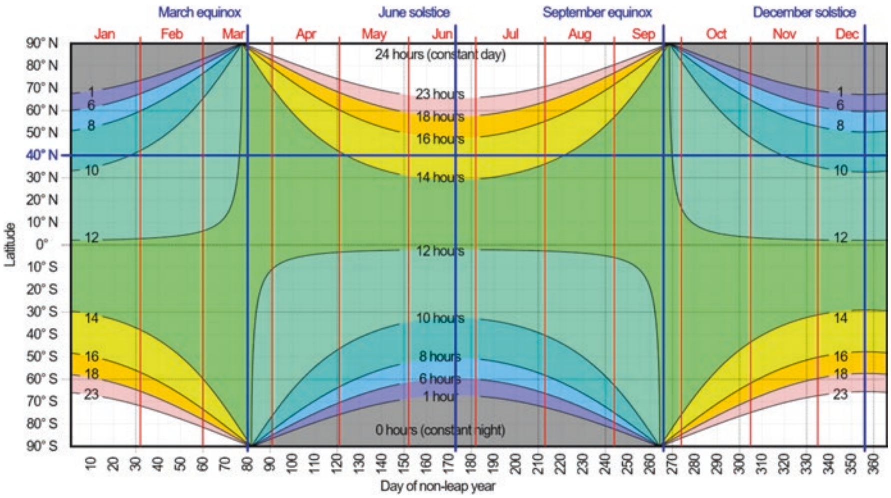

Fig. 2.1 Daylight duration over the year for different latitudes [4]

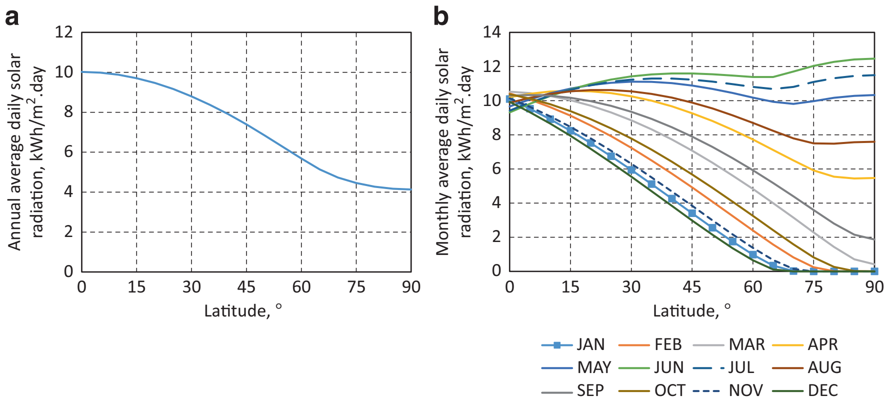

Fig. 2.2 Average daily solar radiation for different latitudes on annual (**a**) and monthly (**b**) basis

On the other hand, the duration of sunshine varies with the latitude. Figure 2.1 shows the daylight duration over the year for different latitudes [4]. The daylight duration variation provides changes in the average daily solar radiation [5]. The changes on an annual basis are illustrated in Fig. 2.2a. We observe that the daily solar radiation decreases more than two times with the latitude increasing. However, in Fig. 2.2b, we can see that for the months from May to July, the daily solar radiation is higher for high latitudes and higher solar electricity production is possible. Thus, the annual simulation of the PV installation is necessary to provide complete information about the installation's energy yield. Figure 2.3 presents the annual variation of the average solar radiation on a daily basis over the year and illustrates the advantage of the high latitudes for some of the months around June [6]. It is

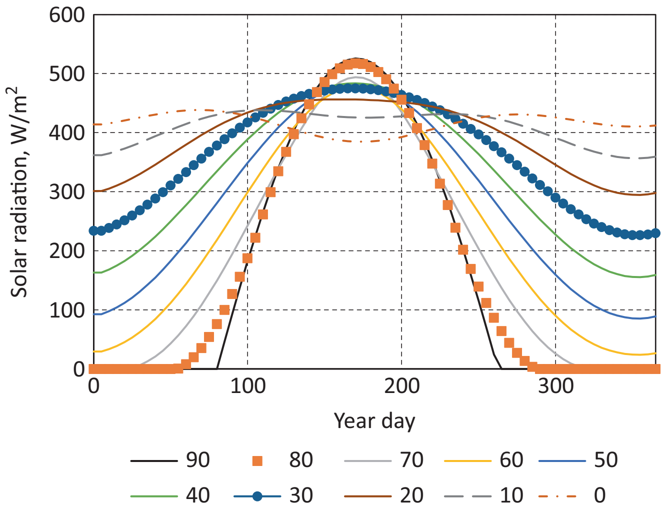

Fig. 2.3 Average solar radiation by year's days for different latitudes

important to notice that Figs. 2.2 and 2.3 use the solar radiation outside the atmosphere (given bellow) and show its theoretical variation.

To estimate the influence of the building shape on the obtained energy yield, the productivity is compared of two crystalline and three thin-film PV technologies – mono-, poly-, and microcrystalline silicon, copper indium gallium selenide (CIGS), and cadmium telluride (CdTe) for different orientations. Five PV technologies with different behavior are examined because of the variable influence of the solar radiation and cell temperature on them. This is illustrated on Fig. 2.4 on the basis of calculations using the mathematical model of PV panel, described below. The solar radiation varies from 0 to 1000 W/m^2, while the cell temperature changes from 15 °C (highest curves) to 55 °C (lowest curves) with step of 10 °C. The influence of both meteorological variables on the PV panels' efficiency is different for each technology. The two technologies differ – for the μSi the cell, temperature has smallest influence, while for CIGS, a positive influence of the solar radiation is observed.

2.2 Methodology

To achieve the objective of this study, the annual energy yield of different panels' technologies for variable orientations should be determined. The energy harvesting is estimated for every hour of the year using a model that provides the PV panels' efficiency. This model uses as input variables the solar radiation and the ambient temperature. Those variables should be converted because the initial data is not appropriate. The variables' conversion and the energy estimation are detailed below.

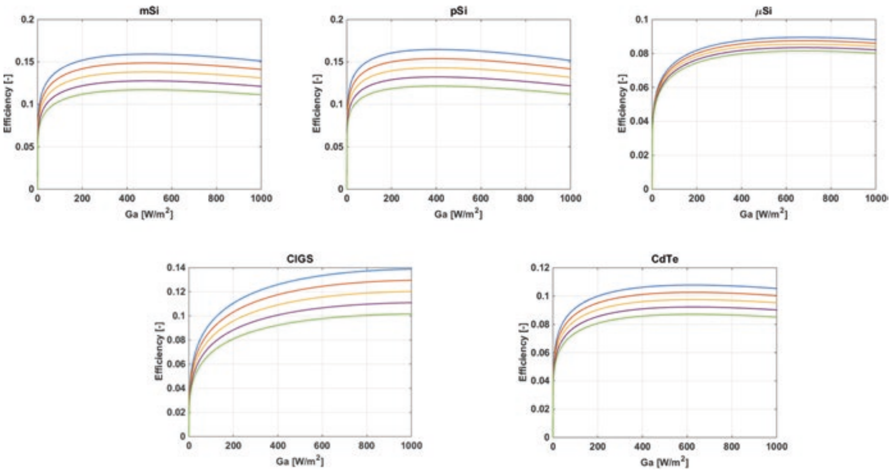

Fig. 2.4 Variation of the efficiency of five studied technologies for different solar radiations and cell temperatures (from 15 °C (highest curves) to 55 °C (lowest curves) with step of 10 °C)

2.2.1 Adaptation of the Solar Radiation

The solar radiation is the most important factor in the estimation of the energy yield of PV panels. The measured values and the initial theoretical estimations are for horizontal surfaces. In this study, these are considered large number of surface's orientations which differ by azimuth and inclination. Thus, it is necessary to transform the initial data into correct input for the model. Two approaches are used in the study – theoretical (idealized) and realistic (using real statistical meteorological data). In the first one, the solar radiation outside the atmosphere is used to avoid the influence of different factors such as shading by clouds, mountains, etc., which allows for general conclusions by civil engineers. In the second one, the use of measured real data for the solar radiation from a given site takes into account the neglected factors from the first approach, and the drawn conclusions are more definite and realistic. Moreover, the diffuse component of the solar radiation is also considered.

The solar radiation outside the atmosphere $G_{\text{ext}\beta}$ on an arbitrary oriented surface depends on the solar constant C_{SC}, the eccentricity correction factor of the Earth's orbit E_0, and the incidence angle θ_{s} [5]:

$$G_{ext\beta} = C_{\text{SC}} E_0 \cos\theta_{\text{s}} \tag{2.1}$$

The solar constant represents the solar radiation that reaches the first layers of the atmosphere and is equal to 1367 W/m^2 [5].

The eccentricity correction factor of the Earth's orbit is the squared ratio between the average r_0 and the actual r distance between the Earth and the Sun and is determined by [5]:

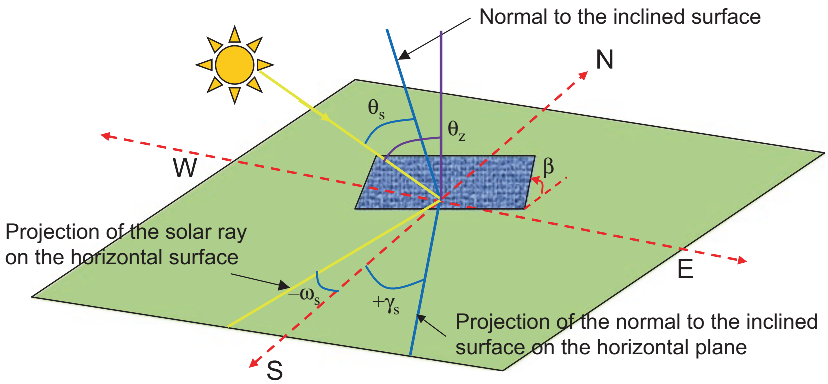

Fig. 2.5 Different angles that characterize arbitrary oriented surface

$$E_0 = \left(\frac{r_0}{r}\right)^2 = 1.000110 + 0.034221\cos\Gamma + 0.001280\sin\Gamma + 0.000719\cos 2\Gamma + 0.000077\sin 2\Gamma \tag{2.2}$$

where Γ is the day angle that takes into account the day of the year and, respectively, the angle of the Earth's orbit covered until this day.

The incidence angle with other characteristic angles for an arbitrary oriented surface is illustrated in Fig. 2.5. This is the angle between the surface normal and the Sun's rays. As it is shown below, this angle depends on the site latitude φ_{site}, the inclination angle β between the surface and the horizontal plane, the Sun declination δ_s for the considered day, the Sun's hour angle ω_s, and the azimuth angle γ_s:

$$\cos\theta_s = (\sin\varphi_{\text{site}}\cos\beta - \cos\varphi_{\text{site}}\sin\beta\cos\gamma_s)\sin\delta_s + \cos\delta_s\sin\beta\sin\gamma_s\sin\omega_s + (\cos\varphi_{\text{site}}\cos\beta + \sin\varphi_{\text{site}}\sin\beta\cos\gamma_s)\cos\delta_s\cos\omega_s \tag{2.3}$$

The Sun declination is the angle between the Earth's equatorial plane and the line connecting the Earth and the Sun centers. It varies over the year and can be calculated by

$$\delta_s = 0{,}006918 - 0{,}399912\cos\Gamma + 0{,}070257\sin\Gamma - 0{,}006758\cos 2\Gamma + 0{,}000907\sin 2\Gamma - 0{,}002697\cos 3\Gamma + 0{,}00148\sin 3\Gamma \tag{2.4}$$

The Sun's hour angle depends on the considered hour using the "true solar time." It is zero at noon with positive values in the morning and, respectively, negative values in the evening. The azimuth angle is the angle between the South direction and the projection of the normal to the inclined surface on the horizontal plane. The sign of this angle takes positive values for deviations to the East and negative values for deviations to the West.

The solar radiation G_h in the meteorological stations is usually measured on a horizontal plane and also needs conversion to the solar radiation on inclined surface G_β. This conversion passes through several steps combining specific methods and geometric approaches. The first step is the application of the CLIMED2 method [7] to determine the diffuse fraction f_G of the measured solar radiation which is defined as the ratio between the diffuse solar radiation and the global one. This fraction is calculated by

$$\{\begin{array}{lll} f_G = 0{,}995 - 0{,}081 M_T & \text{if} & M_T \le 0{,}21 \\ f_G = 0{,}724 + 2{,}738 M_T - 8{,}32 M_T^2 + 4{,}967 M_T^3 & \text{if} & 0{,}21 < M_T \le 0{,}76 \\ f_G = 0{,}180 & \text{if} & M_T > 0{,}76 \end{array} \tag{2.5}$$

where M_T is the clarity index, defined as the ratio between the measured solar radiation on the Earth's surface and the solar radiation outside the atmosphere.

Once the diffuse fraction is calculated, it is possible to determine the diffuse component G_d of the solar radiation on the horizontal plane and then the direct (beam) component of the solar radiation G_b [5]:

$$G_d = f_G G_h \quad G_b = G_h - G_d \tag{2.6}$$

The next step is to estimate the beam solar radiation on the inclined surface $G_{b,\beta}$ using the following formula:

$$G_{b,\beta} = G_b \frac{\cos\theta_s}{\cos\theta_Z} \tag{2.7}$$

where θ_Z is the zenith angle (see Fig. 2.5), defined as the angle between the normal of horizontal surface and the Sun's rays. This is the angle that complements to 90° the solar elevation and depends on the Sun's hour angle, the Sun's declination, and the site latitude.

The next determined component of the solar radiation on the inclined surface is the diffuse one. For this purpose is used the method proposed by Klucher [8], where the searched component is calculated by

$$G_{d,\beta} = G_d \left[0{,}5\left(1+\cos\left(\frac{\beta}{2}\right)\right)\right]\left[1+\left(1-f_G^2\right)\sin^3\left(\frac{\beta}{2}\right)\right] \left[1+\left(1-f_G^2\right)\cos^2\left(\theta_s\right)\sin^3\left(\theta_Z\right)\right] \tag{2.8}$$

The last component of the inclined solar radiation is the ground reflected one. It is calculated by

$$G_{r,\beta} = \frac{1}{2}\rho_g G_h \left(1-\cos\beta\right) \tag{2.9}$$

where ρ_g is the albedo coefficient that takes into account the ground properties to reflect the Sun's rays. If there are no other information, its value can be taken to 0.2.

In the literature, it is possible to find another methodology for the conversion to inclined solar radiation, such as the artificial neuron networks, but usually they need a large number of measured data that limits their application.

It is important to notice that the presented conversion of the solar radiation takes into account the phenomenon that the sunrise and the sunset on an inclined surface have different Sun's hour angles than those of horizontal surfaces. For surfaces with zero azimuth (South oriented), this phenomenon appears during the summer, while when the azimuth is different from zero, it can be presented during the full year.

2.2.2 Temperature Adaptation

The meteorological data provides data for the ambient temperature T_a. In the physical model, the needed input data is the cell temperature of the panels T_c. The conversion is performed using the formula proposed by Ross [9], where the cell temperature is linked to the ambient one and the solar radiation on the PV panels' surface:

$$T_c = T_a + hG_\beta \tag{2.10}$$

where h is an empirical parameter that is determined experimentally for the considered PV panel.

2.2.3 Model of the PV Efficiency

The energy yield estimation passes through a calculation of the output power of the panels P_{PV}, which depends on the solar radiation, the panels' area A, and their efficiency η_{PV}:

$$P_{PV} = G_\beta A \eta_{PV} \tag{2.11}$$

The PV panels' efficiency can be determined by different approaches and models [9–11], but in this study, reduced model is used, developed by the authors, based on Durisch's model [9] showing satisfying performance for less computations and input variables [12]. The used model is given by

$$\eta_{PV} = p\left[q\frac{G_\beta}{G_{ref}} + \left(\frac{G_\beta}{G_{ref}}\right)^m\right] \times \left[1 + r\frac{T_c}{T_{ref}}\right] \tag{2.12}$$

This model uses referent values for the solar radiation $G_{ref} = 1000$ W/m^2 and for the cell temperature $T_{ref} = 25$ °C and four empirical parameters p, q, m, and r, which

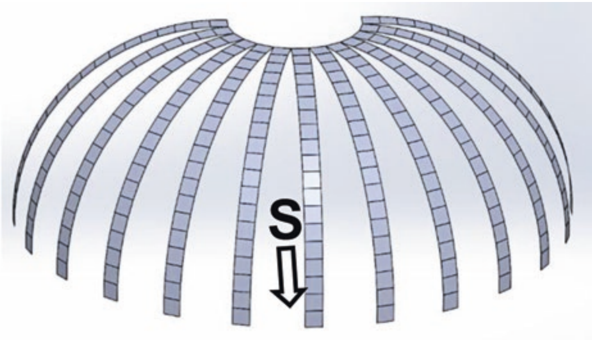

Fig. 2.6 Spectrum of studied orientations

vary for each panels' technology and can be determined experimentally. The presence of the empirical parameters allows the estimation of the panel's efficiency for different technology which is one of the main advantages of this model following its satisfying precision.

2.2.4 Studied Orientations

The proposed methodology allows the estimation of the efficiency and energy production of PV panels with arbitrary orientation. However, the aim of the chapter is to trace guidelines for the architects and civil engineers, and thus, the studied orientations are limited to the combinations between 13 azimuths and 19 inclinations. The azimuth varies from 90° to −90° scilicet from East, to the South, to the West with step of 15°. The inclination changes from 0° (horizontal panels) to 90° (vertical panels). The variation step is 5°. Those combinations form large spectrum of orientations, which covers one-fourth sphere (illustrated on Fig. 2.6).

2.3 Computation Study

The described methodology is applied for 10 sites over the Northern Hemisphere. The sites' names, coordinates, and their geographical position are summarized in Fig. 2.7. The sites are chosen because they have meteorological stations and provide real measured data for the solar radiation and the ambient temperature. The sites' latitudes are with step of about 10° and cover the whole Northern Hemisphere. Two sites with latitude of about 40° (Sofia and Ajaccio) are considered because in these cities the authors' affiliations are located.

In this study, as mentioned, five PV technologies are considered, mono-, poly-, and microcrystalline silicon (*m*Si, *p*Si, and μSi), copper indium gallium selenide (CIGS), and cadmium telluride (CdTe). The Technical University of Sofia has an

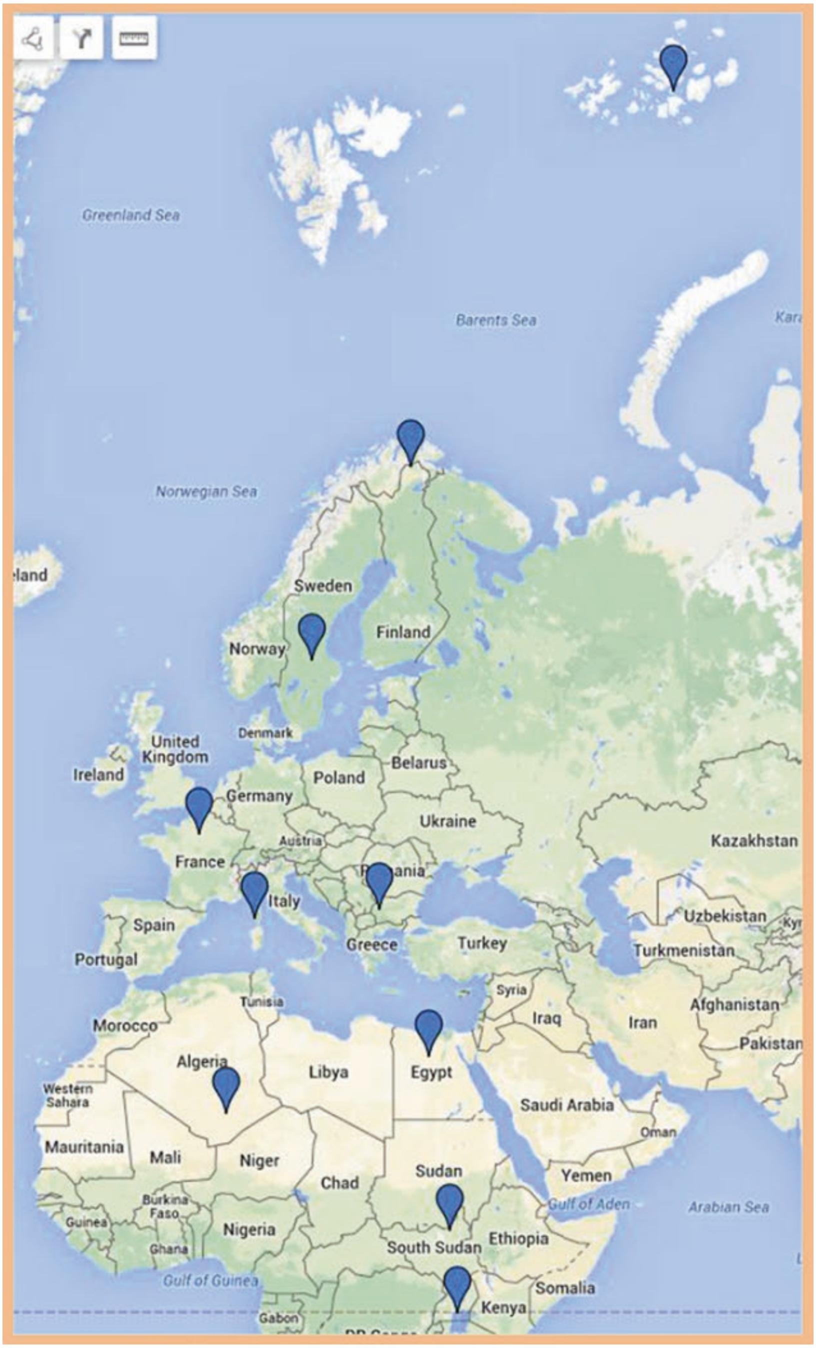

Fig. 2.7 Studied sites' information

Country	Station	Latitude	Longitude	Altitude
Uganda	Entebbe	N0°03’	E32°37’	1155
South Sudan	Malakal	N9°33’	E31°39’	390
Algeria	Tamanrasset	N22°47’	E5°31’	1377
Egypt	Giza	N30°03	E31°13	21
France	Ajaccio	N41°55’	E8°48	4
Bulgaria	Sofia	N42°41’	E23°20’	588
France	Paris	N48°49’	E2°20’	75
Sweden	Borlaenge	N60°26’	E15°30’	153
Norway	Utsjoki	N69°45	E44°02	101
Russia	Krenkel polar	N80°37’	E58°03’	21

Fig. 2.7 (continued)

Table 2.1 Empirical parameters for the model

	Technology				
Parameter	*m*Si	*p*Si	*μ*Si	CIGS	CdTe
p	23.1	23.5	12.1	20.4	15.1
q	−0.281	−0.291	−0.248	−0.251	−0.252
m	0.155	0.132	0.180	0.271	0.171
r	−0.150	−0.149	−0.054	−0.152	−0.112
h	0.028	0.026	0.022	0.032	0.03

experimental platform, equipped with PV panels from those technologies. They are used in the experimental study, and their parameters are shown in the respective section. For the application of the model, the values of the empirical parameters are used that depend on the PV panels. Their values for the studied five technologies are shown in Table 2.1. Those parameters are determined using data from the experimental platform in the Technical University of Sofia.

The presented above methodology is applied to the studied sites for all described orientations. Table 2.2 summarizes the maximal obtained values for the annual energy yield *E* and the respective orientation for all considered PV technologies when the solar radiation outside the atmosphere is used. The results when real measured data is used are shown in Table 2.3. The two crystalline technologies (*m*Si and *p*Si) have greater annual energy yield, followed by the CIGS technology, while the *μ*Si and CdTe also have similar energy harvesting. The maximal energy harvesting for the crystalline technologies and CIGS is obtained for latitudes between 40° and 60° because for those sites the temperature is lower and the daylight duration is good. The *μ*Si and CdTe technologies are less sensitive to the temperature, and their energy yield is almost constant except for high latitudes. The optimal orientation with solar radiation outside the atmosphere is with inclination that corresponds to the site’s latitude for sites with latitude smaller than 45. For greater latitudes, the Sun’s declination plays a significant role and is summed with the panels’ inclination during the period with high daylight duration, and thus for those latitudes, the

Table 2.2 Maximal annual energy yield and its orientation for five technologies with solar radiation outside the atmosphere

	*m*Si			*p*Si			*μ*Si		
Site	*E*, kWh/m²	*β*, °	γ_s, °	*E*, kWh/m²	*β*, °	γ_s, °	*E*, kWh/m²	*β*, °	γ_s, °
Entebbe	393.77	5	90	403.48	5	90	280.83	0	−90:90
Malakal	367.69	10	30	377.55	10	15	275.54	10	0
Tamanrasset	380.33	20	0	390.14	20	0	277.49	20	0
Giza	387.68	30	0	397.27	30	0	278.34	30	0
Ajaccio	402.47	40	0	411.8	40	0	279.27	40	0
Sofia	416.69	40	0	425.95	40	0	281.92	40	0
Paris	410.46	45	0	419.56	45	0	278.61	45	0
Borlaenge	411.38	55	0	419.76	50	0	269.6	55	0
Utsjoki	357.04	55	0	364.18	55	0	228.17	55	0
Krenkel Polar	319.75	55	0	325.86	55	0	193.61	60	0

	CIGS			CdTe		
Site	*E*, kWh/m²	*β*, °	γ_s, °	*E*, kWh/m²	*β*, °	γ_s, °
Entebbe	345.44	5	90	290.52	5	90
Malakal	320.98	10	30	277.28	10	15
Tamanrasset	332.67	20	0	283.47	20	0
Giza	340.19	30	0	286.98	30	0
Ajaccio	354.63	40	0	293.62	40	0
Sofia	367.98	40	0	300.79	40	0
Paris	362.64	45	0	296.71	45	0
Borlaenge	365.4	55	0	293.12	55	0
Utsjoki	316.96	55	0	251.79	55	0
Krenkel Polar	284.42	60	0	220.59	60	0

optimal inclination is smaller than the latitude. The optimal azimuth corresponds to South-oriented panels except for the stations near the Equator – Entebbe (N0°03′) and Malakal (N9°33′) where the results show as optimal the orientations with East or Southeast azimuth. Only in the case of μSi the azimuth for Entebbe is without influence because of the horizontal inclination. Table 2.3 shows that the sites' particularities discredit the conclusions above when real measured solar radiation is used for the energy yield calculations. The maximal energy yield for all technologies is obtained for Tamanrasset (N22°47′), while the previous leader was Sofia (N42°41′). The optimal inclination is different from the latitude. The azimuth is also very different – only four stations has South as optimal orientation of the panels. Most of the optimal azimuths are West or Southwest, and only one site has Southeast azimuth for the maximal energy yield.

The building conception cannot be strictly limited by the optimal orientation of the panels. Thus, it is interesting to consider how the annual energy yield varies when the orientation is not optimal. For this purpose, isoline figures are presented. The influence of the technology is considered first, and Fig. 2.8 shows the obtained isolines for all five technologies for Sofia using the solar radiation outside the atmosphere. It is observed that *μ*Si and CdTe are less sensitive to the deviation of the

Table 2.3 Maximal annual energy yield and its orientation for five technologies with measured solar radiation

	*m*Si			*p*Si			*μ*Si		
Site	*E*, kWh/m²	*β*, °	γ_s, °	*E*, kWh/m²	*β*, °	γ_s, °	*E*, kWh/m²	*β*, °	γ_s, °
Entebbe	240.54	25	−90	247.57	25	−90	180.51	40	−90
Malakal	266.53	30	−75	275.33	30	−75	194.03	40	−75
Tamanrasset	338.65	35	60	347.57	35	60	241.45	40	60
Giza	312.77	40	−60	321.97	40	−60	219.82	45	−60
Ajaccio	225.23	30	0	233.76	30	0	142.21	30	0
Sofia	171.59	25	0	178.82	25	0	104.71	25	0
Paris	153.81	30	0	160.55	30	0	92.94	30	0
Borlaenge	167.02	45	0	174.01	40	0	98.51	45	0
Utsjoki	178.21	55	−75	183.42	50	−75	113.38	60	−75
Krenkel Polar	191.14	55	−90	196.15	55	−90	113.96	60	−90

	CIGS			CdTe		
Site	*E*, kWh/m²	*β*, °	γ_s, °	*E*, kWh/m²	*β*, °	γ_s, °
Entebbe	207.29	30	−90	179.84	30	−90
Malakal	225.5	35	−75	198.16	35	−75
Tamanrasset	294.88	40	60	249.62	40	60
Giza	267.93	40	−60	229.12	40	−60
Ajaccio	183.82	30	0	157.72	30	0
Sofia	136.75	25	0	118.35	25	0
Paris	121.47	30	0	105.63	30	0
Borlaenge	133.1	45	0	113.59	45	0
Utsjoki	151.54	60	−75	124.97	55	−75
Krenkel Polar	163.87	60	−90	130.87	60	−90

inclination angle and the orientation azimuth from the optimal panel's orientation. However, it is necessary to notice that for those two technologies, the energy harvesting is lower. For the other three technologies, there is higher variation of the energy yield with orientation's deviation.

Figure 2.9 shows the obtained isolines for all 10 sites when the technology is *p*Si and the solar radiation outside the atmosphere is used. The aim is to illustrate the influence of the latitude on the annual energy yield. For the sites with small latitude (less than 30°), we observe high influence of the inclination angle with its deviation from the optimal value. The reason is the negative influence of the Sun's declination for those sites. The azimuth influence here is negligible except for inclinations near vertical one where the annual energy yield drop is significant for South orientation. With augmentation of the latitude, the inclination influence decreases at the expense of one of the azimuth. However, it is possible to consider that the range between 45° and − 45° has an acceptable deviation from the optimal azimuth. The sites near the polar circle are more sensitive to deviations of the inclination and of the azimuth, but we should notice that the energy yield for those sites is smaller, and thus, the orientation deviations cannot imply significant losses in the annual energy harvesting.

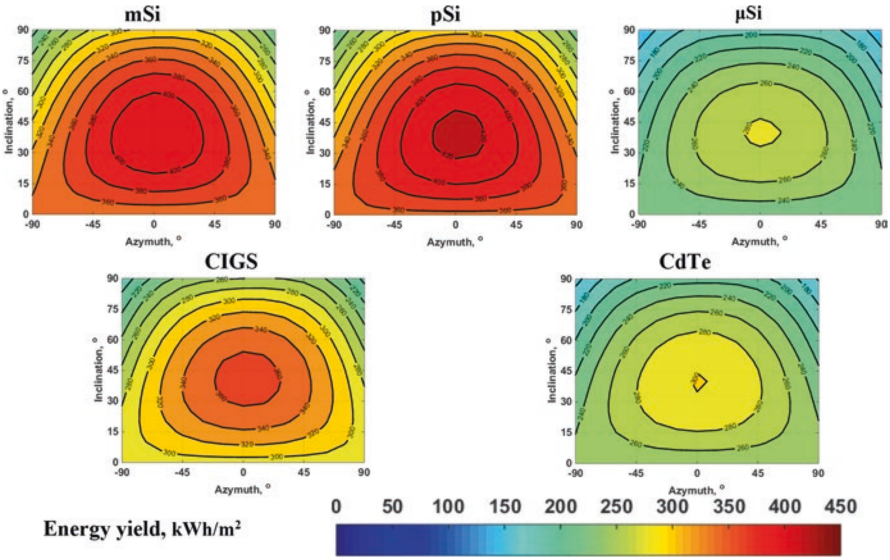

Fig. 2.8 Isolines of the annual energy yield for all considered technologies for Sofia with solar radiation outside the atmosphere

Figure 2.10 shows the isolines for all sites for the polycrystalline technology. As the figure illustrates, the isolines change significantly when the atmosphere influence is taken into account. It is impossible to obtain general conclusions because the particularities of each site influence on the isolines' distribution. Only the sites Ajaccio, Sofia, Paris, and Borlaenge are with South as optimal azimuth. However, it is possible to make some conclusions. For example, the possibilities for deviation of the azimuth from the optimal value are much reduced for the sites with optimal azimuth different from South. Moreover, in those cases, the influence of the inclination is small for orientation with an appropriate azimuth. For the sites with South as optimal azimuth, the inclination has higher influence than the azimuth.

2.4 Experimental Study

The Technical University of Sofia has an experimental platform composed of grid-connected PV installations from the five technologies considered in this work – *m*Si, *p*Si, *μ*Si, CIGS, and CdTe. The five PV generators have approximately the same peak power and are mounted to three solar trackers. The trackers are controlled on the basis of astronomical equations and allow two modes of operation – solar tracking and fixed orientation. The second possibility allows the orientation of the PV generator to arbitrary positions in the one-fourth sphere, considered in the computational study. Thus, it is possible to obtain experimental confirmation of the results. The connection to the grid of the PV installations is realized with inverters

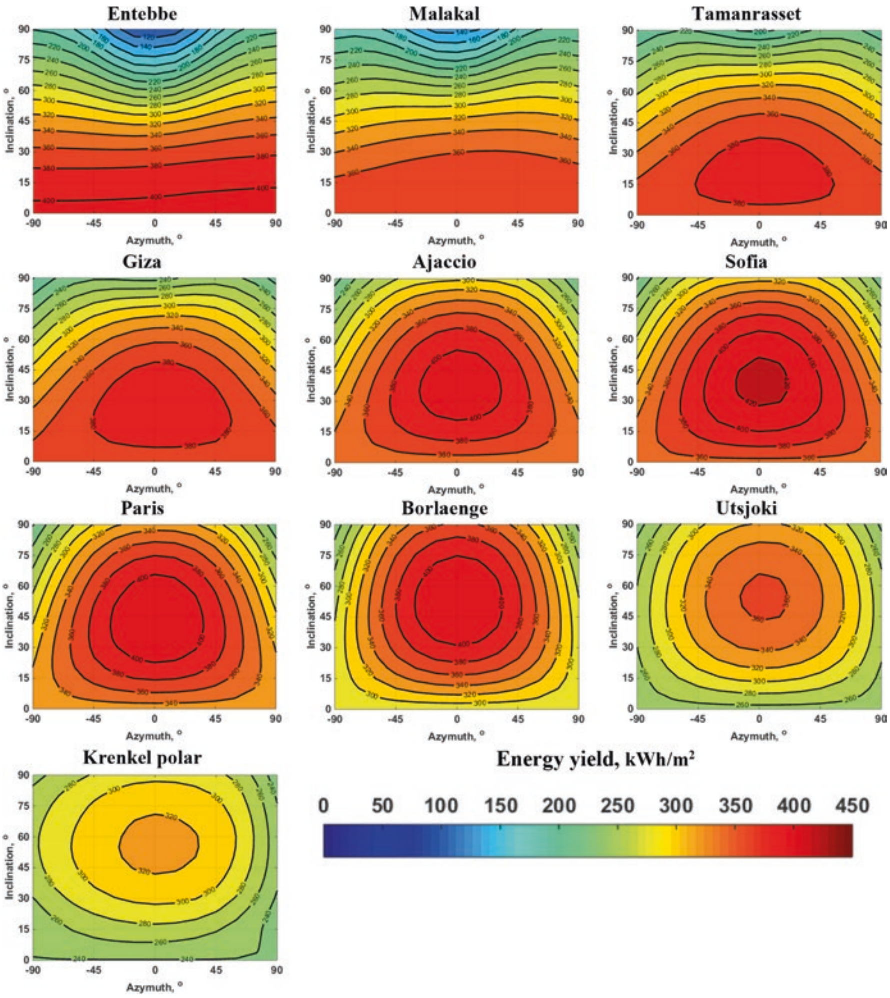

Fig. 2.9 Isolines of the annual energy yield for all considered sites for pSi with solar radiation outside the atmosphere

Sunny Boy of SMA. The measurement of the solar radiation on the panels' plane, the wind speed, and the ambient and cell's temperature of the generators is realized with SensorBox of SMA, and for the data acquisition of all collected data by the measurement equipment and the inverters, the Sunny WebBox is used. The experimental platform is shown on Fig. 2.11, while the characteristics of the PV panels and installations are summarized in Table 2.4 [12].

Experiments with fixed inclination and azimuth of panels for a period of 1 year require a very long time, so the studies have been conducted for limited periods of time with different orientations and azimuths of the PV panels. The experimental research was carried out for several years with different orientations of the panels and under different real meteorological conditions.

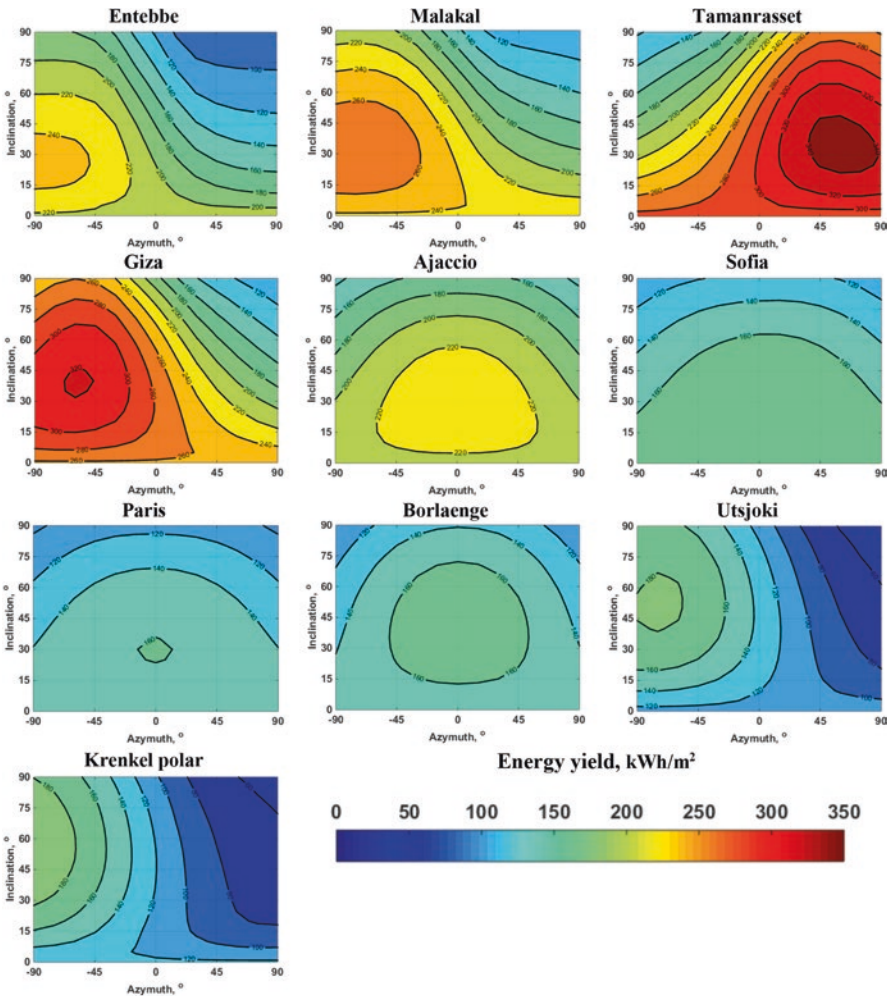

Fig. 2.10 Isolines of the annual energy yield for all considered sites for *p*Si with measured solar radiation

The used mathematical model is validated by the authors in more detailed study [12]. Some of the results are shown in Table 2.5. Here, the theoretical productivity of the panels is calculated using the real (measured) values of the solar radiation and cell temperature by applying (12). As it can be seen, the calculated values are very close to the experimental ones (with differences under 3%).

In Fig. 2.12, graphs of the measured solar radiation in the panels' surface for five azimuths of the panels and a fixed inclination angle of 60° are shown. The following orientations are studied: West, Southwest, South, Southeast, and East. The results are for sunny days without clouds, obtained on different dates. This is why the peak solar radiation (measured on the panels' plane) varies significantly.

The measured daily energy production for each position and each technology of the PV panels is summarized in Table 2.6. In the same table, the theoretically

Fig. 2.11 Experimental platform at the Technical University of Sofia with five PV systems from five technologies, mounted on three solar trackers

Table 2.4 Parameters of the installed PV generators at the Technical University of Sofia

	Technology				
Parameter	*m*Si	*p*Si	*μ*Si	CIGS	CdTe
Panel peak power at STC, W	240	240	128	110	75
Installed peak power, Wp	1200	1200	1280	990	1125
Efficiency at STC η, %	14.81	14.63	9.01	11.70	10.42
Panel's surface S, m^2	1.62	1.64	1.42	0.94	0.72
Array area, m^2	8.2	8.2	14.2	8.45	10.8

calculated productivity is also shown. It is calculated by using the developed approach using idealized solar radiation (outside the atmosphere) with the precisions below. This methodology may give one first approximation for the energy yield of given PV installation on a given site. The precision of the approach can be increased using the maximal solar radiation on the considered site instead of the solar constant. In this case, the impact of the atmosphere is neglected, and the sky is assumed clear (without clouds). The measurements and the available meteorological data show that the maximum direct radiation in the region of Sofia is about 1000 W/m^2 (see Fig. 2.12), and this value replaces the solar constant in the calculations. The results show a good level of overlap, which validates the proposed approach. It should be noted that the bigger differences in the comparison are due to the presence of vapors and air pollutions in the city of Sofia during the winter and spring. This is illustrated by the solar radiation for 17-02-19 characterized with maximal value of about 730 W/m^2 despite the absence of clouds. Another possible reason for those differences is deviations in the ambient temperature.

The most precise estimation of the energy production of the building-integrated PV systems can be done by application of the realistic approach using statistical

Table 2.5 Comparison of the performance parameters of studied PV generators under different weather conditions

	10.08.2014 Southwest, inclination 30°, average cell temperature 28.3 °C					14.12.2014 South, inclination 30°, average cell temperature 2.7 °C				
Module type	*m*Si	*p*Si	*μ*Si	CIGS	CdTe	*m*Si	*p*Si	*μ*Si	CIGS	CdTe
Experimental energy E_e [kWh/m²]	0.904	0.918	0.611	0.767	0.669	0.050	0.048	0.025	0.033	0.028
Theoretical energy E_t [kWh/m²]	0.891	0.906	0.600	0.767	0.651	0.050	0.048	0.024	0.032	0.028
Difference $(E_e - E_t)/E_e$ [%]	1.47	1.37	1.80	0.02	2.76	0.00	−1.23	2.11	1.78	1.49
Experimental productivity [kWh/kWp]	6.18	6.28	6.95	6.55	6.42	0.344	0.326	0.284	0.281	0.269
Theoretical productivity [kWh/kWp]	6.09	6.19	6.82	6.55	6.25	0.344	0.330	0.278	0.276	0.265
Experimental daily efficiency [%]	12.05	12.33	8.20	10.30	9.00	14.47	15.35	7.30	9.49	9.03
Experimental performance ratio PR	0.895	0.930	1.010	0.984	0.955	0.989	1.049	0.809	0.810	0.867

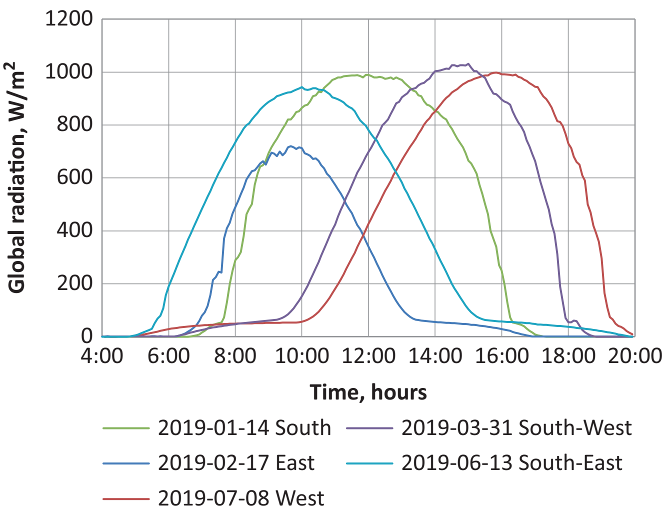

Fig. 2.12 Experimentally measured solar radiation in the panels' plane for five different orientations (azimuths) and fixed inclination angle of 60° for sunny days

Table 2.6 Results from experimental study of PV panels' energy production for different orientations

	Sunny days	*p*Si		CIGS		CdTe		*μ*cSi		*m*Si	
		kWh/m²		kWh/m²		kWh/m²		kWh/m²		kWh/m²	
Date	Orientation	Exp.	Theor.	Exp.	Theor.	Exp.	Theor.	Exp.	Theor.	Exp.	Theor.
14-01-19	South, 60°	0.988	1.081	0.936	0.913	0.672	0.726	0.568	0.635	0.964	1.055
17-02-19	East, 60°	0.493	0.562	0.391	0.453	0.291	0.370	0.236	0.320	0.487	0.544
08-07-19	West, 60°	0.794	0.777	0.602	0.639	0.546	0.550	0.488	0.523	0.767	0.754
31-03-19	Southwest, 60°	0.791	0.876	0.671	0.724	0.523	0.603	0.481	0.552	0.792	0.851
13-06-19	Southeast, 60°	0.807	0.799	0.676	0.639	0.531	0.545	0.480	0.497	0.780	0.772

meteorological data with relatively small step (1 hour). The verification of this approach is done by comparison of the energy produced by the PV panels from the five technologies for whole month for different positions of the panels. The theoretical energy production is calculated using the realistic approach. Those results are compared to the experimentally obtained ones for April and June 2019 for two orientations of the panels – Southwest and Southeast and inclination of 60°, as it is shown in Table 2.7. The results for April are very close with differences up to 8.5%. The results for June are with bigger differences up to −18.9%. This difference may be explained by the fact that in June 2019, there were more sunny days than usual (considered in the meteorological data used for calculations), and the energy production is bigger than usual.

The experimental validation of the calculation results allows the proposal of the following recommendations for the architects and civil engineers. As first approximation of the energy yield, it should be calculated using idealized (outside the atmosphere) solar radiation. As a second step, the precision can be improved using the maximal solar radiation for the considered site instead of the solar constant. The third step should be the use of statistical meteorological data, which gives realistic results for the energy production of the building-integrated PV system. In some cases, the study can start directly with the second step.

2.5 Conclusions

The particularity of the building integration of PV panels consists in the fact that the panels' orientation and inclination may be arbitrary depending on the buildings' placement and shape. The chapter proposes a novel, complete, and experimentally validated approach in three steps for determination of the energy yield from building-integrated PV panels. It uses, developed by the authors, modified Durisch's model with reduced number of parameters. This model provides the possibility to examine different PV technologies and has good precision. The energy production is calculated on the basis of the meteorological conditions (solar radiation and

Table 2.7 Monthly energy production of PV panels under different positions

		*p*Si		CIGS		CdTe		*μ*cSi		*m*Si	
		kWh/m^2		kWh/m^2		kWh/m^2		kWh/m^2		kWh/m^2	
Month	Orientation	Exp.	Theor.	Exp.	Theor.	Exp.	Theor.	Exp.	Theor.	Exp.	Theor.
April	Southwest, 60°	14.57	14.97	11.13	11.37	8.96	9.81	8.17	8.93	14.42	14.35
June	Southeast, 60°	19.43	17.39	15.59	13.11	12.38	11.52	11.24	10.23	18.87	16.65

ambient temperature), the geographical coordinates of the installation, and the panels' orientation and inclination as input variables. The proposed methodology is applied to different sites to the north of the equator using idealized and realistic meteorological data. In the first case, the solar radiation outside the atmosphere is used, while in the second case, statistical real data is used, and the atmosphere's and the relief's influences are taken into account. The annual energy yield for combinations of 13 azimuths and 19 inclinations is calculated for five different PV technologies. The influence of a site's latitude and the PV technology is estimated. The calculations show that it is difficult to trace universal guidelines for the PV orientation, because the particularities of each site have specific influence on the energy yield. The results are validated on an experimental platform at the Technical University of Sofia, Bulgaria, and show a good overlap on a daily and monthly basis. It can be considered that the methodology developed here provides a response of the question of how architectural decisions about building design influence the obtained energy yield.

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References

1. Directive 2010/31/EU of the European parliament and of the council on the energy performance of buildings. Off. J. Eur. Union **153**, 13–35
2. REN21, Renewables 2017 – Global status report, ISBN 978-3-9818107-6-9
3. M. Kummu, O. Varis, The world by latitudes: a global analysis of human population, development level and environment across the north-south axis over the past half century. Appl. Geogr. **31**, 495–507 (2010)
4. By Cmglee – Own work, CC BY-SA 3.0. https://commons.wikimedia.org/w/index.php?curid=30611313
5. M. Iqbal, *An introduction to solar radiation* (Academic Press, Toronto, 1983)
6. M. Pidwirny, Earth-sun relationships and insolation. in *Fundamentals of Physical Geography*, 2nd edn, University of British Columbia Okanagan (2006), available on:http://www.physicalgeography.net/fundamentals/6i.html
7. A. De Miguel, J. Bilbao, R. Aguiar, H. Kambezidis, E. Negro, Diffuse solar irradiation model evaluation in the North Mediterranean belt area. Sol. Energy **70**(2), 143–153 (2001)
8. T.M. Klucher, Evaluation of models to predict insolation on tilted surfaces. Sol. Energy **23**(2), 111–114 (1979)
9. W. Durisch, B. Bitnar, J.C. Mayor, H. Kiess, K.H. Lam, J. Close, Efficiency model for photovoltaic modules and demonstration of its application to energy yield estimation. Sol. Energy Mater. Sol. Cells **91**, 79–84 (2007)
10. A. Balaska, A. Tahri, A.B. Stambouli, F. Tahri, T. Oozeki, Comparative performance evaluation of different technologies of photovoltaic modules in Algeria, 2016 7th International Renewable Energy Congress (IREC), Hammamet, 2016, pp. 1–5
11. R. Kumar, S.K. Singh, Solar photovoltaic modeling and simulation: as a renewable energy solution. Energy Rep. **4**, 701–712 (2018)
12. Z. Zarkov, L. Stoyanov, V. Milenov, H. Voynova, V. Lazarov, Modeling of PV generators from different technologies – case study, 2016 IEEE International Power Electronics and Motion Control Conference (PEMC), 25–30 Sept 2016, Varna, Bulgaria, 2016, pp. 419–424

Chapter 3
Optimization of Performances and Reliability for Building-Integrated Photovoltaic (BIPV) Systems

Dan Crăciunescu, Laurențiu Fara, and Ana-Maria Dabija

3.1 Introduction

The increasing electricity dependence of the current population has led to an increase in the produced electricity. The high demand in electricity supply also forced the concerns about the quality aspects of electricity, namely, the energy production to be a reliable and stable one, thus increasing the consumer's safety regarding electricity supply. Unfortunately, the quality aspects of the electricity produced from renewable sources are not yet favorable to the energy system, raising compatibility problems with the electricity grid.

There are a number of concerns about increasing the conversion efficiency of photovoltaic (PV) solar cells. So far, the maximum conversion efficiency of solar cells is about 47% under laboratory conditions [1–3]. Due to the fact that the conversion rate is still low, different methods of improving the electrical efficiency for building-integrated photovoltaic systems (BIPV) are considered, such as using the maximum power point tracking (MPPT), the implementation of different techniques based on Fuzzy Logic Controllers (FLC), and the development of intelligent tracking systems for optimal point tracking and conversion of solar irradiance [4–7].

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3.2 Standards Used for BIPV Systems

Strategic planning and standardization efforts are becoming increasingly challenging, due to the high levels of interdisciplinary complexity that encompass photovoltaic systems and modern technologies. Given that standardization issues that are based on the large-scale approach to PV equipment and systems, it is necessary to implement a perspective on technological forecasting and innovation planning. This approach offers the possibility of acquiring collective information for mapping future innovation activities and developing new standardization strategies for photovoltaic systems and their applications.

The design of the each component of a photovoltaic system can be realized by means of mathematical calculations or by using dedicated software; nevertheless, there are certain protocols and standards in the selection of the Balance of System (BOS) components, which must be respected when installing and putting into operation a PV system. Although the problems may seem insignificant during the installation, they may ultimately affect the performance, efficiency, reliability, maintenance costs, and aesthetics of the system on the long term. In addition, the Underwriters Laboratories (ULs) offer the certification of BOS system equipment to the standards identified in the standardization strategic planning framework chart. The framework chart incorporates principles, structures, and perspectives on the main dimensions of the multi-life standardization of photovoltaic technology (with complexity levels in the evolution of PV systems and applications) [8–11].

Anticipating and prioritizing the technological fields in which more efforts and resources relevant to standardization, research, and development are needed, the complex innovation systems that involve various technical fields, including photovoltaic technology, can support. The sequence of PV innovation and standardization activities based on the temporal ordering of events is depicted in Fig. 3.1. This approach offers the possibility of purchasing collective information for mapping future innovation activities and developing new standardization strategies for photovoltaic systems and applications.

3.3 State of the Art for BIPV Systems

The photovoltaic technology developed by one of the important companies in the field, namely, SunPower, has a major impact, contributing to the development of some of the most ambitious and futuristic projects in the world. Thus, the city of Masdar from Abu Dhabi, United Arab Emirates, represents a developing global technology cluster, with the aim of being one of the most sustainable urban areas in the world, powered by renewable energy. By 2017, over 6000 SunPower E19/315 W panels were installed in Masdar, both on the facades of the buildings, where shading and production of “green” energy is ensured, as well as on their roofs.

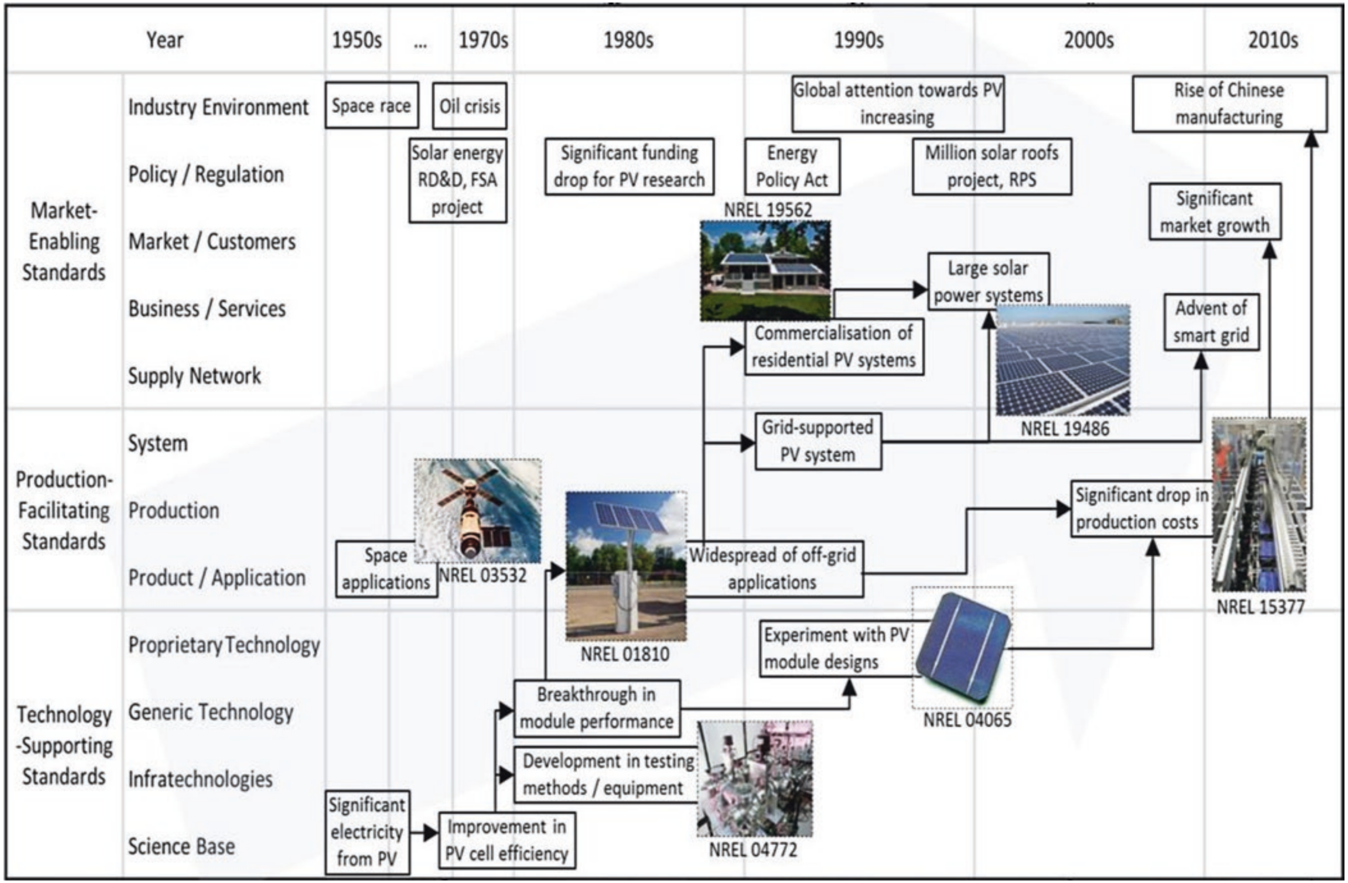


Fig. 3.1 Quality standards. Analysis of standardization during the innovation process of photovoltaic technology. (NREL Image Gallery, 2016)

The sophisticated campus in this city offers an ideal framework for innovation and real development of new PV technologies. At the same time, the Masdar Institute, in collaboration with International Renewable Energy Agency (IRENA), aims to certify the Estidama Pearl Building Rating System, one of the strictest standards of energy efficiency and sustainability in the world [12–15]. The main objective of the PV program is for the city of Masdar to produce 7% renewable energy from the country's energy potential by 2020 [16–18].

The Masdar Institute hosts both educational institutions and important actors in the energy field, such as Siemens Electric Company and the International Renewable Energy Agency (located in an Nearly Zero Energy Building (nZEB)), which contributed to the development and implementation of pilot projects based on PV systems [19].

Residential buildings in Masdar City are governed by well-defined standards, which provide heights up to five floors for buildings built on narrow streets and which must be equipped with roofs covered with PV modules and solar tarpaulins at street level, which ensures both the shading of the sidewalk and the production of electricity (see Fig. 3.2).

There are also other challenges to the pilot project developed by the Masdar Institute, such as the sustainable development of photovoltaic technology (PV modules) for both land and air transport (see Fig. 3.3). In this respect, alternative smart buses (up to four people) that do not have manual operation (they are fully automated) have been developed and tested. The Masdar Institute also presents a daring project in relation to alternative airplanes using solar energy [20].

The energy strategy of Masdar City presented in Fig. 3.4 consists of the exclusive use of renewable energy and in particular the production of the city's electricity demand using photovoltaic systems. The Abu Dhabi region, which also includes Masdar, uses 62% of the emirate's electricity [21]. At the same time, a considerable amount of electricity produced in the town of Masdar will be directed and used in

Fig. 3.2 Architecture of integrated photovoltaic systems in the structure of buildings located on the campus of the Masdar Institute, Abu Dhabi. (Photo taken by Dan Craciunescu, one of the authors of this work during his visit to the Masdar Institute, Abu Dhabi, on the occasion of the SWC2017 Congress)

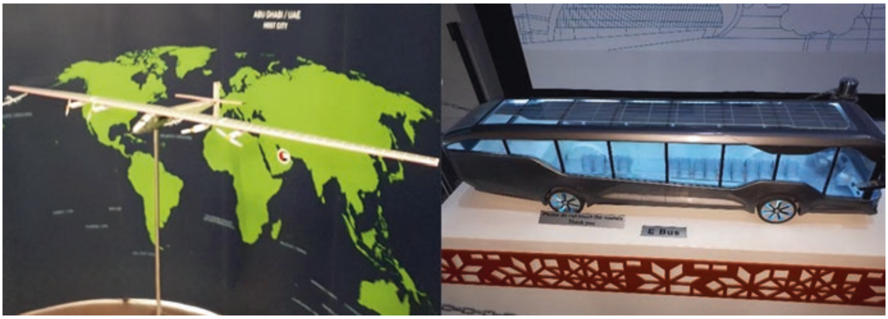


Fig. 3.3 Pilot project based on the sustainable development of transport means based on the use of photovoltaic technology developed by the Masdar Institute, Abu Dhabi. (Photo taken by Dan Craciunescu, one of the authors of this work during his visit to the Masdar Institute, Abu Dhabi, on the occasion of the SWC2017 Congress)

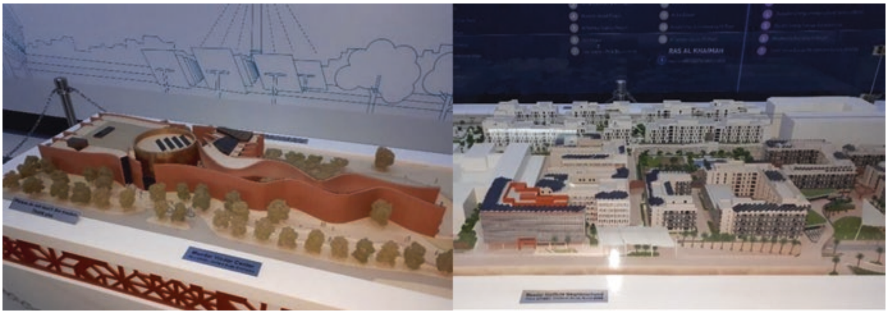


Fig. 3.4 Pilot project based on the sustainable development of a city/town based on the use of photovoltaic technology developed by the Masdar Institute, Abu Dhabi. (Photo taken by Dan Craciunescu, one of the authors of this work during his visit to the Masdar Institute, Abu Dhabi, on the occasion of the SWC2017 Congress)

the desalination of water and will be produced by the help of the central solar systems with concentrators (based on tower and heliostat field).

3.4 Modeling, Numerical Simulation, and Optimization of BIPV Systems

3.4.1 Modeling and Simulation Techniques for BIPV Systems

The design of the BIPV system was fully developed using MATLAB/Simulink software in order to characterize the PV components, as well as the entire BIPV system. This section describes the procedure used to simulate the electrical characteristics of the PV generator, namely, the I-V and P-V characteristics, respectively,

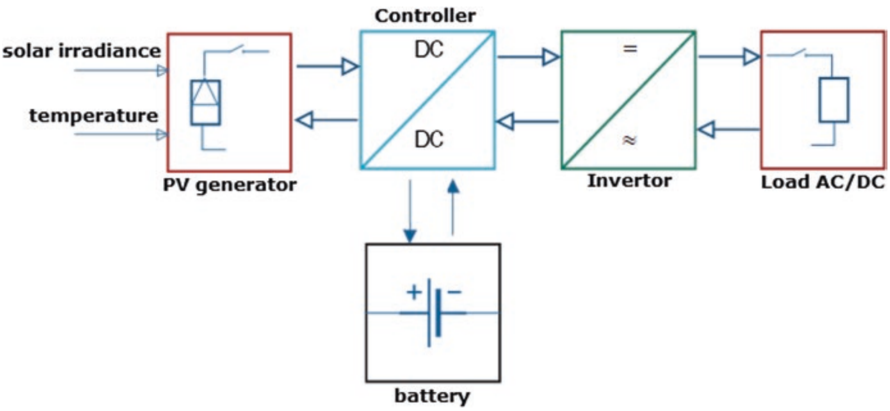


Fig. 3.5 Block diagram of the BIPV system

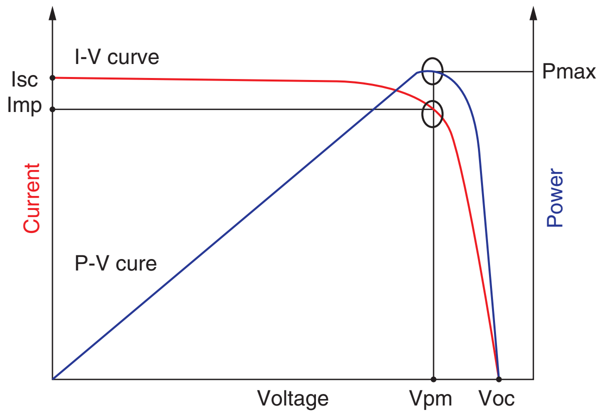
determining the maximum power point by implementing the Fuzzy Logic Controller. The block diagram specific to the BIPV system is shown in Fig. 3.5 and includes the following components: BOS elements (battery, controller, and inverter), PV generator, and electrical consumer. The modeling and simulation of the photovoltaic system's behavior is based on the block elements that form the BIPV system considered.

3.4.1.1 MPPT Techniques

The nonlinear feature of the I-V characteristic for a PV module results in unequal power distribution during its operation. Figure 3.6 shows the relationship between power, voltage, and current for a PV module [22]. Figure 3.7 shows the changes in the maximum power point according to variations in solar irradiation for 25 °C.

It can be noticed that there is a point associated with certain values of voltage and current that have the highest power. When the PV module corresponds to the maximum power point, its maximum available power (P_{max}) is provided. The current and voltage values at this point are called the maximum power point current (I_{mp}) and the maximum power point voltage (V_{mp}). When operating conditions such as temperature or solar irradiance change, the P_{max}, V_{mp}, and I_{mp} values change as well. Maximum power point tracking (MPPT) techniques are algorithms that find the maximum power point for any PV module system/system state and represent inputs for a controller that connects to the rest of the system. The output signal of the controller is directed to a modulation technique called pulse width modulation (PWM), which generates control pulses that allow the system to operate at maximum values [23, 24].

Fig. 3.6 I-V and P-V characteristics of a PV module for MPPT highlighting



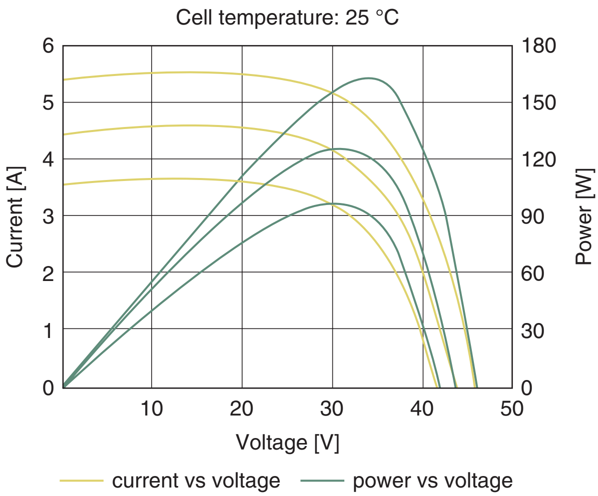


Fig. 3.7 I-V and P-V characteristics of a PV module in standard testing conditions (STC): 25 °C, 1000 W/m²

3.4.1.2 Fuzzy Logic Controller (FLC)

For a fuzzy system, the fuzzy input is described as being u_i and its variable as $\widehat{u_i}$, and for the fuzzy output as being y_i and its variable as $\widehat{y_i}$. After setting the input and output of the Fuzzy Logic Controller (FLC), a description of each of the variables will be made, namely, for $\widehat{u_i}$ and $\widehat{y_i}$. Figure 3.8 shows the fuzzy block that converts the real number of fuzzy sets input values, and then through the inference mechanism (which uses the specific fuzzy or base rules to produce the default fuzzy sets or fuzzy conclusions that ultimately serve to setting output values), FLC outputs are obtained.

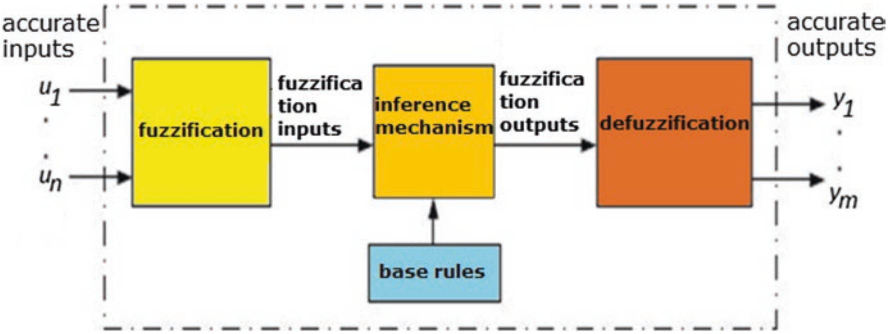


Fig. 3.8 Block diagram of fuzzification and defuzzification of an input size

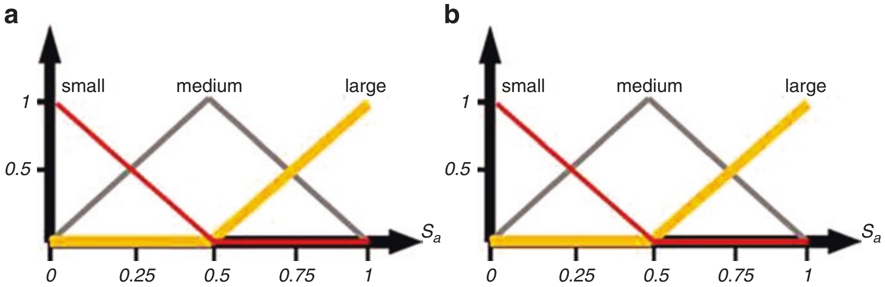


Fig. 3.9 (**a**) The first entry membership function (absolute value S_a); (**b**) the membership function of the second entry (C_{old})

To create a FLC, we will repeat the following steps, namely, to fuse the two input variables using normalized fuzzy sets for each of the three triangular membership functions (MFs): small, medium, and big, as shown in Fig. 3.9.

In Fig. 3.9, the three triangular member functions signify the real power of the system (C_{old}) for three cases: (1) when C_{old} has small values, (2) when C_{old} has medium values, and (3) when C_{old} has high values. The real power has to coincide with the maximum estimated reference power (S_a), and if the real power were lower than the reference power, the control signal would trigger the increase of real power.

There are six fuzzy rules, three rules for each diagram, acording to Fig. 3.9a, b. The triangular membership functions can be written as follows:

1. If C_{old} is small and S_a is small, then the control signal is small.
2. If C_{old} is medium and S_a is small, then the control signal is medium.
3. If C_{old} is medium and S_a is medium, then the control signal is small.
4. If C_{old} is high and S_a is small, then the control signal is high.
5. If C_{old} is high and S_a is medium, then the control signal is medium.
6. If C_{old} is high and S_a is high, then the control signal is medium.

Depending on the absolute slope value, the P-V curve of the panel is divided into three regions, as shown in Fig. 3.10. Given the old disturbance stage C_{old}, the

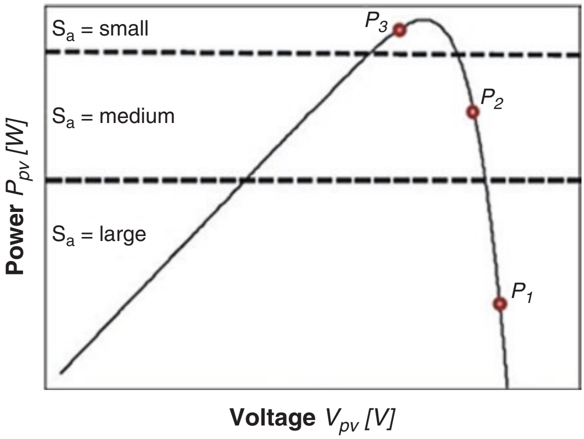


Fig. 3.10 Power voltage (P-V) characteristic with P&O based on FLC

controller could determine the change to the new step in order to reach the MPP, moving from one region to another one and respecting the membership functions.

3.4.2 *Implementation of the FLC-Based MPPT Algorithm for Numerical Modeling of BIPV Systems*

Maximum power point tracking is implemented using a Perturb and Observe (P&O) algorithm and a FLC controller. The P&O algorithm compares the actual PV power (P_{PV}) with an estimated maximum power (reference power) (P_r) value via the FLC at equal time intervals. The output of the FLC is used to direct the reference power to a new level, which is added to the previous value of each range. The highest value of power can be considered as the maximum power. The output signal from the FLC is directed to a PWM to control the duty cycle of the DC–DC voltage converter.

The DC–DC converter raises the voltage to the value at which the PV system can operate at full power. To implement the MPPT algorithm based on FLC, the Fuzzy tool in MATLAB Fuzzy is used to design the FLC. The first step in implementation the controller is to define the FLC design parameters (inputs, outputs, defuzzification method) in the fuzzy inference system (FIS) editor as shown in Fig. 3.11, and then each member function is defined and named as shown in Figs. 3.12a, b, and c.

The last step is the controller implementation. The FLC is defining the basic rules to create the output entry maps, according to Fig. 3.13.

The proposed method of optimizing a BIPV system using the FLC-based MPPT algorithm has allowed to improve its overall efficiency. It is considered an application of the BIPV system, represented by a residential complex building that allows the use of the present study for different existing residential complex buildings. The influence of the shading degree on the generated power (PV), respectively, on the performances determined by the FLC controller on the BIPV system is analyzed.

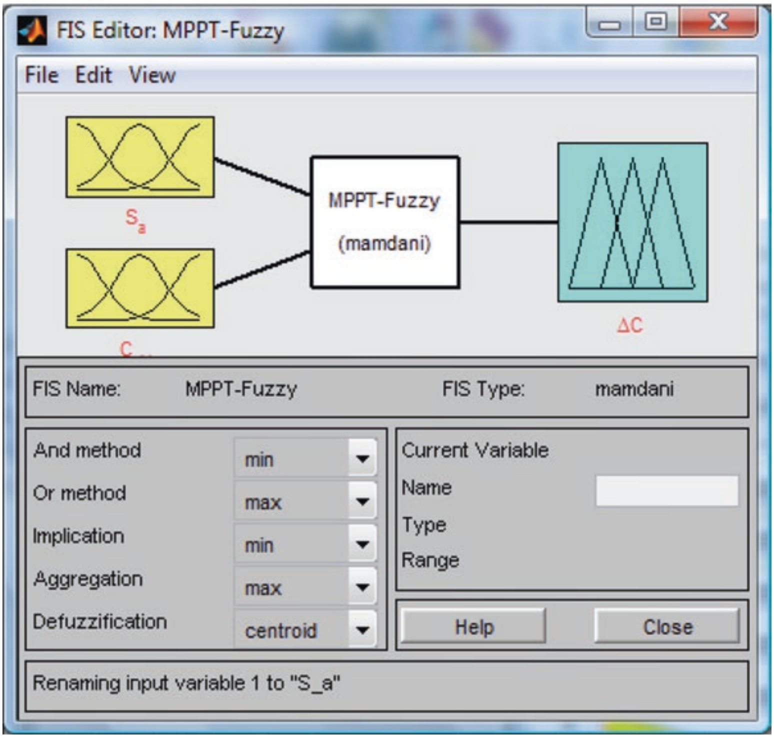


Fig. 3.11 FIS window of the MATLAB/Simulink editor

The minimum degree of shading is determined for the operational optimization of the BIPV system by using the MPPT algorithm (the conventional approach cannot meet this objective). The analysis allows a correct pre-sizing of BIPV systems that can be applied to all types of BIPV applications.

3.5 Case Study: Results Obtained by Optimizing a BIPV System

It is considered a specific case study, representing a complex BIPV system of residential buildings with 30 kW power, located in the urban area of Bucharest, Romania. This BIPV system is analyzed to establish an optimized tool for pre-sizing. Table 3.1 presents the input data for this BIPV system.

The following section presents the simulation results based on MATLAB/Simulink software.

To improve the performance of BIPV systems, a numerical modeling/simulation is developed based on the following approaches: (1) the influence of shading on BIPV and (2) applying a method based on the MPPT algorithm.

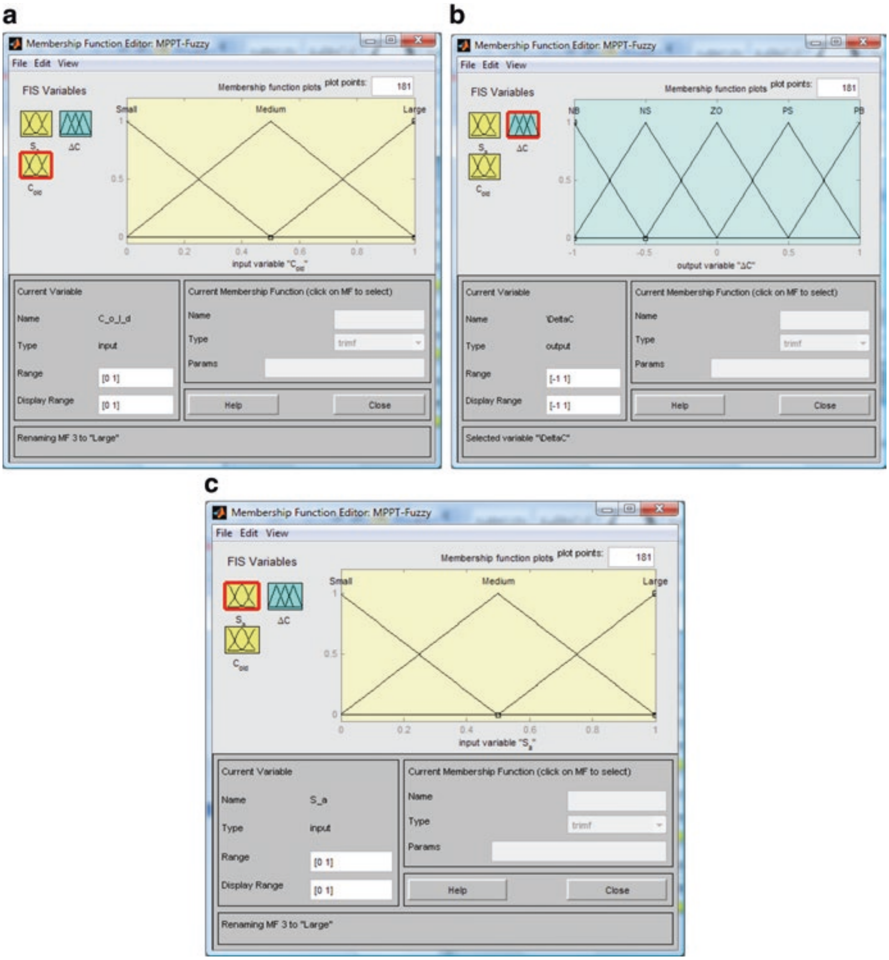


Fig. 3.12 Membership function editor in MATLAB/Simulink: (**a**) S_a MF, (**b**) C_{old} MF, (**c**) ΔC MF

The power of the photovoltaic generator (the total of 120 photovoltaic modules) is obtained by numerical modeling over a 3-day period. The power of the studied BIPV system (30 kW power output) is analyzed from the point of view of photovoltaic modules for different degrees of shading, namely, 50%, 40%, and 30% (see Fig. 3.14). As expected, the power variation is most affected by shading of 50%; in this case, an optimized operation of the BIPV system is achieved at a power of 12 kW.

Under 50% shading, the performance of the BIPV system decreases drastically, making virtually impossible to apply any optimization method. Also, the 30% shading value was considered as an average of the shading degree encountered by a BIPV system over a day, in order to improve BIPV performance.

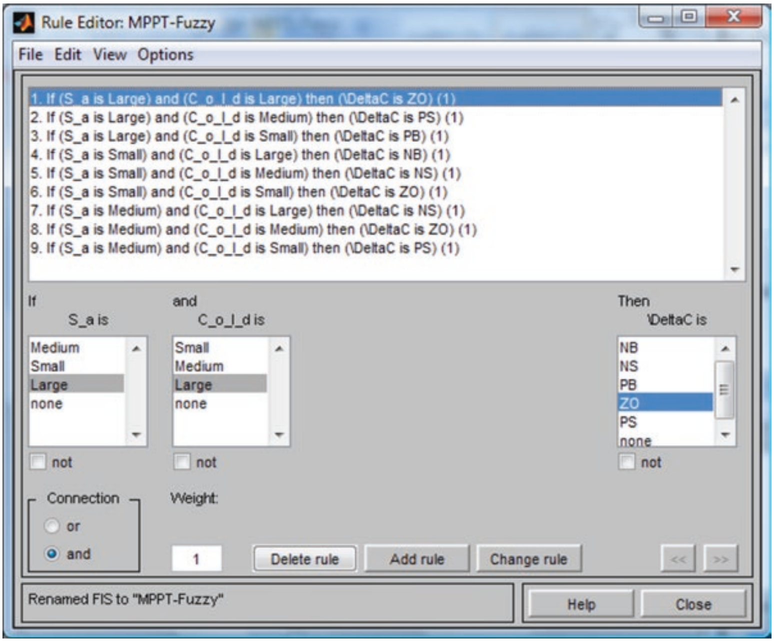


Fig. 3.13 Rules editor from the MATLAB/Simulink window

Table. 3.1 BIPV system input data

BIPV system parameters		
Nominal power of the PV generator	kW	30
Nominal voltage	V	380–400
Panel characteristics	Type	250 W polycrystalline
Number of modules	Quantity	120
Solar radiation	W/m^2	100–1000
Temperature	°C	15–85

In order to determine the behavior of the BIPV system, an analysis of the PV generator function for three cases (shading 30%, 40% and 50%) was considered, which was presented in Fig. 3.14. For each case, the MPPT algorithm was applied to improve the efficiency of the studied BIPV system.

The power variation of the BIPV system for a 50% shading degree is shown in Fig. 3.15.

The power generated is indicated by the blue line in the case without MPPT and the orange line in the case with MPPT. There is an increase in power of 4 kW when considering the MPPT algorithm; this approach achieves an optimized power value of 16 kW.

Figure 3.16 shows the operation of the BIPV system for a shading degree of 40%. It is noted that although the BIPV power does not exceed 19 kW compared to

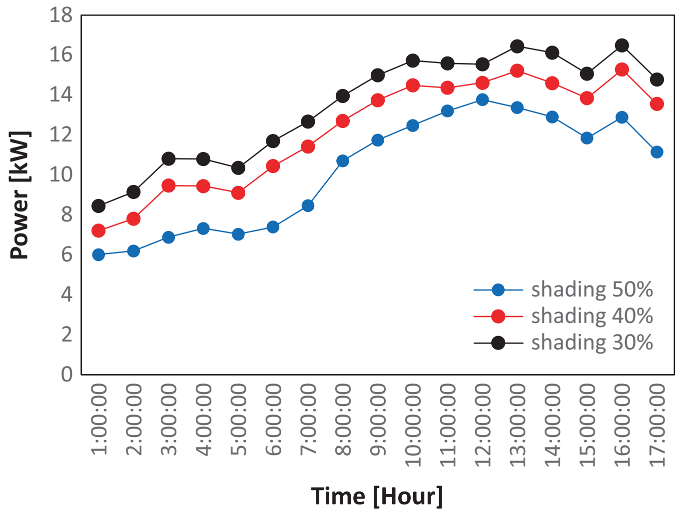


Fig. 3.14 Behavior of the BIPV generator for different degrees of shading: conventional approach

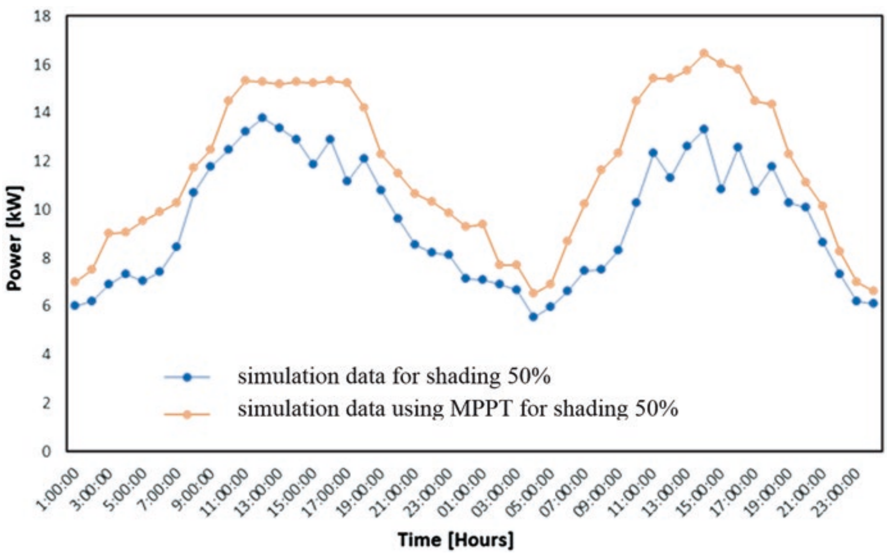


Fig. 3.15 Power generated by BIPV at 50% shading operation: MPPT approach

the proposed target of 30 kW, there is an improvement in MPPT operation (a gain of approximately 6 kW) compared to the non-MPPT case.

Figure 3.17 is characterized by the lowest shading degree (30%) of the three analyzed cases. It is remarkable that the BIPV system has an important improvement for the MPPT operation case, represented by the orange line, reaching a value of approximately 29 kW, which represents a 9 kW gain.

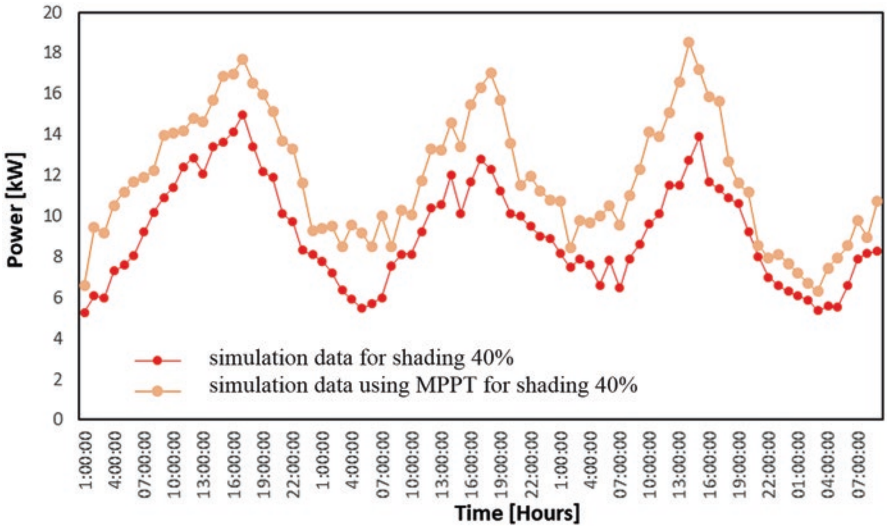


Fig. 3.16 Power generated by BIPV at 40% shading operation: MPPT approach

For a clearer understanding of the method based on the MPPT controller, that is, the influence of the MPPT method on the BIPV operation, the performance of the BIPV system is presented in Fig. 3.18. It is noted that the use of the MPPT algorithm is a complementary method for obtaining a gain over the entire daytime operating time.

The modeling and simulation of the analyzed BIPV system is completed by determining its efficiency against the electrical consumer. It is noted that the use of the MPPT algorithm leads to a safety in the power supply of the electric consumer and a stabilization of the system. The efficiency of the BIPV system with respect to the electric consumer is shown in Fig. 3.19.

Thus, it is found that the FLC-based MPPT method is very efficient in the three considered situations (shading: 50%, 40%, and 30%), managing to determine as accurately as possible the maximum power of the BIPV system (by tracking the maximum power point), which contributes to its most accurate dimensioning, by fully satisfying the requirements of the electric consumer (stability, continuity, and high electrical parameters of the system).

This is all the more relevant in Nearly Zero Energy Building (nZEB) when it is necessary to extract all production capacity of the BIPV system.

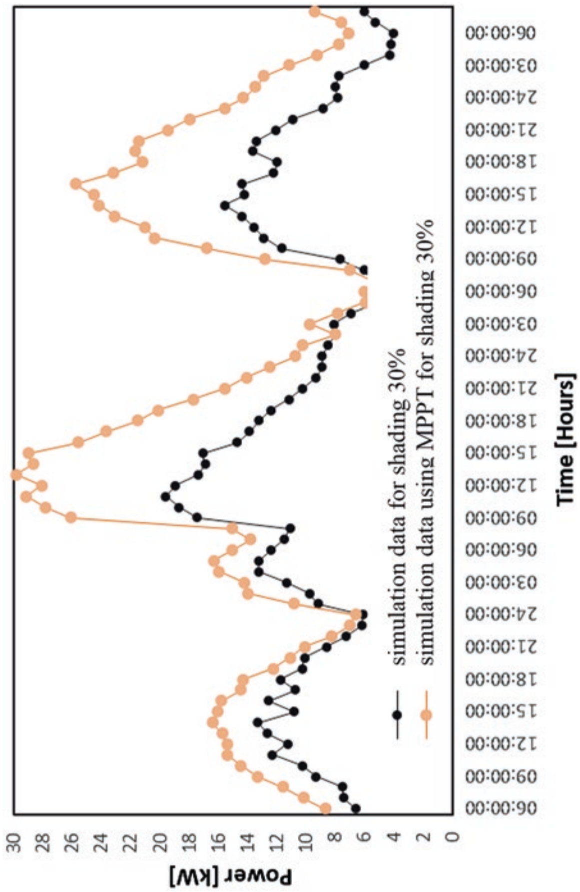


Fig. 3.17 Power generated by BIPV at 30% shading operation: MPPT approach

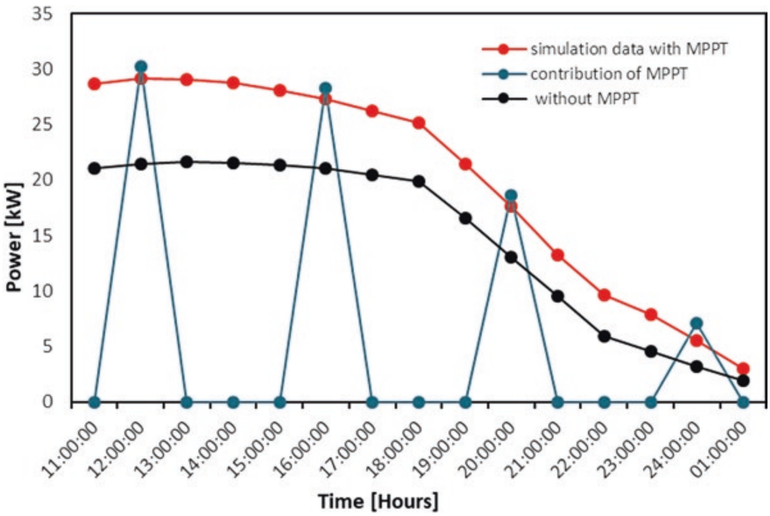


Fig. 3.18 Performance of the BIPV system using the MPPT method

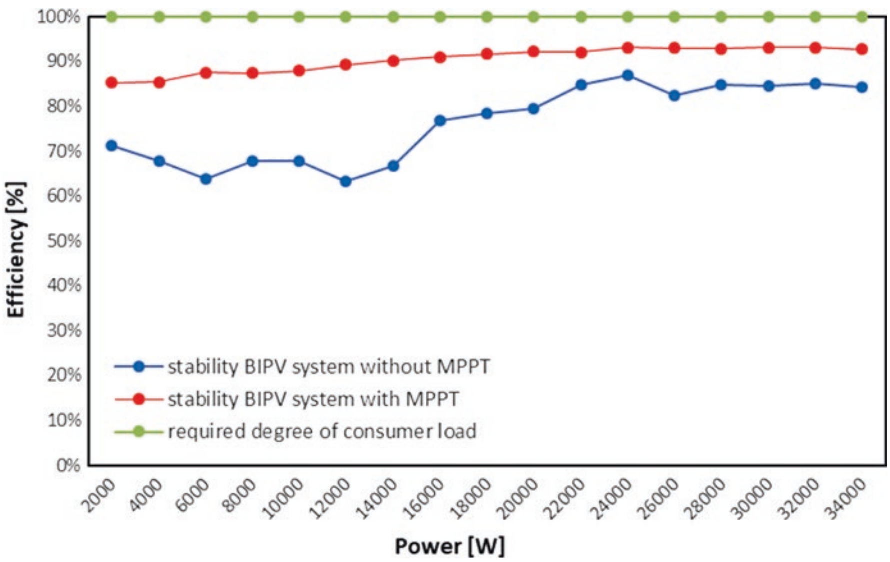


Fig. 3.19 BIPV system efficiency with respect to the electric consumer, based on MPPT/conventional approach

3.6 Reliability Analysis of the Studied BIPV System: Obtained Results

The analyzed PV system consists of a set of components, designed to achieve high performance if a reliability analysis is performed as accurately as possible. The implementation of the Reliability, Availability, Maintenance, and Safety (RAMS) approach for the studied BIPV system was performed using a software platform for modeling and simulation of the system reliability, namely, Synthesis, developed by ReliaSoft [25]. For a thorough understanding of the RAMS approach required for the BIPV systems, we have highlighted the degradation of its components, as well as the determination of specific performance indicators, namely, Availability, Unreliability, Average Interruption Frequency Index, and Average Interruption Duration Index.

For the analysis of the BIPV system reliability, the BlockSim simulation module from the same platform was used. The simulation of the BIPV system is based on the reliability block diagram (RBD), as well as the types of components (repairable/non-repairable) and the way they are arranged in the system.

The reliability characteristics of the BIPV system, respectively, of its components have been processed using the RBD charts that highlight their possible failures (failures due to an incomplete analysis of failure risks).

The interpretation of the results is presented in Fig. 3.20 (the level of degradation for each component of the BIPV system), respectively, in Fig. 3.21 (the availability/unavailability diagram for both each component and the entire BIPV system).

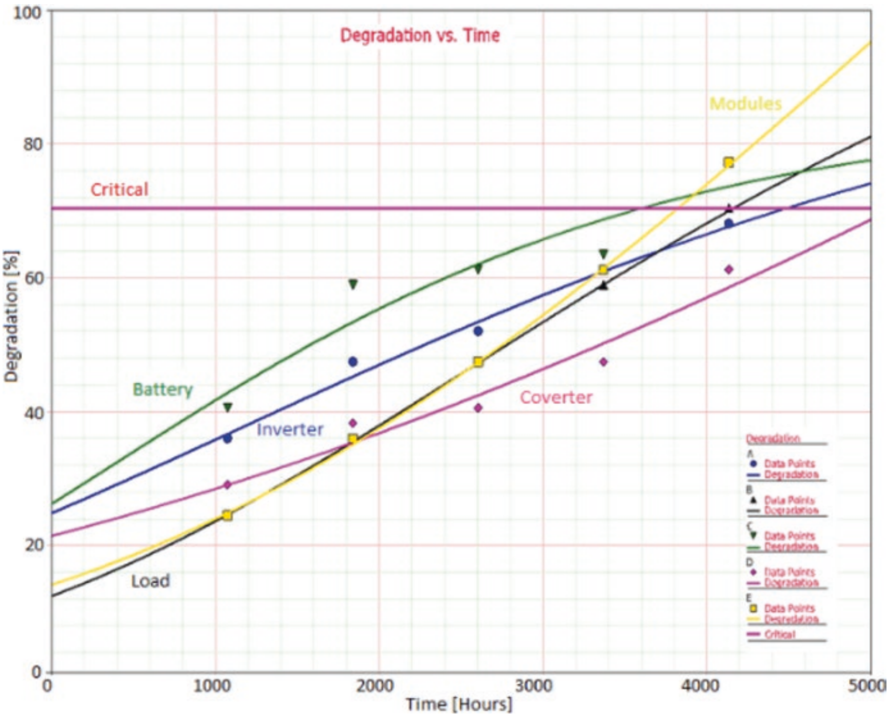


Fig. 3.20 Degradation mode of BIPV system components based on availability/unavailability diagram

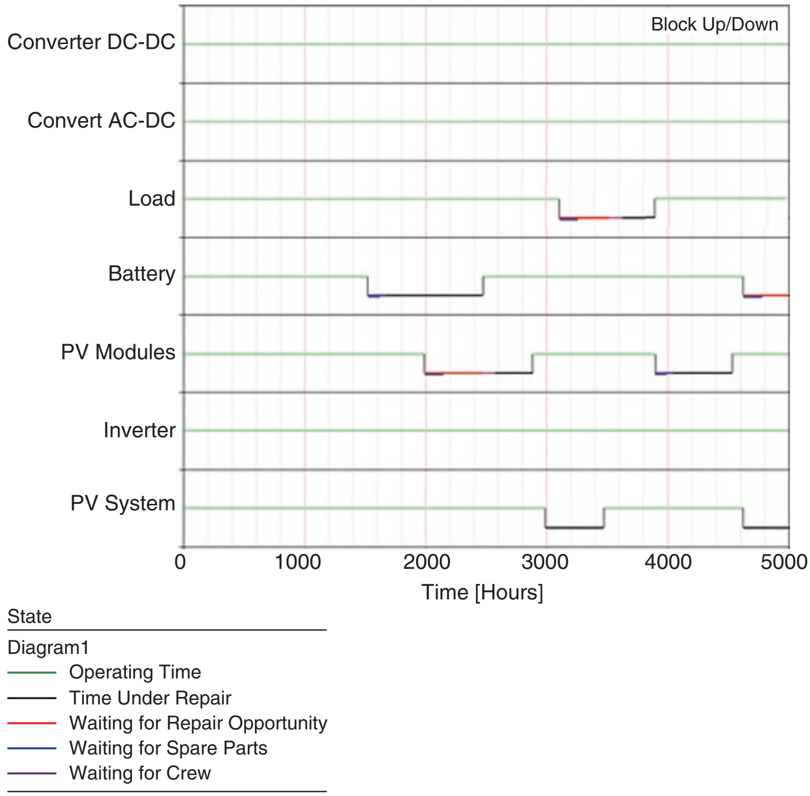


Fig. 3.21 Availability/unavailability diagram of the BIPV system

In conclusion, a reliable BIPV system is characterized by low fluctuations during the unavailability duration, which causes a functional degradation in accordance with the requirements of normal operation.

3.7 Conclusion

The operational optimization of the BIPV system using MPPT techniques based on the Perturb and Observe (P&O) algorithm implemented in the FLC controller leads to the improvement of the system performance (high electrical parameters) while maintaining at the same time a stable output power under low solar irradiance conditions.

By optimizing different types of FLC algorithms, other than P&O (incremental conductance, neural networks, current sweep, ripple correlation control, load current, or load voltage maximization), an interesting research direction can be realized in optimizing BIPV systems.

The reliability analysis developed is based on an original approach, which aimed to determine the reliability of the BIPV system, by using the RAMS approach, respectively, by adapting the up/down reliability block diagrams (RBD) in order to determine its functionality and availability and to establish the duration of unavailability, that is, the duration of maintenance; indicators needed to be able to evaluate in real time the state of the BIPV system were determined.

The final goal of the reliability analysis is to use the up/down diagram for the development of a maintenance plan, which will contribute to minimizing spontaneous or even irreversible defects occurring in BIPV systems.

References

1. F. Garde, A. Bastide, E. Wurtz, G. Achard, O. Dobre, ENERPOS: A National French Research Program for developing new methods for the Design of Zero Energy Buildings, CESB 07; Central Europe towards Sustainable Buildings: Prague, Czech Republic, 2007
2. A. Diaconu, D. Craciunescu, L. Fara, P. Sterian, C. Oprea, S. Fara Estimation of electricity production for a photovoltaic park using specialized advanced software, in *Proceedings of the ISES EuroSun 2016 Conference*, pp. 1180–1182, 2017
3. M. Shah, W. Robert, L. Biate, Design and simulation of solar PV model using MATLAB/ Simulink. Int. J. Sci. Eng. Res. **7**(3) (2016)
4. N. Onat, Recent developments in maximum power point tracking technologies for photovoltaic systems. Int. J. Photogr. **2010**(245316), 1–11 (2010)
5. D. Sharma, Designing and modeling fuzzy control systems. Int. J. Comput. Appl. **16**(1), 0975–8887 (2011)
6. J.K. Shiau, Y.C. Wei, M.Y. Lee, Fuzzy controller for a voltage-regulated solar -powers MPPT system for hybrid power system application. Energies **8**, 3292–3312 (2015)
7. L.K. Letting, L.J. Munda, Y. Hamam, Optimization of fuzzy logic controller design for maximum power point tracking in photovoltaic systems. Soft. Comput. Green Renew. Ener. Sys **269**, 233–260 (2011)
8. L.A. Zadeh, Toward a theory of fuzzy information granulation and its centrality in human reasoning and fuzzy logic. Fuzzy Sets Syst **90**, 111–127 (2007)
9. D.S. Ouil, Effect of different membership functions on fuzzy power system stability for synchronous machine connected to infinite bus. Int. J. Comput. Appl. **71**(7), 0975–8872 (2013)
10. M.H. Sherif, T.M. Egyedi, K. Jakobs, Standards of quality and quality of standards for telecommunications and information technologies, in *Proceedings of IEEESIIT*, pp. 221–230, 2005
11. J. Wohlgemuth, IEC Technical Specification for PV Module Quality Management, 2014
12. Y.Y. Sivan, K. Jakobs, *Knowledge age standards: A brief introduction to their dimensions, information technology standards and standardization: A global perspective* (Idea Group Publishing, London, 1999), pp. 1–18
13. P.M. Wiegmann, H.J. Vries, K. Blind, Multi-mode standardization: A critical review and a research agenda. Res. Policy **46**(8), 1370–1386 (2017)
14. L. Fara, S. Fara, A-M. Dabija, First results of a BIPV project in Romania, in *Proceedings of PLEA Conference*, Dublin, Ireland, 2008
15. A. Singh, P. Basak, J.S.M. Shehzad, Modelling and simulation of building integrated photovoltaic (BIPV) system for energy efficient buildings. Int. J. Comput. Appl. **975**, 8887 (2017)
16. B. Bartok, L. Fara, A. Galbeaza, A. Diaconu, Estimation of a BIPV system performance based on solar radiation forecast models, in *Proceedings of ISES –Europe Conference*, EUROSUN, Opatija, Croatia, 2012

17. ∗∗∗Masdar. A Mubadala Company. Masdar Factsheet. Fast Facts. Available at: http://www.londonarray.com/wp-content/uploads/Masdar-Factsheet.pdf. Accessed June 2019
18. ∗∗∗Masdar City. Frequently asked questions. Available at: http://tinyurl.com/pcpfubu. Accessed June 2019
19. ∗∗∗Masdar City role model for a sustainable future. Available at: http://9mp.com/HqIbp. Accessed June 2019
20. ∗∗∗International Energy Agency (IEA), Energy statistics of non-OECD countries. Available at: http://tinyurl.com/nz8xfaa. Accessed June 2019
21. R.M. Essefi, M. Souissi, H.H. Abdallah, Maximum power point tracking control using neural networks for standalone photovoltaic systems. Int. J. Mod. Nonlinear Theory Appl. **3**, 53–65 (2014)
22. L.H. Crow, Evaluating the reliability of repairable systems, *IEEE Proceedings Annual Reliability and Maintainability Symposium*, pp. 275–279, 1990
23. L.H. Crow, Methods for reducing the cost to maintain a fleet of repairable systems, *IEEE Proceedings Annual Reliability and Maintainability Symposium*, pp. 392–399, 2003
24. D.L. Huffman, F. Antelme, Availability analysis of a solar power system with graceful degradation, in *Proceedings of the Reliability and Maintainability Symposium*, Fort Worth, TX, pp. 26–29, Jan 2009
25. ∗∗∗https://www.reliasoft.com. Accessed June 2019

Chapter 4
Inorganic, Coloured Thin Films for Solar Thermal Energy Convertors in Sustainable Buildings

Dana Perniu, Maria Covei, Cristina Bogatu, Luminita Isac, Ion Visa, and Anca Duta

4.1 Introduction

The continuous development of the socio-economic system along with the population growth has as direct consequence an increasing need for energy that causes unprecedented environmental unbalance. To cope with this problem, a promising alternative to fossil fuels is the use of renewable energy systems. Among renewable energy sources, solar energy is recognized as an attractive option, due to its wide availability, abundance and sustainability. Harnessing solar energy does not cause any harmful impact on ecosystems, being suitable in urban and rural areas, for residential and industrial applications [1].

The implementation of renewable energy sources, particularly in the building sector (that is responsible for 40% of the total primary energy consumption and for 30% of the greenhouse gas emissions in OECD countries [2]), is dominated by the use of solar thermal systems that reach a conversion efficiency of about 70–80%. The integration of the solar thermal systems in the built environment has to meet prerequisites on functionality (in terms of efficiency) and affordability (in terms of costs). Because the landscape (natural or built) might be altered by the solar collectors' integration, an important issue is the social acceptance where visual impact plays a major role [3].

The work hereby reported focuses on two aspects of the solar thermal collectors' integration in/on the buildings. As this integration is the result of a decision taken by individuals (building owner(s), architect(s), etc.), aspects related to the factors influencing this decision are presented in the first part. The second part is dedicated to

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the coloured flat plate solar thermal collectors developed in the Transilvania University of Brasov, the Renewable Energy Systems and Recycling R&D Center (RES-REC).

4.2 Driving Forces in Implementing Solar Thermal Systems

By far, the major driving force for the use of solar thermal systems (renewable energy systems, in general) in meeting the energy demand in residential applications is the environmental deterioration (in terms of pollution and resource depletion), as a consequence of using traditional fossil fuels as energy source. Consequently, at different levels of the socio-economic systems, actions are taken in order to cope with the potential threats.

4.2.1 Social System in Interaction with Environment

Interactions between the natural environment and the social system can be approached at three levels, and the behaviour towards energy consumption can be discussed in this frame:

(a) *The micro-level* corresponds to individuals and their habitat, either natural ecosystem or built environment as living space in a building. At this level, the individuals' habits and needs related to the quality of life directly influence the energy consumption. Consequently, the indoor environment and the natural environment in the building proximity are those mostly influenced. The actions taken to control (prevent) the natural environment disturbances are mostly at individual level and strongly depend on the individual biological status (age, gender) and acquired status (income, level of education): low-income groups are more dependent on domestic, fundamental energy products, while high(er)-income groups rely more heavily on energy services [4].

(b) *The meso-level* represents the community level, the living spaces in collectivities. In the context of this analysis, it addresses the urban-built environment, cities as predominant habitat for humans, accounting for more than half of the population. The energy demand at city level represents the energy used by the energy systems (with various efficiency values) and also depends on the behaviour of the users asking for energy services [5]. The answer, both to the energy demand and to the citizens' requirements (in terms of health and well-being), can be translated into local strategies to support a functional and well-accepted urban design, preserving the natural environment and preventing its pollution. The implementation of the measures is strongly dependent on the perceived common aspirations, beliefs and values of the inhabitants. At this level, a driving force for solar energy conversion systems' implementation is the quality of the architectural integration [3].

(c) *The macro-level* represents the global level. In this case, the energy demand is evaluated in terms of resource depletion and climate change. At national and/or international level, policies are formulated and implemented to limit the greenhouse gas (GHG) emissions [4].

There is no doubt that the system functioning at a certain level influences the other levels, either in terms of energy production/consumption and related environmental problems or in terms of measures formulated to cope with environmental imbalances.

4.2.2 Environmental Perturbation as Consequence of Energy Consumption

At global level, for the almost 7.6 billion inhabitants (7,594,270.36 thousand in 2018, 1.1% increase compared to 2017 [6]), the energy demand in 2018 compared to 2017 increased by 2.3%, of which the energy coming from fossil fuels represents 70% [7]. The building sector has a major contribution to the primary global energy demand, which is 36% in 2018 [8]. A projection states that from 2017 to 2040, a yearly increase of 0.5% [9] is expected, as consequence of the increase in the floor area, nearly 3% per year [8]. The CO_2 emissions related to the energy consumption increased by 1.7% in 2018 compared to 2017, leading to 33.1 Gt. This value corresponds to 407.4 ppm in the atmosphere, a significant increase compared to the average value recorded in the pre-industrial era (180–280 ppm), the "normal" value in a naturally balanced environment [7]. Nearly 40% of the CO_2 emissions come from the building and construction sectors [7]. The significant amount of CO_2 in the atmosphere comes mainly from fossil fuel burning in the power sector (this accounting nearly two-thirds of the emissions growth) [7]. However, as result of the pressures imposed by regulations and market that supported the implementation of renewable energy systems, in 2018, 215 Mt. of CO_2 emissions were avoided at global level [7]; these savings can be attributed mainly to Europe and China.

More than half of the population (55% [6]) live in urban areas, accounting for 67–76% of the energy use and 71–76% of the CO_2 emissions [10]. Differences are encountered considering the geographical location and the socio-economic status. As example, the CO_2 emissions of low-income households are primarily for essential needs (housing, transportation, etc.), while nearly 50% of the CO_2 emissions of high-income households are from the consumption of nonenergy goods and services [4].

People spend a substantial period in buildings; thus, the indoor air quality is recognized as a major risk factor for human health. The interiors are subject to pollution from many sources, and one of the most important is the use of fossil fuels for space and/or water heating. Household air pollution, especially in developing countries, was responsible of 4.3 million premature deaths in 2016 [10] as a result of exposure to pollutants such as carbon monoxide, CO, particulate matters (PM_{10}, $PM_{2.5}$ and submicrometric ones) and polyaromatic hydrocarbons (PAH).

To mitigate the energy and environment pressure caused by the household energy consumption, policy instruments are developed, and governments provide subsidies and grants for the development of renewable energy implementation [4]. Since 1990, solar energy convertors have been widely implemented in/on the buildings; thus in 2017, the solar thermal installed capacity represented 472GW [11] as a cumulative result of various factors, such as increased efficiency of the systems, affordable costs and increased awareness towards environmental benefits.

4.3 Coloured Solar Thermal Flat Plate Collectors

4.3.1 Flat Plate Solar Thermal Collectors

With a history of almost 120 years, solar thermal collectors are used for water and space heating, in domestic or industrial applications. The flat plate solar thermal collectors (FPSTC) are by far the most used, accounting for 26.4% of the global installed solar thermal capacity and for 84.9% of the European installed capacity [12].

Basically, a common flat plate solar thermal collector consists of an absorber plate, a tube array, a glazing and an insulated box. The solar radiation incident on the transparent glass cover is intercepted by the spectral selective absorber coating/plate (that supports the absorption of the UV and VIS radiation of the solar spectrum and does not allow the emission of the long-wave, IR, converted radiation). The converted thermal energy is transferred to the tube array and then to the thermal fluid inside the tubes (water, water–glycol mixture, phase-change materials, hydrocarbon oils, nano-fluids, and molten salts [13]) that further ensures the heat transport into the system. The assembly glazing–absorber plate–tube array is placed into a well-insulated box (to reduce the heat losses). The absorber plate represents the key component in the solar thermal flat plate collector, hosting the conversion (UV and VIS radiation to heat) and the convection (NIR) processes [14]. The absorber plates are usually black because of the high optical absorbance of the dark colours or dark blue when covered with a thin TiO_2 antireflective coating with anticorrosion properties. These dark colours represent a serious drawback considering the limited architectural acceptance of these collectors, for example their façade implementation [15].

Thus, a quite recent challenge is to meet both functional criteria (water and space heating for residential applications) and the architectural integration in the (urban) built environment [16]. When speaking about architectural integration, the development of coloured solar thermal collectors is intensively investigated [17–19]. It was proved that the efficiency of differently coloured collectors is lower compared to that of the black collectors; however, they are able to reach a reasonable efficiency in the solar thermal conversion [16]. The integration in façades also requires a flexible design to ensure, beyond a pleasant view, a better coverage of the available (opaque) parts of the building. Thus, solar thermal collectors, with a lower surface area and with various shapes (e.g. trapeze and triangle), were proposed [20, 21] to cover the new solar façades.

4.3.2 Materials for the Absorber Layer

More than 2000 years ago, in his *Ten Books of Architecture*, Vitruvius stated that 'a machine is a continuous material system' [22]. Today there is no doubt that materials are expected to support the quest towards efficient, affordable, socially acceptable systems based on the solar energy conversion in thermal energy for residential applications.

The paradigm *from material to prototype* drives the work of the groups in the Renewable Energy Systems and Recycling R&D Center (RES-REC). The development of innovative solar thermal collectors as building blocks for Lego-type solar thermal arrays and/or façades followed complex design, modelling, development and testing steps [21] starting with the concept of non-rectangular (trapeze or triangular) flat plate solar thermal collectors along with variously coloured materials used as spectral selective absorber coatings in the demonstrators.

Generally, the design and development of materials for a specific application require an integrated approach. A unified view has been developed by the US National Research Council [23] integrating four elements: synthesis/processing (aiming to 'fit' the atoms/substances and larger-scale components of a system into the targeted configuration), structure/composition (providing the understanding of the materials' behaviour), properties (to support the underlying working mechanisms of the targeted system) and performance (to assess the suitability for the targeted application). In Fig. 4.1, this concept is concretely formulated for the development of coloured flat plate solar thermal collectors.

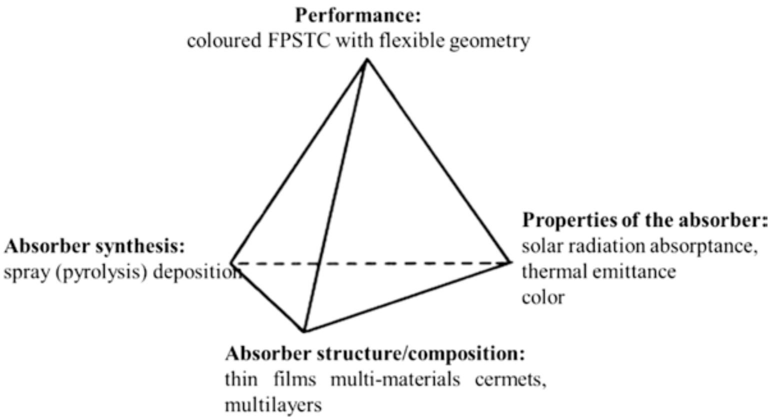

Fig. 4.1 The materials' tetrahedron applied to materials for coloured FPSTC

When the materials' design for solar thermal conversion in flat plate solar thermal collectors represents the goal, the targeted performance is to ensure the system's functionality and, thus, a good energy conversion efficiency, where the absorber spectral selectivity has an essential role. Additionally, architectural integration represents an important focus, by 'playing' with the collectors' features such as size, shape and colour.

The *spectral selectivity* (SS) of the absorber coating was introduced by Tabor in the middle of the twentieth century and opened a new era of high-performance solar-absorbing coatings [24]. It is understood as maximizing the energy collection and its conversion by layers with high absorption of the short-wave solar radiation and relatively non-absorption (transparency) of the long-wave thermal radiation [25]. The SS parameter depends on two material's optical properties and is estimated by the ratio of the *solar absorptance* (α_{sol}, defined as the weighted fraction between the absorbed radiation and the incoming solar radiation in the wavelength interval 0.3–2.5 μm, corresponding mostly to the VIS and NIR region of the solar spectrum) and *thermal emittance* (ε_T defined as the ability of a surface to radiate thermal energy, corresponding to a wavelength larger than 2.5 μm, in the IR region of the solar spectrum). For an efficient flat plate solar thermal collector, the targeted performance expressed in terms of spectral selectivity is translated to a material that has low reflectance (less than 10%) and a high absorptance (over 90%), consequently SS > 9 [26]. Highly efficient solar thermal coatings have the SS higher than 13.

Since no intrinsic material reaches the ideal spectral selectivity, novel materials/combinations of materials are developed to tailor the optical and structural properties to reach the targeted solar energy absorption and the low thermal emittance. The spectral selectivity control is done by adjusting various parameters of the (multi-)materials such as composition, thickness, porosity, surface morphology and nanostructure. Currently, widespread solar selective coatings are based on the semiconductor-metal tandems or on multilayered absorbers or on cermet-type composites (metallic particles dispersed in ceramic matrices) [27]. Usually, the absorber material for flat plate solar collectors is deposited as thin film using physical or chemical methods, like magnetron sputtering, electrochemical deposition, physical or chemical spray deposition, sol-gel and spray pyrolysis [27].

4.3.3 Coloured Materials for Absorber Coatings in FPSTC

Spray pyrolysis deposition (SPD) was used to develop the absorber coatings within the RES-REC Center, as this deposition technique allows a good and easy-to-implement control; it involves small amount of chemicals, leads to non-toxic by-products and has an acceptable cost. Moreover, the technique is up-scalable for industrial applications, allowing the deposition of large surfaces. Common SPD consists of the reaction, on a heated substrate, of the components in the liquid precursor system, dispersed in fine aerosol droplets using a slight over-pressured carrier gas. The process is divided into three main steps: (a) atomization of the precursors' solution generating the aerosol, (b) aerosol transport towards the heated substrate and (c) chemical reaction (usually thermal decomposition) of the precursor(s) on the substrate [28].

To be integrated in FPSTC, the absorber plate consists of the solar thermal multi-material coating (characterized by high solar absorptance and low thermal emittance to ensure the system functionality and colour to support the acceptance) deposited on the metallic substrate (e.g. copper or aluminium).

The research aimed at developing novel absorber coatings usually involves two phases:

(a) Developing the absorber coating on lab-scale substrates (3 cm × 5 cm). This phase contains iterative steps of deposition and characterization aiming at optimizing the materials in terms of composition, structure and morphology using as control properties the absorptance and the emittance. Correlations between the deposition parameters (temperature, duration, precursor, qualitative and quantitative composition) and materials' properties are developed.
(b) Deposition of the absorber coating on large surfaces, adapted to the FPSTC geometry, to develop the collector prototype. During this step, reiterations of the steps done during the absorber development may be required to optimize the output properties.

The absorbers developed in the RES-REC Center to be integrated in solar thermal collectors with non-traditional colours and geometry are multilayers with the following structure Al/Al_2O_3/AM:

- Metallic substrate: aluminium plate (Al).
- Alumina matrix (Al_2O_3) to support the infiltration of the active material(s) (AM); this matrix has controlled morphology and is deposited by spray pyrolysis or is developed through chemical treatment of the Al plate [29].
- Active material (AM)—usually embedded in the alumina matrix. The AM can be of cermet type, for example, metallic nanoparticles dispersed in a semiconductor (oxide or sulphide) or inorganic semiconductors, acting as pigments (metallic oxides or sulphides).

There are mainly two routes to develop the active material as an inorganic compound, obtained with minimal negative environmental impact:

(a) By spray pyrolysis deposition (SPD) which involves spraying a precursors solution on a preheated substrate (300–500 °C). Usually the precursors are inorganic salts that, through a chemical reaction, form the targeted compound along with volatile, non-toxic by-products. The high temperature required for the chemical reaction is the major drawback in the production of the large absorber surfaces in FPSTC [28].
(b) By spraying a dispersion of the active material powder (previously prepared by, for example sol-gel synthesis), at low temperature (lower than 100 °C). One of the major challenges in this route is the stability of the dispersion, ensured by addition of stabilizers, usually surfactants or polymers [30].

Table 4.1 gives a synthetic presentation of the absorbers developed at laboratory scale along with the output properties: solar absorptance (α_{sol}), thermal emittance (ε_T) and spectral selectivity. The data in Table 4.1 outline promising materials that were integrated in the solar thermal collectors with non-traditional colour and shape. During the scaling-up process, several issues were considered. First of all, the materials (precursors) should be low cost. Thus, the use of Au nanoparticles was avoided, although spectral selectivity value was very good. Furthermore, the active material (pigment) deposition should be done at low(er) temperature to reduce the production costs; thus, the synthesis was done based on the following steps:

(a) Preparation of the active material (pigment) powder (using the sol-gel synthesis).
(b) Preparation of the dispersion using the pigment powder and non-toxic continuous medium along with additives for the dispersion stabilization.
(c) Spraying the dispersion on the substrate at temperature lower than 100 °C.

Table 4.1 Coloured absorber materials and associated properties

Absorber material	Absorber composition	Colour	α_{sol}	ε_T	S	Reference
$Al/Al_2O_3/$ $Au\text{-}Fe_2O_3$	Au nanoparticles dispersed in the oxide semiconductor infiltrated in the alumina matrix deposited on the Al substrate	Red	0.62	0.05	12.40	[32]
$Al/Al_2O_3/$ $Au\text{-}V_2O_5$	Au nanoparticles dispersed in the oxide semiconductor infiltrated in the alumina matrix deposited on the Al substrate	Yellow	0.52	0.17	3.06	[32]
$Al/Al_2O_3/$ $Au\text{-}Cu_xS$	Au nanoparticles dispersed in the sulphide semiconductor infiltrated in the alumina matrix deposited on the Al substrate (cermet type)	Green	0.75	0.23	3.26	[32]
$Al/Al_2O_3/$ Fe_2O_3	Ferric oxide infiltrated in the alumina matrix with controlled morphology	Red	0.51	0.15	4.07	[29]
$Al/Al_2O_3/$ Cu_xS	Copper sulphides (x = 1.8–2) infiltrated in the alumina matrix with controlled morphology	Grey-green	0.61	0.24	2.79	[29]
$Al/Al_2O_3/$ NiS_x	Nonstoichiometric nickel sulphides deposited on the alumina matrix at low temperature	Black	0.82	0.41	2.02	[31]
$Al/Al_2O_3/$ Fe_2O_3	Ferric oxide deposited on the alumina matrix at low temperature	Red	0.69	0.12	5.36	[31]
Al/Fe_2O_3	Ferric oxide deposited on the Al plate at low temperature	Red	0.64	0.05	12.8	[31]
Al/V_2O_5	Vanadium oxide deposited on the Al plate at low temperature	Yellow-orange	0.63	0.33	1.91	Unpublished
Al/Cu_xS	Copper sulphides (x = 1.8–2) deposited on alumina matrix at low temperature	Green	0.74	0.32	2.34	Unpublished

Following this procedure, red coatings were developed to obtain trapeze solar collectors and yellow-orange and green coatings for the triangular ones.

For the development of the *red coatings* [31], the Fe_2O_3 powder was obtained using an aqueous-ethanolic ferric chloride ($FeCl_3 \cdot 6H_2O$) 1 M solution and ammonia (10% solution), under magnetic stirring. The colloidal system was aged and then thermally treated to evaporate the continuous medium followed by drying, and finally it was annealed at 500 °C. The resulted dark-red powder (the pigment) was dispersed in aqueous-alcoholic continuous medium, using (1-dodecyl)trimethylammonium bromide (DTAB) as stabilizer. The dispersion was sprayed on the pretreated substrate at 100 °C. To prepare the substrate, commercial Al foil (0.7 mm) was used. After preliminary cleaning, the foil was conditioned by successive immersions in alkaline (NaOH) and acidic (H_2SO_4 and HNO_3) solutions. The lab-scale substrates (3 cm × 5 cm), Fig. 4.2a, were subject of testing and characterization.

The integration at the demonstrator scale was further ensured, by depositing the pigment dispersion on large surfaces, Fig. 4.2b, to obtain the absorber plate for the trapeze collector with a nominal area of $0.67 m^2$. The collector was further tested on an indoor testing rig and outdoor (Fig. 4.2c) [33]. For the black prototype collector, a nominal efficiency of 69.42% was recorded [34].

For developing the triangular solar thermal collectors, the inorganic pigment was deposited on pre-treated Al substrate from dispersions containing the powders prepared by sol-gel method.

To prepare the substrate, commercial Al foil was cleaned and successively immersed in alkaline (NaOH) and acidic (HNO_3) solutions. To obtain the *yellow-orange* absorbers, the V_2O_5 powder, prepared using the sol-gel method from vanadium tri-isopropoxide precursor, was dispersed in aqueous-alcoholic (isopropylic alcohol) continuous medium using PEG 2000 (polyethylene glycol) as stabilizer. The dispersion was sprayed on the Al substrate at 130 °C, obtaining the lab-scale samples in the first stage (Fig. 4.3a) and the larger plates with triangular shape for integration in the collector (Fig. 4.3b), with a surface of $0.083 m^2$.

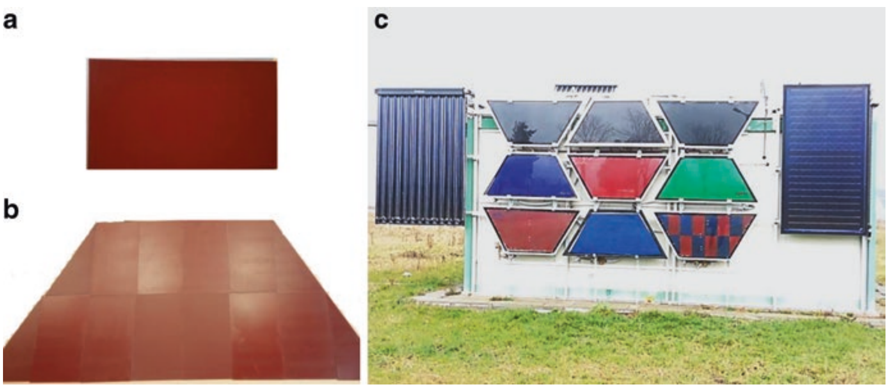

Fig. 4.2 The red-coloured absorber plate development at (**a**) lab-test plate, (**b**) trapeze absorber (**c**) and façade-integrated demonstrator

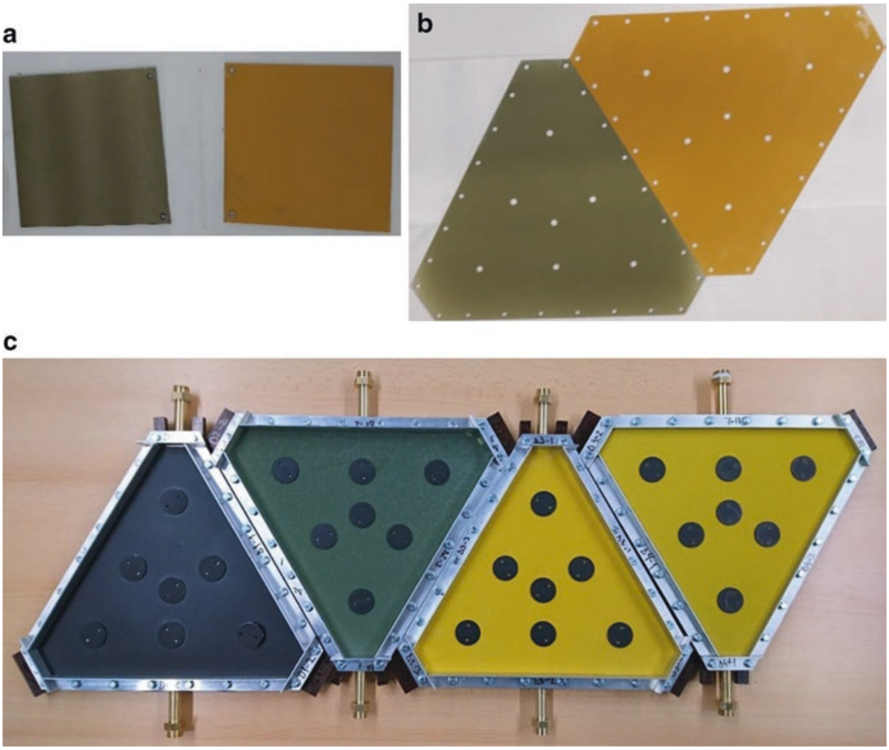

Fig. 4.3 The yellow-orange and green absorber plate development at (**a**) lab-test plates, (**b**) triangular absorbers and (**c**) demonstrators

Following similar steps, the *green* absorber was obtained by infiltrating the alumina matrix with Cu_xS powder prepared using copper chloride ($CuCl_2$) mixed with thiourea as precursors in the sol-gel synthesis. To ensure the stability of the powder dispersion, DTAB was used as additive in the aqueous-alcoholic continuous medium. In Fig. 4.3a, b, the absorber plates are presented at lab and demonstrator scale (0.083m^2 surface).

The demonstrators using these absorber plates were assembled along with a black one, considered as reference (Fig. 4.3c). The indoor testing led to a nominal efficiency of 55% for the black collector, 42% for the green one and 35% for the orange one [35]. These can be considered good results considering the low dimensions and thus the ratio of the collector's perimeter to its area that supports larger thermal energy losses.

4.4 Conclusions

The increasing need to slow down (or stop) climate change asks for changes in energy consumption and production at different levels of the socio-economic system, involving actions driven by complex factors.

One of the most attractive alternatives for domestic hot water production and for heating, ventilation and air conditioning is the solar thermal conversion using flat plate collectors, where the absorber plate is a critical component and is a subject of research. Targeting façades integration and architectural acceptance, the need to develop flat plate solar thermal collectors with non-traditional shapes and colour was identified. Absorber plates were obtained at prototype level, involving low-cost techniques using materials that are stable and that are not harmful for the environment.

Coloured FPSTC with trapezoidal and triangular geometry were developed as building blocks for arrays with complex geometries to be integrated on the façades. The coloured absorber coating was developed by spray deposition. Red-coloured plates were obtained using the ferric oxide pigment, while the green one used copper sulphide, and the yellow-orange used vanadium oxide infiltrated in an aluminium oxide matrix, deposited on an aluminium foil. The optical properties investigated at laboratory scale showed acceptable values; therefore the absorber plates were integrated at demonstrator level, and the nominal efficiencies recorded promising values.

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References

1. S. Rashidi, M.H. Kashefi, F. Hormozi, Potential applications of inserts in solar thermal energy systems – A review to identify gaps and frontier challenges. Sol. Energy **171**, 929–952 (2018)
2. A. Buonomano, C. Forzano, S.A. Kalogirou, A. Palombo, Building-façade integrated solar thermal collectors: Energy economic performance and indoor comfort simulation model of a water based prototype for heating, cooling and DHW production. Renew. Energy **137**, 20–36 (2019)
3. P. Florio, M.C. Munari Probst, A. Schuller, C. Roecker, J.L. Scartezzini, Assessing visibility in multi-scale urban planning: A contribution to a method enhancing social acceptability of solar energy in cities. Sol. Energy **173**, 97–109 (2018)
4. X. Zhang, Y. Wang, How to reduce household carbon emissions: A review of experience and policy design consideration. Energy Policy **102**, 116–124 (2017)
5. D. Mauree, E. Naboni, S. Coccolo, A.T.D. Perera, V.M. Nik, J.L. Scartezzini, A review of assessment methods for the urban environment and its energy sustainability to guarantee climate adaptation of future cities. Renew. Sust. Energ. Rev. **112**, 733–746 (2019)
6. https://data.worldbank.org/indicator/SP.POP.TOTL
7. https://www.iea.org/geco
8. https://www.bp.com/en/global/corporate/energy-economics/energy-outlook/demand-by-sector.html
9. https://www.iea.org/tcep/buildings
10. World Health Organisation, (2016), Burning Opportunity: Clean Household Energy for Health, Sustainable Development and Wellbeing of Women and Children, https://www.who.int/airpollution/publications/burning-opportunities/en/

11. G. Lobaccaro, S. Croce, C. lindkvist, M.C. Munari Probst, A. Sconamiglio, J. Dahberg, M. Lundgren, M. Wall, A cross-country perspective on solar energy in urban planning: Lessons learned from international case studies. Renew. Sust. Energ. Rev. **108**, 209–237 (2019)
12. R. O'hegarty, O. Kinnane, S.J. McCormack, Review and analysis of solar thermal facades. Sol. Energy **135**, 408–422 (2016)
13. M. Imtiaz Hussain, C. Menezo, J.T. Kim, Advances in solar thermal harvesting technology based on surface solar absorption collectors: A review. Sol. Energy Mater. Sol. Cells **187**, 123–139 (2018)
14. M.S. Buker, S.B. Riffat, Building integrated solar thermal collectors – A review. Renew. Sust. Energ. Rev. **51**, 327–346 (2015)
15. M.C. Munari Probst, C. Roecker, Towards an improved architectural quality of building integrated solar thermal systems (BIST). Sol. Energy **81**, 1104–1116 (2007)
16. T.N. Anderson, M. Duke, J.K. Carson, The effect of colour on the thermal performance of building integrated solar collectors. Sol. Energy Mater. Sol. Cells **94**, 350–354 (2010)
17. N. Jolissaint, R. Hanabali, J.C. Hadorn, A. Schuller, Colored solar facades for buildings, CISBAT 2017 International Conference – Future Buildings & Districts – Energy Efficiency from nano to Urban Scale, 6–8 September 2017, *Energy Procedia*, **122** 175–180, (2017)
18. S. Kalogirou, Y. Tripanagnostopoulos, M. Souliotis, Performance of solar systems employing collectors with colored absorber. Energ. Buildings **37**, 824–835 (2005)
19. Y. Tripanagnostopoulos, M. Souliotis, T. Nousia, Solar collectors with colored absorbers. Sol. Energy **68**, 343–356 (2000)
20. M. Comsit, I. Visa, M.D. Moldovan, L. Isac, Architecturally integrated multifunctional solar-thermal facades, in: I. Visa ed. sustainable Energy in the built environment – Steps towards nZEB, Proceedings of the Conference for Sustainable Energy (CSE) 2014, (Springer, 2014), pp. 47–65
21. I. Visa, M. Comsit, A. Duta, M. Neagoe, M. Moldovan, B. Burduhos, D. Perniu, A. Enesca, L. Isac, M. Cosnita, I. Totu, A. Savvides, C. Vassiliades, Novel solar-thermal collectors/array with increased architectural acceptance for building integration, in: S.A. Kalogirou ed. *Building Integrated Solar Thermal Systems, Design and Applications Handbook*, (COST Office, 2017), pp. 373–390
22. M.E. Fine, H.L. Marcus, Materials science and engineering, an educational discipline. Annual Reviews of Materials Science **24**, 1–17 (1994). https://www.annualreviews.org/doi/pdf/10.1146/annurev.ms.24.080194.000245
23. National Research Council, *Materials Science and Engineering for the 1990: Maintaining Competitiveness in the Age of Materials* (National Academic Press, Washington D.C., 1989), p. 29
24. K. Zhang, L. Hao, M. Du, J. Mi, J.N. Wang, J.P. Meng, A review on thermal stability and high temperature induced ageing mechanisms of solar absorber coatings. Renew. Sust. Energ. Rev. **67**, 1282–1299 (2017)
25. Y. Tian, C.Y. Zhao, A review of solar thermal collectors and thermal energy storage in solar thermal applications. Appl. Energy **104**, 538–553 (2013)
26. G. Katumba, L. Olumekor, A. Forbes, G. Makiwa, B. Mwakikunga, J. Lu, E. Wäckelgård, Optical, thermal and structural characteristics of carbon nanoparticles embedded in ZnO and NiO as selective solar absorbers. Sol. Energy Mater. Sol. Cells **92**, 1285–1292 (2008)
27. L. Isac, A. Enesca, C. Mihoreanu, D. Perniu, A. Duta, Spectrally solar selective coatings for colored flat plate solar thermal collectors, in: I. Visa ed. Sustainable Energy in the Built Environment – Steps Towards nZEB, Proceedings of the Conference for Sustainable Energy (CSE) 2014, (Springer, 2014), pp. 279–298
28. A. Duta, L. Andronic, D. Perniu, L. Manceriu, A. Enesca, Chapter 9: Crystalline wide band gap semiconductors with optoelectronic properties, in: M. Aliofkhazraei ed., *Handbook of Functional Nanomaterials,* Vol 1 (Nova Science Publishers, 2014), (eBook), https://novapublishers.com/shop/handbook-of-functional-nanomaterials-volume-1-synthesis-and-modification/

29. L. Isac, L. Nicoara, R. Panait, A. Enesca, D. Perniu, A. Duta, Alumina matrix with controlled morphology for colored spectrally selective coatings. Environ. Eng. Manag. J. **16**, 715–724 (2017)
30. C. Bogatu, D. Perniu, A. Duta, Challenges in development of photocatalytic inks. Powder Technol. **287**, 82–95 (2016)
31. L. Isac, R. Panait, A. Enesca, C. Bogatu, D. Perniu, A. Duta, Development of black and red absorber coatings for solar thermal collectors, in: I. Visa, A. Duta eds. Nearly Zero Energy Communities, Proceedings of the Conference for Sustainable Energy (CSE) 2017, (Springer, 2017), pp. 263–282
32. A. Duta, L. Isac, A. Milea, E. Ienei, D. Perniu, Coloured solar-thermal absorbers – A comparative analysis of cermet structures, SHC 2013, International Conference on Solar Heating and Cooling for Buildings and Industry September, 2013, *Energy Procedia,* **48**, 543–553 (2013)
33. I. Visa, M. Moldovan, M. Comsit, M. Neagoe, A. Duta, Facades integrated solar thermal collectors- challenges and solutions, in: Sustainable Solutions for Energy and Environment, EENVIRO 2016, October 2016, *Energy Procedia,* **112**, 176–185, (2017)
34. I. Visa, A. Duta, M. Moldovan, Outdoor performance of a trapeze solar thermal collector for facades integration. Renew. Energy **137**, 37–44 (2019)
35. I. Visa, M. Moldovan, A. Duta, Novel triangle flat plate solar thermal collector for facades integration. Renew. Energy **143**, 252–262 (2019)

Chapter 5
Capitalizing on Solar Energy in Romania and Improving the Thermal Comfort of Buildings with Solar Air Collectors

Sanda Budea and Viorel Bădescu

5.1 Introduction

In the context of expanding the production and usage of the energy from renewable resources at European level, Romania places above the EU average (see Table 5.1), using approximately 27% of the energy required in heating and cooling processes from renewable energies. In Romania, great deal of effort goes into researching solar panel technologies and, subsequently, applying and integrating solar panels into buildings' architecture.

'In 2017, renewable energy accounted for 19.5% of total energy use for heating and cooling in the EU-28. ... Increases in industrial sectors, services and households (building sector) contributed to this growth [1].'

This chapter starts with the analysis of the solar energy present in the eastern area of Europe, particularly Romania. The global solar irradiation by average monthly values and the sunshine duration were analysed, based on the statistical data for the last 21 years, for several cities in Romania – Constanta, Craiova, Galati, Timisoara, Gura Portitei-Tulcea, Cluj, Iasi and Bucharest. The values for these parameters for Bucharest are then compared with data from other seven European cities (Geneva, Barcelona, Bordeaux, Strasbourg, Vienna, Prague and Moscow) using the archive data of the World Radiation Data Centre [2], for the period 1995–2016, in the months of January, April, July and October.

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Table 5.1 Share of renewable energy sources in heating and cooling, 2010–2016

	2010	2011	2012	2013	2014	2015	2016
EU-28	15.0	15.6	16.4	17.0	18.1	18.7	19.1
Belgium	6.1	6.6	7.3	7.4	7.7	7.8	8.1
Bulgaria	24.4	24.9	27.5	29.2	28.3	28.6	30.0
Czech Republic	14.0	15.3	16.1	17.6	19.3	19.6	19.9
Denmark	31.0	32.3	33.6	35.1	38.5	40.1	41.7
Germany	9.8	10.5	10.4	10.6	12.2	12.9	13.0
Estonia	43.3	44.1	43.1	43.2	45.2	49.6	51.2
Ireland	4.5	4.9	5.1	5.5	6.6	6.6	6.8
Greece	17.9	19.4	23.4	26.5	26.9	25.6	24.2
Spain	12.6	13.6	14.1	14.1	15.7	16.8	16.8
France	16.2	15.9	17.1	18.3	18.9	19.7	21.1
Croatia	32.8	33.7	36.4	37.1	36.0	38.5	37.5
Italy	15.6	13.8	17.0	18.1	18.9	19.3	18.9
Cyprus	18.2	19.2	20.7	21.6	21.6	22.5	23.0
Latvia	40.7	44.7	47.3	49.7	52.2	51.8	51.9
Lithuania	32.5	32.8	34.5	36.9	40.6	46.1	46.5
Luxembourg	4.7	4.8	5.0	5.5	7.2	7.1	7.3
Hungary	18.1	20.0	23.3	23.7	21.2	21.2	20.8
Malta	7.8	12.2	13.2	15.7	14.5	14.1	15.3
Netherlands	3.1	3.7	3.9	4.1	5.1	5.5	5.5
Austria	29.0	30.0	31.1	33.0	32.4	32.4	33.3
Poland	11.7	13.1	13.4	14.1	14.0	14.5	14.7
Portugal	33.9	35.2	33.2	34.6	34.0	33.4	35.1
Romania	27.2	24.3	25.8	26.2	26.7	25.9	26.9
Slovenia	28.1	30.3	31.5	33.4	32.4	33.9	34.0
Slovakia	7.9	9.3	8.8	7.9	8.9	10.8	9.9
Finland	44.2	45.9	48.4	50.8	52.0	52.5	53.7
Sweden	60.9	62.2	65.8	67.1	68.0	68.6	68.6
United Kingdom	2.7	3.0	3.2	4.0	4.7	6.3	7.0
Norway	33.3	34.5	33.5	32.7	31.1	32.2	31.7
Iceland	63.9	65.2	64.6	59.0	58.1	63.4	71.1
Albania	31.3	31.4	39.1	37.8	31.0	34.6	33.8
Montenegro	76.5	81.3	79.8	68.5	67.6	68.5	69.2
Former Yugoslav Republic of Macedonia	26.5	27.3	29.6	31.8	35.0	34.4	31.7
Serbia	23.2	21.1	23.2	25.2	28.8	26.5	24.2

Source Eurostat (online data co ec.europa.eu/eurostat)

The authors present values of the solar irradiation, experimentally measured, with high accuracy, during 2017–2018 in Bucharest, in each season. It is shown that high values of solar radiation have been maintained in the last 2 years, in Bucharest.

In the final section, various types of solar thermal collectors are reviewed. These solar collectors can be used to improve the thermal comfort of buildings. The authors present solar air collectors in various solutions, their performances and technologies for storage of solar energy.

There are multiple applications of these thermal solar collectors, installed both separately and in thermoelectric hybrid systems, for heating and cooling the space. All these solar collectors can be used to improve the thermal comfort of buildings and to capitalize on the solar energy present in Romania.

The objectives of this chapter are as follows: (i) an analysis of solar irradiation in eight European cities including Bucharest and in eight Romanian localities comparing the heating demand, (ii) experimental data for solar irradiation in Bucharest during 2017–2018, and (iii) a brief review of solar air collector used to improve the thermal comfort of buildings.

5.2 Solar Irradiation

5.2.1 Climate of Selected Localities

In this section, the global solar irradiation by average monthly values and the sunshine duration are analysed. The analysis is based on the statistical data from the last 22 years, specific in eight European cities (Geneva, Barcelona, Bordeaux, Strasbourg, Vienna, Prague, Bucharest and Moscow; Fig. 5.1a) and specific to Romania, in eight cities including Bucharest (Fig. 5.1b).

The climate zones and types correspond to the classification used by Briggs et al. (2002, 2003a, b) (in Table 5.2) [3–5]. NASA's online Climatology Resource for Sustainable Buildings (NASA 2015) [6] has been used to classify the localities according to their climate area.

One remark from this table is that Romanian cities have average solar irradiation and sunshine duration better than many European localities. Comparing these European localities, Bucharest has in summer a solar irradiation better than European localities selected, while Cluj has similar values with Vienna or Geneva, with a sunshine duration. In many areas of Romania, especially southern areas, the solar irradiation and sunshine duration have high values and are favourable to capitalize the solar energy by using solar air collectors, to improve the thermal comfort of buildings.

a

Fig. 5.1 (**a**) Selected localities from Europe (**b**) Selected localities from Romania

5.2.2 Solar Global Irradiation: Average Monthly Values

Statistical data for 22 years (during 1995–2016) regarding average daily values of global solar irradiation are presented graphically in Fig. 5.2a–d, for selected European localities and a specific month during each season (winter, spring, summer, autumn) characteristic to each individual climate zone. Similar information for the eight selected Romanian localities is presented in Fig. 5.3a–d.

In terms of global solar irradiation, the highest daily values during the observed period are reported for Barcelona, followed by Bucharest, in January, April and October. In July, Bucharest has solar irradiation to the average of European cities The lowest monthly values of the global solar irradiation were measured in Moscow, b

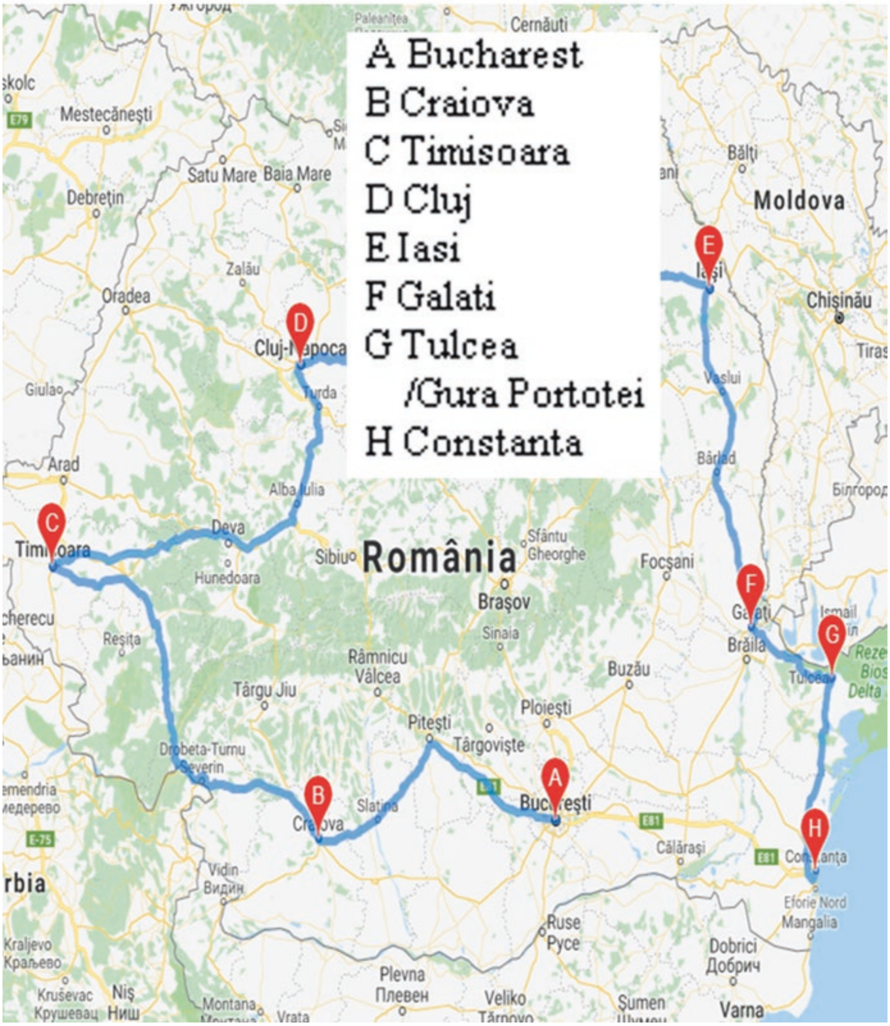


Fig. 5.1 (continued)

given the Nordic location of the city, with the exception of the summer season, when the solar irradiation has high values.

Bucharest is well placed when considering the months of January (with global irradiation mean 500 W/m^2), April (with global irradiation mean 1800 W/m^2) and October (with global irradiation mean 1000 W/m^2). An exception is July, when the global irradiation mean is 2200 W/m^2, below the value for Barcelona, Moscow or Geneva.

It can be observed from the graphs shown in Fig. 5.3 that the highest monthly values of the global solar irradiation are reported for Bucharest, Constanta (with the

Table 5.2 Climate zone and type, average solar irradiation and sunshine duration for the last 22 years for July

Climate zone	Climate type	Locality	Latitude (°N)	Longitude (°E)	Altitude (m)	Average solar irradiation for July	Average sunshine duration for July (hours)
4	1	Constanta	44°13’	28°38′E	12	2523	107
4	2	Craiova	44°19’	23°52′E	93	2298	102
		Bucharest	44°30’	26°13′E	91	2367	103
		Galati	45°30’	28°02′E	30	2361	94
		Timisoara	45°47’	21°17′E	87	2187	91
		Gura Portitei	44°41’	29°00′E	2	2436	105
5	2	Cluj	46°46’	23°35’	380	2095	92
		Iasi	47°09’	27°35’	50	2236	95
3	2	Geneva	46°15’	6°08′E	420	2175	87
3	1	Barcelona	41°23’	2°12′E	25	2987	92
4	2	Bordeaux	44°49’	0°41’W	47	2160	82
4	2	Strasbourg	48°32’	7°38′E	150	1953	75
5	2	Vienna	48°12	16°34′E	157	2013	87
5	2	Prague	50°05’	14°26′E	232	1878	75
6	2	Moscow	55°42’	37°30E	192	1977	99

exception of winter) and Craiova (which has the highest value for winter). At the end of the ranking, there are Cluj and Timisoara.

The average multi-annual values vary from 500 W/m^2 during winter to 1500 W/m^2 in spring, to 2200 W/m^2 in summer time and then return to under an average value of 900 W/m^2 in autumn.

Therefore, it can be easily concluded that the maximal efficiency of solar air collectors can be obtained during the spring and autumn seasons and only partially during winter when considering heating, while the maximal efficiency for cooling systems can be achieved in summer.

5.2.3 *Sunshine Duration*

Sunshine duration (in hours) in European cities, including Bucharest, are represented in Fig. 5.4a–d for a month from each season – January, April, July and October.

As it can be seen, in terms of the sunshine duration, Moscow is badly positioned for winter, but it is well positioned for summer, over the means of the other European cities. Barcelona is positioned the best for winter, autumn and summer, but during spring, it has values under Bordeaux. Moscow and Prague are well positioned for summer, but not for winter. The biggest differences between selected cities regarding

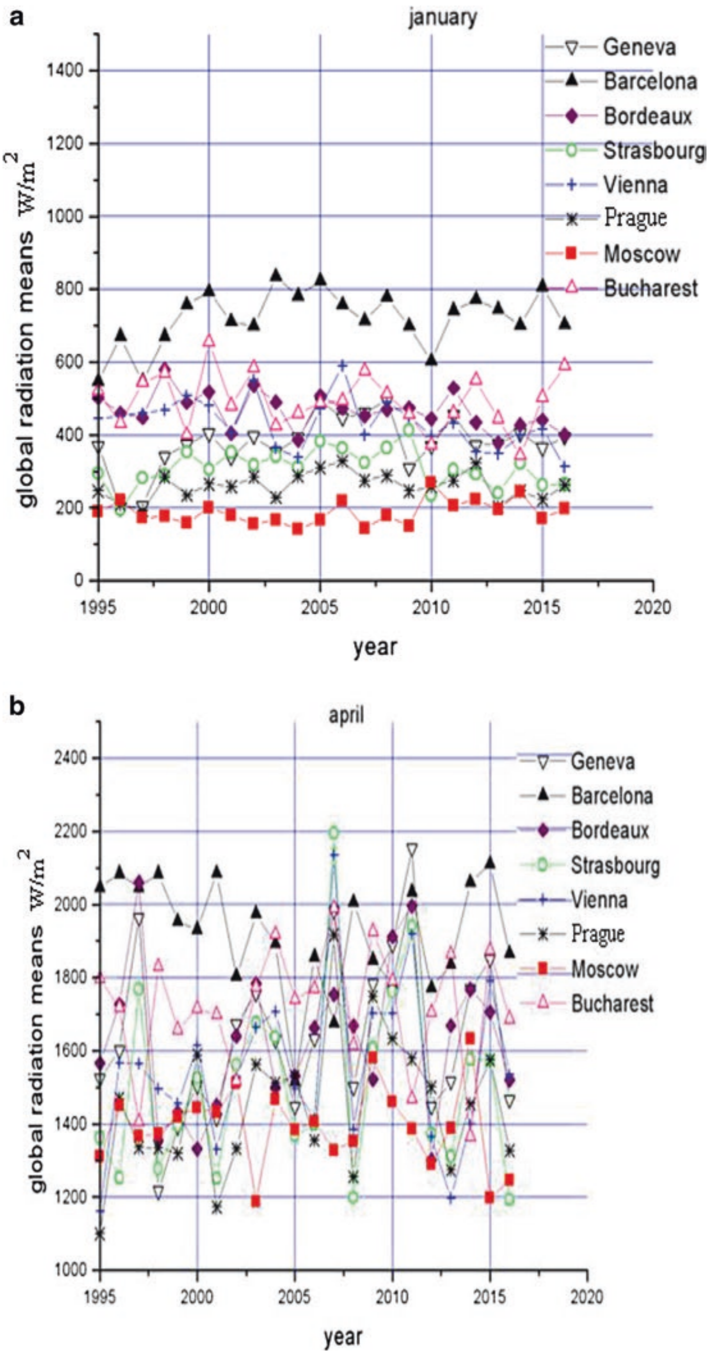


Fig. 5.2 Solar global irradiation mean daily values in January (**a**) and in April (**b**), in Europe. Solar global irradiation mean daily values in July (**c**) and in October (**d**), in Europe

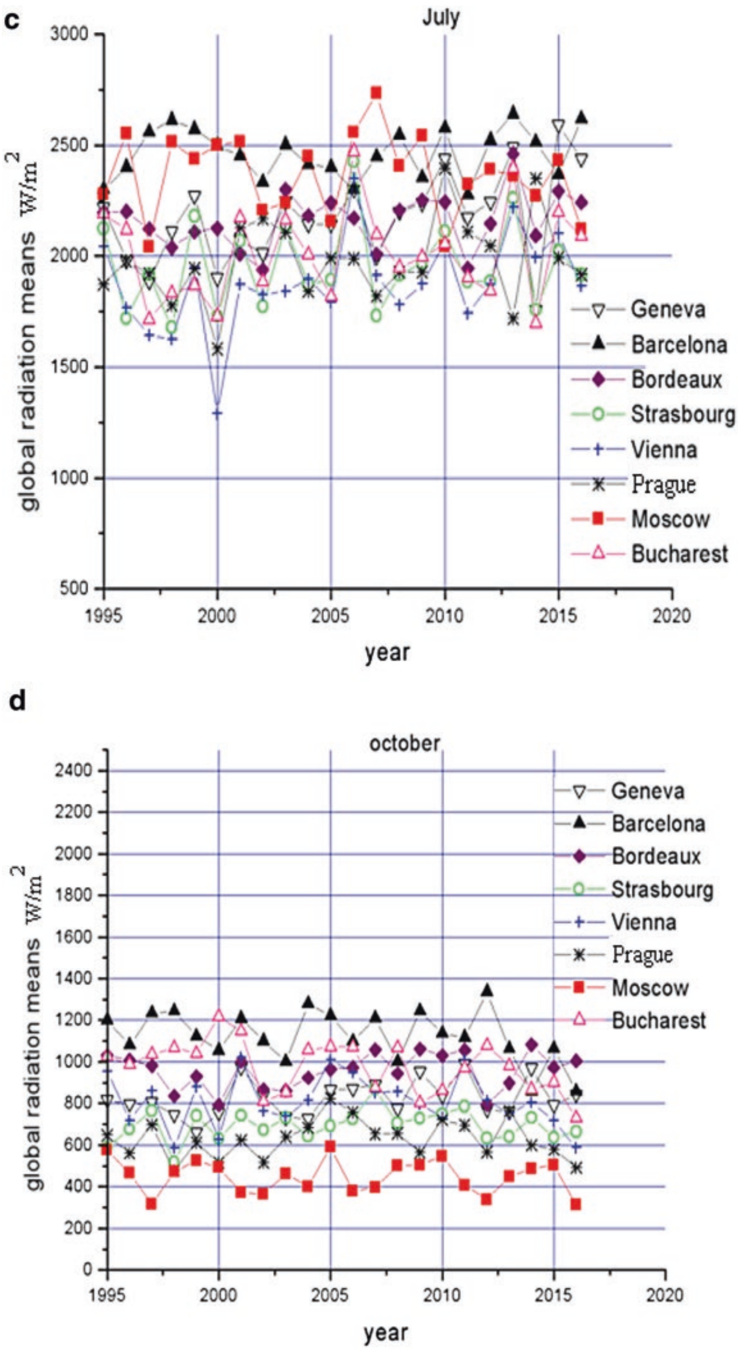
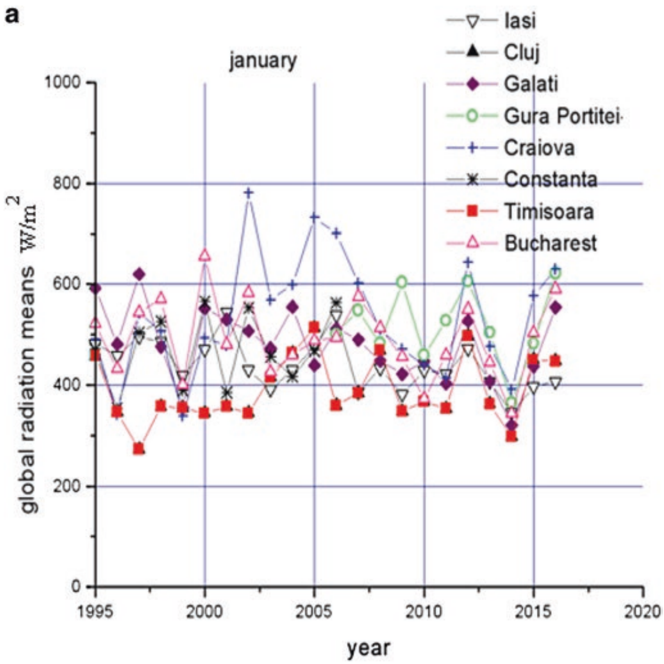


Fig. 5.2 (continued)



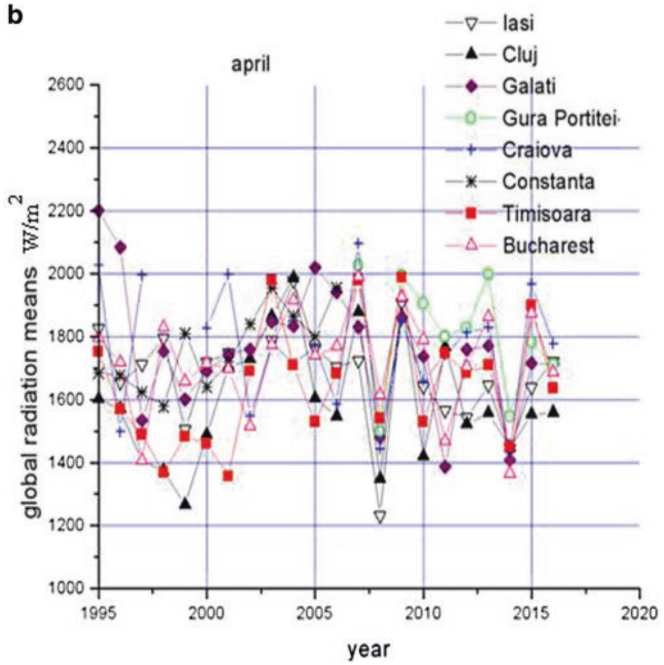


Fig. 5.3 Solar global irradiation mean daily values in January (**a**) and in April (**b**), in Romania. Solar global irradiation mean daily values in July (**c**) and in October (**d**), in Romania

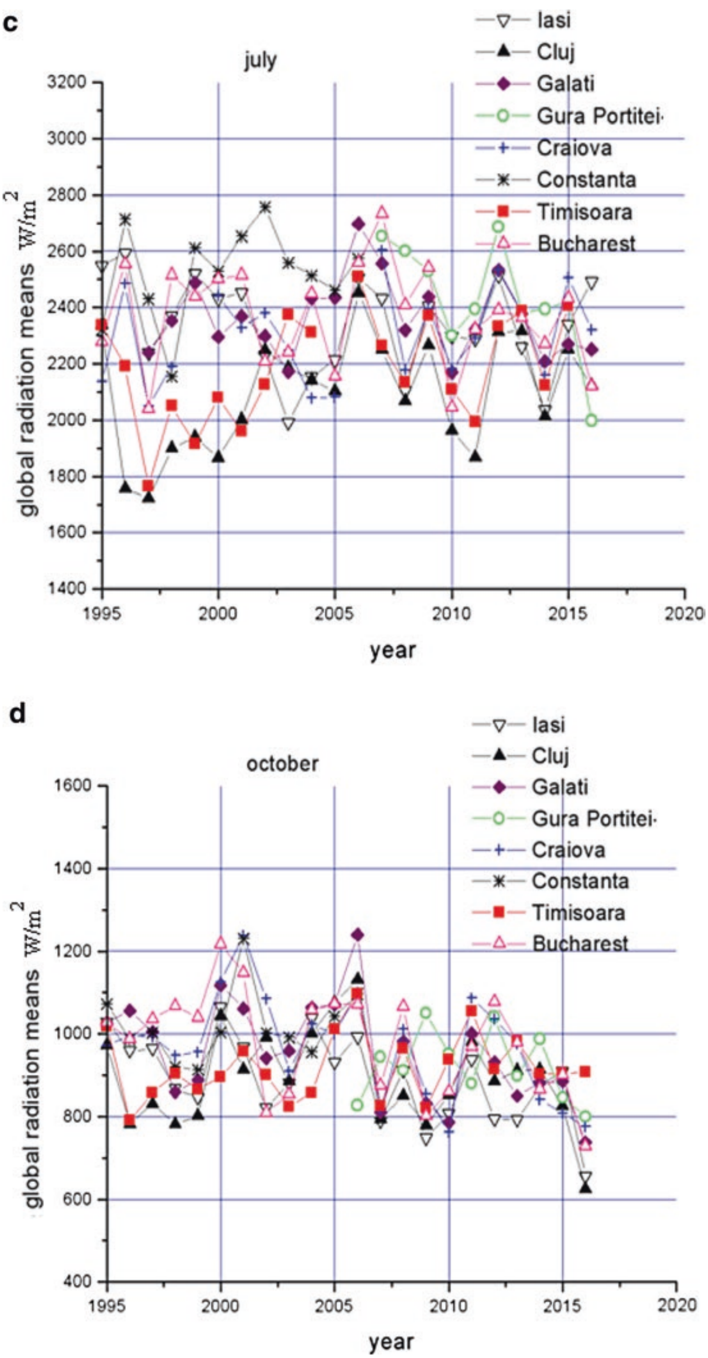


Fig. 5.3 (continued)

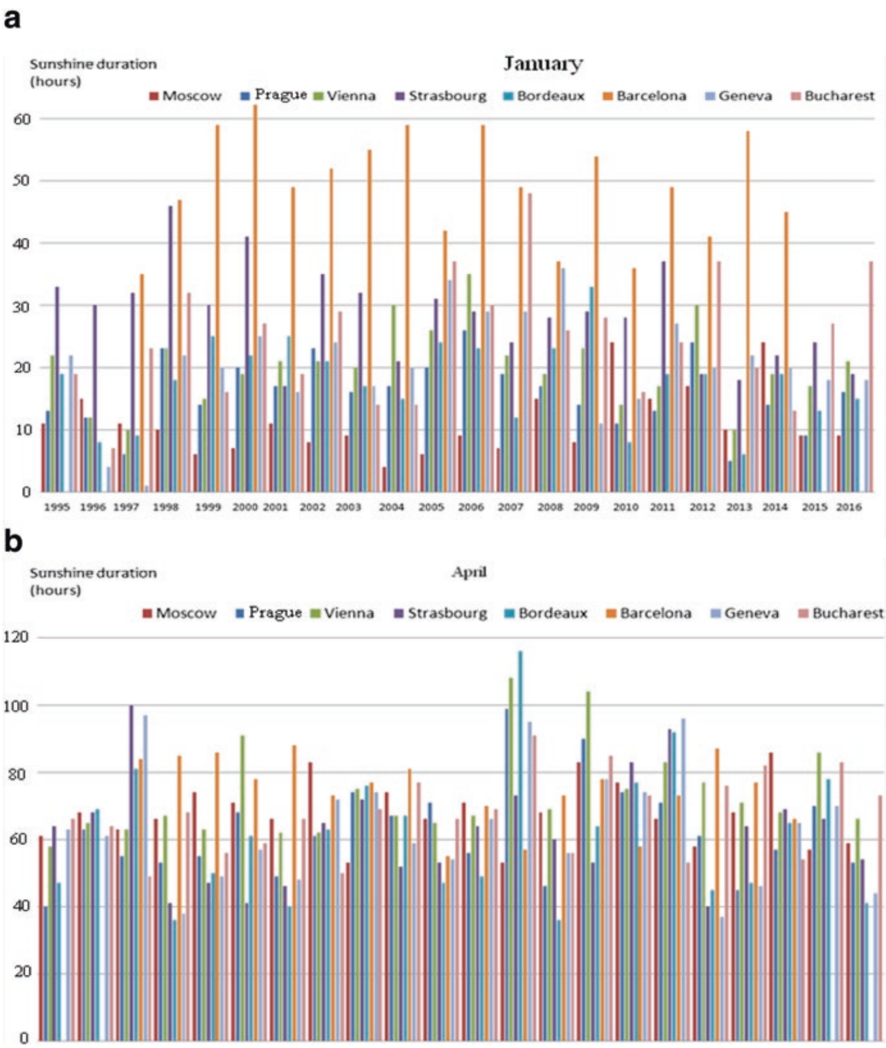


Fig. 5.4 (**a**) Sunshine duration in January monthly sums (**a**) in Europe, during 1995–2016. (**b**) Sunshine duration in April monthly sums during 1995–2016. (**c**) Sunshine duration in July monthly sums during 1995–2016. (**d**) Sunshine duration in October monthly sums during 1995–2016

the sunshine duration are in winter, because of their climatic and geographic position. However, Bucharest is placed over those mean values, also in autumn and winter.

On these graphs, it can observe that the average sunshine durations in Europe are as follows: 10–20 hours in January, 30–40 hours in October, over 80 hours in July and 50–60 hours in April. In all these cases Bucharest are positioned over each average sunshine duration value.

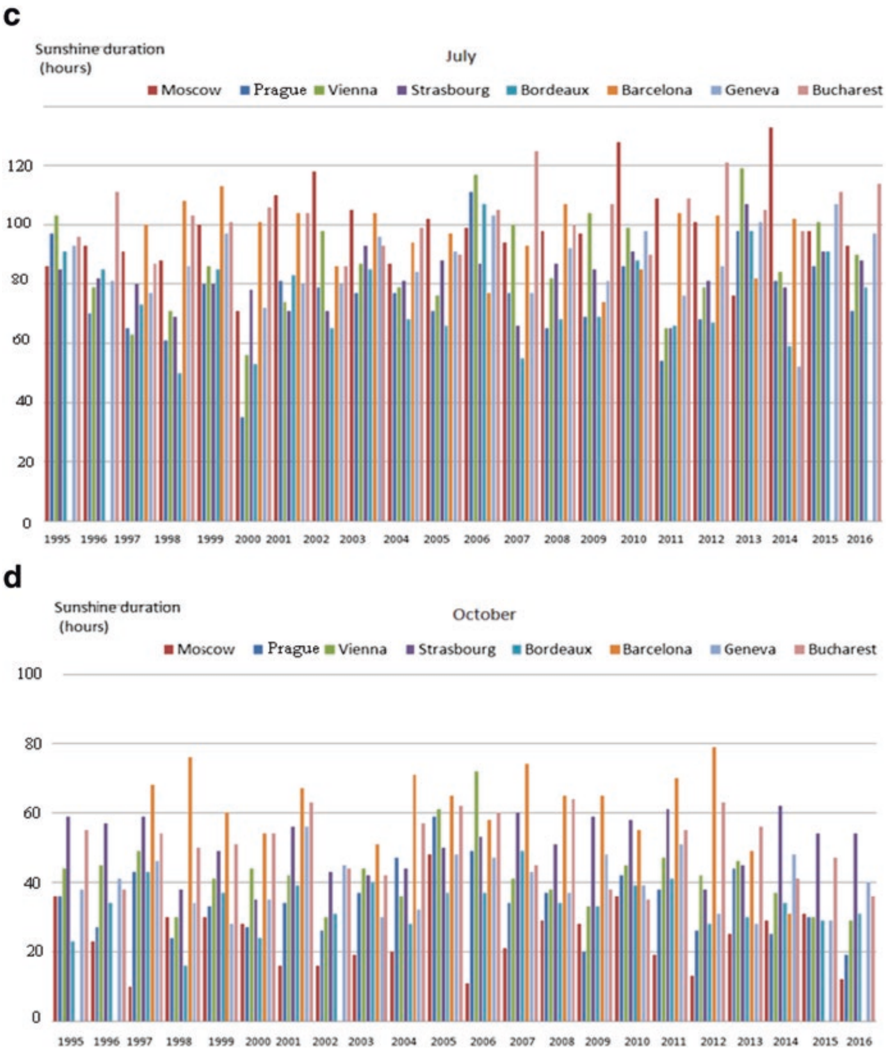


Fig. 5.4 (continued)

The sunshine durations in Romania are the following: 15–20 hours in January, 45 hours in October, over 90 hours in July and over 60 hours in April. In all these cases, these means of sunshine duration are over the values of the other European localities.

In Fig. 5.5, the sunshine duration in Constanta, Craiova and Gura Portitei in summer is not high, but in January, this localities are well positioned, over the means of the Romanian localities. Bucharest, Galati and Constanta are well positioned in April, October and July. Also, in January, there are the biggest differences between selected localities regarding the sunshine duration, because of their climatic and

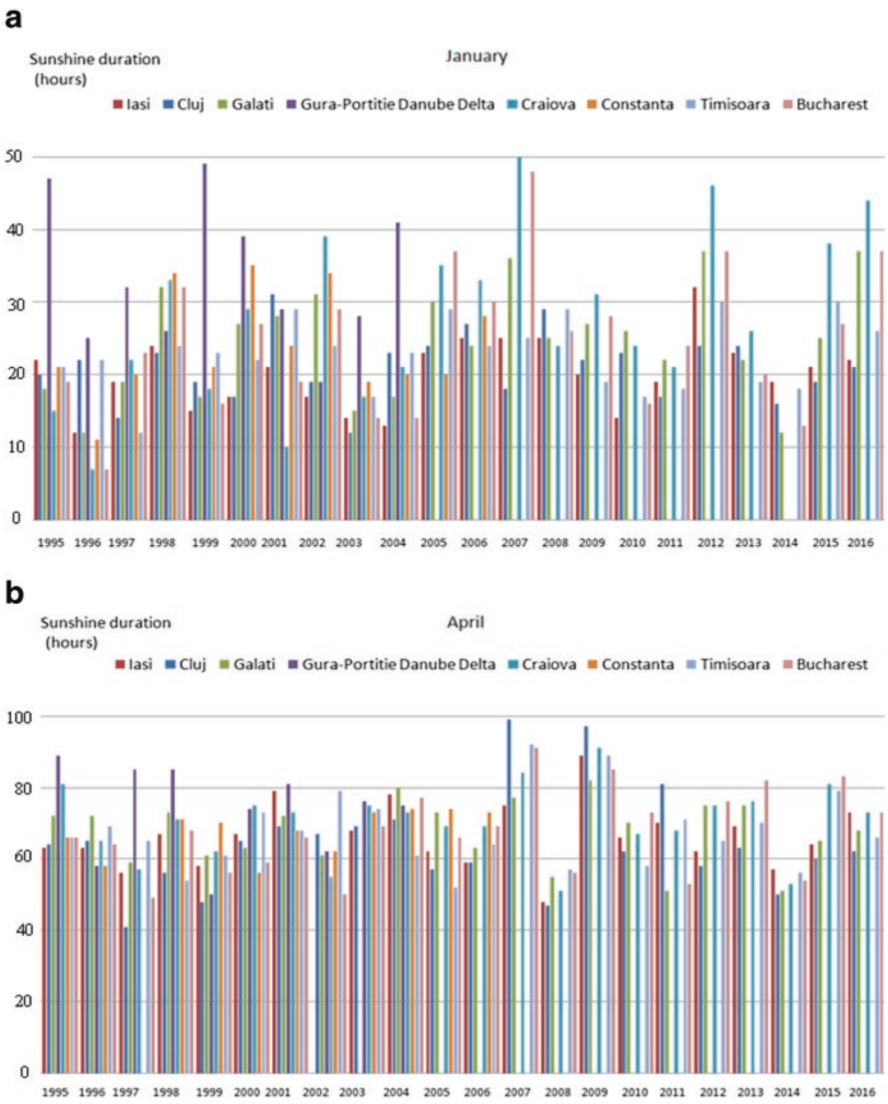
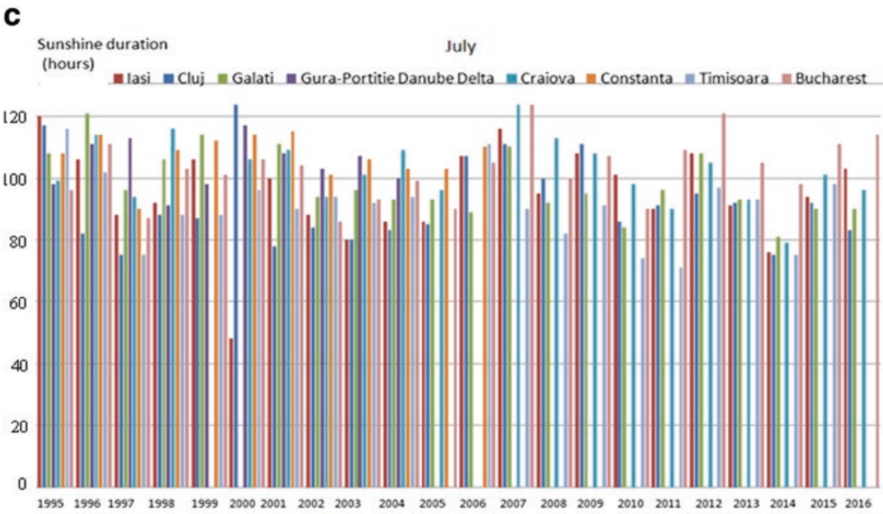


Fig. 5.5 (**a**) Sunshine duration in January monthly sums, in Romanian localities. (**b**) Sunshine duration in April monthly sums, in Romanian localities. (**c**) Sunshine duration in July monthly sums, in Romanian localities. (**d**) Sunshine duration in October monthly sums, in Romanian localities

geographic position. Bucharest is placed over the mean values, except for the October month.

In conclusion, it is justifiable to use solar air collectors in all seasons, including winter, in the southern localities of Romania, having good energy efficiency.



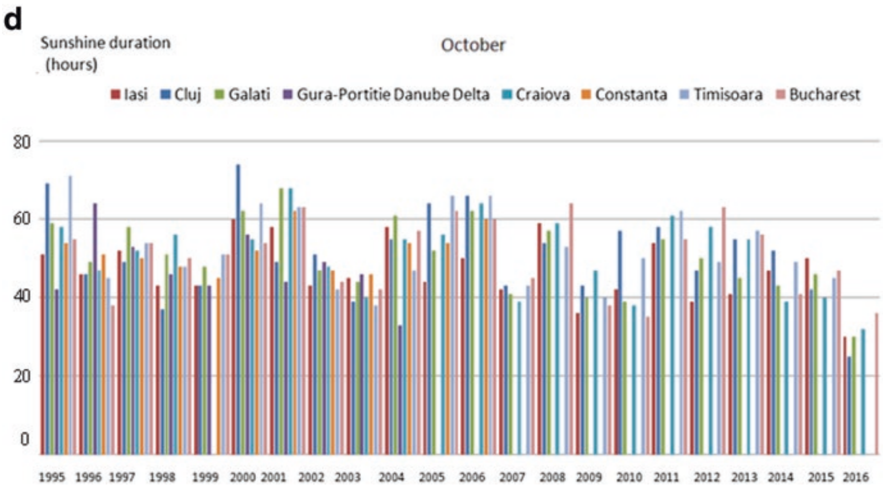


Fig. 5.5 (continued)

5.3 Experimental Measurement of Solar Irradiation in Bucharest During 2017–2018

For Bucharest (located at 44°30′ N and 26°13′E, 91 m altitude above mean sea level), located in the south of Romania, there were no meteorological or radiometric data. With logistic support from Technical University of Civil Engineering of Bucharest, under a research contract, the authors analyse several measurements.

Solar radiation was recorded with a Star Pyranometer FLA 628S, with a resolution of 0.1 W/m^2. Data acquisition has been performed using an AHLBORN ALMEMO 2890–9 data logger.

This chapter presents an analysis of the solar irradiation and the stability of the solar radiative regime, available for Bucharest and the southern area of Romania. The study is based on meteorological data measured at 3.6 seconds, on several consecutive days during all four seasons, in the years 2017 and 2018.

In Fig. 5.6a–d, some examples of the solar irradiation values measured during 2017–2018 are depicted. Some days of January can benefit from a surprisingly good value of the solar irradiation (Fig. 5.6b). It can further be deduced that other two factors or indicators, which influence the energy obtained from the sun, are as follows: sunshine number (ssn) and solar stability number (sssn), indicators defined in [7, 8]. Days with less solar irradiation, but with more stability, can generate more energy than days with high values of the solar irradiation but unstable.

'Dominant regime is medium cloudiness class for sunshine number – ssn, with values between (0.4÷ 0.7). Regarding sssn, the best sunshine stability is achieved in July.' The worst stability regime is achieved in April and October [9].

It is shown that high values of solar radiation have been maintained in the last 2 years, in Bucharest. A complete analysis can be found in articles [9, 10], which include Electronic Supplementary Material (ESM).

5.4 Solar Air Collectors to Improve the Thermal Buildings' Comfort

5.4.1 Classification Based on Technologies

Thermo-solar air collectors can be classified, based on their technologies, as follows:

Upon the surface exposed to the sun, there are two types:

- Glazed – with a transparent sheet and insulated side and back panels to minimize heat loss. The absorber plates in modern panels can have *absorptivity* of more than 93% [11].
- Unglazed – these are good for industrial applications, but the system is influenced by meteorological conditions and dust.

By air-ducting methods, there are three types:

- Through-pass collectors offer the highest efficiency of any air solar technology, and air passes through a perforated material and is heated from the conductive properties of the material and the convective properties of the moving air. Through-pass collectors have the most surface area that enables relatively high conductive heat transfer rates. As disadvantage, significant pressure drop that can require greater fan power.

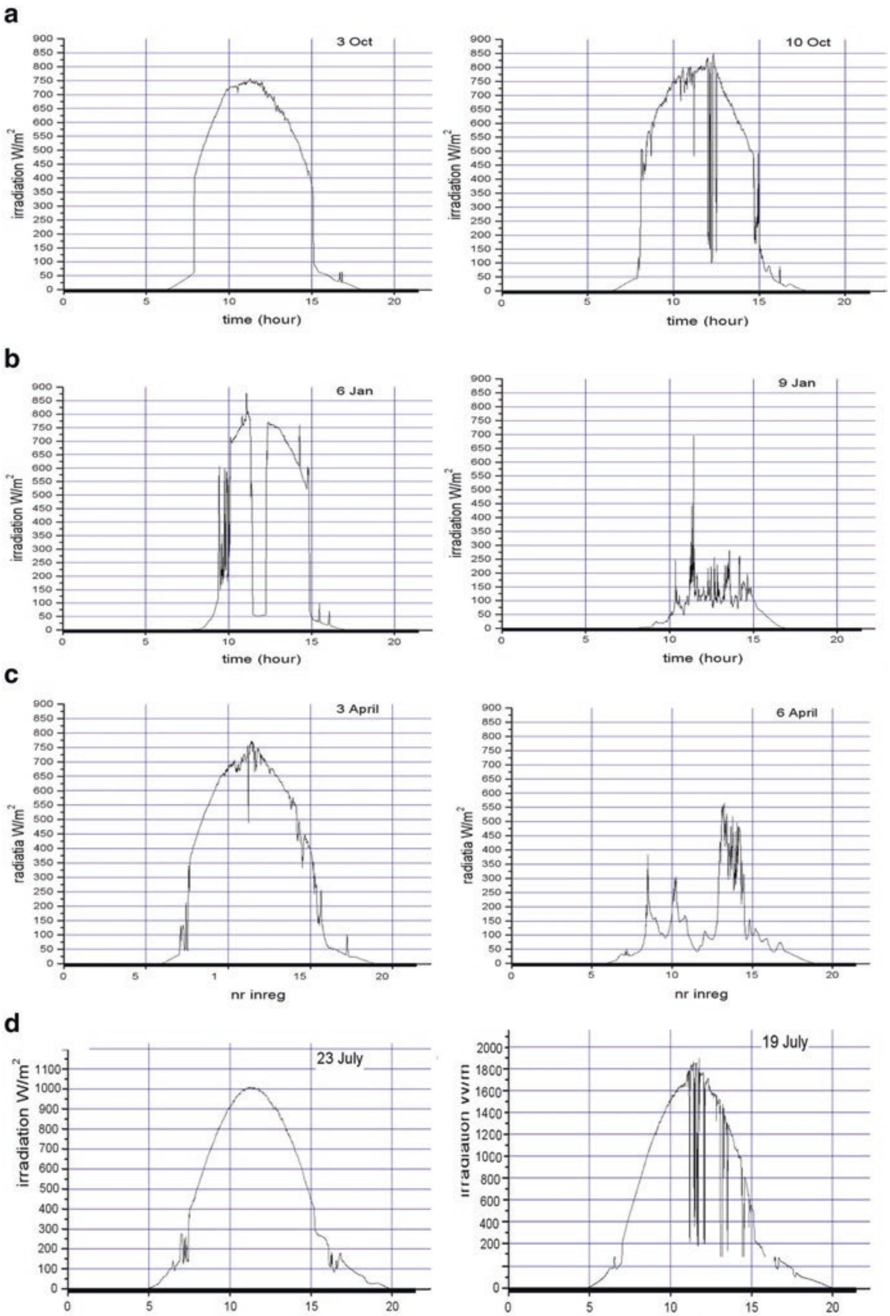


Fig. 5.6 Solar irradiation time variations during 2017–2018 for two reprezentative days in (**a**) October, (**b**) January, (**c**) April and (**d**) July

- Front-pass collectors or back-pass [12].
- Combination between front- and back-pass collectors [12].

Solar air collectors can have fins or baffles to improve the energy storage capacity. Other air collectors use phase change materials (PCMs) to provide higher energy and to store the energy [10, 13] (see the next paragraph). Many images to exemplify all these types of solar air collectors can be found in paper [12].

5.4.2 Performances of Thermo-Solar Collectors

Authors like Shukla A [12], Fleck B. A [14]. and Budea S [15]. have highlighted that the efficiency of thermo-solar collectors can be higher than 60% and depend on solar irradiation I (W/m^2), wind speed v (m/s), air density ρ (kg/m^3), heat transfer coefficient (W/m^2 K) or Cv-specific heat capacity.

In Figs. 5.7 and 5.8, the efficiency of the solar air collector, depending of many of those parameters, can be seen. Figure 5.7b shows that after approximately 55–60 minutes the operation of the solar air collector (glazed, through-pass) was stabilized [15].

Regarding the energy contribution of phase change materials, the authors studied the behaviour of two different materials, RT27 and RT35 (with similar density, but different latent enthalpy for RT27 H_{latent} = 157 kJ/kg and 179 kJ/kg for RT35), integrated in an air collector in the installation from Technical University of Civil Engineering of Bucharest.

Using PCM plates – RT27 or RT35 – the heating time was extended with more than an hour (Fig. 5.9).

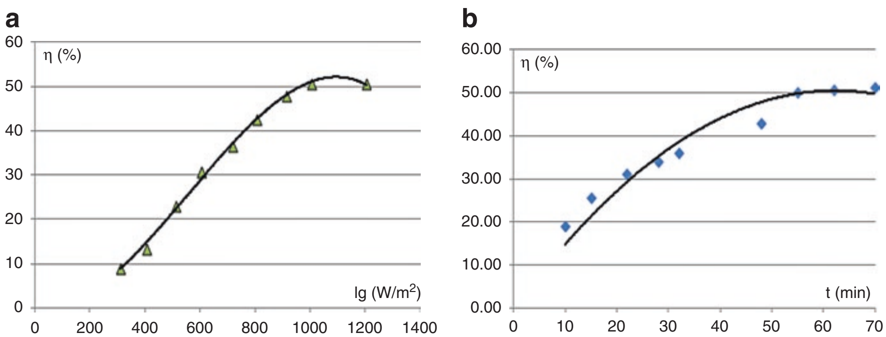


Fig. 5.7 Efficiency of solar air collector (**a**) with solar radiation Ig (W/m^2) and (**b**) time t (min) variation [15]

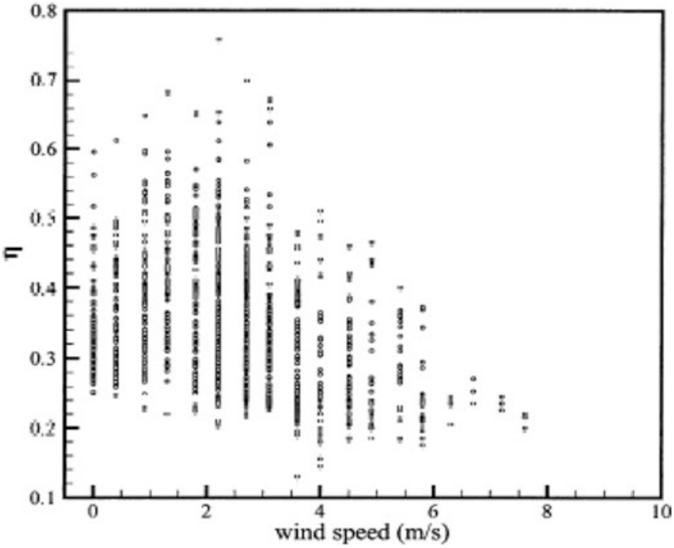


Fig. 5.8 Transpired solar air collector efficiency with solar irradiation [14]

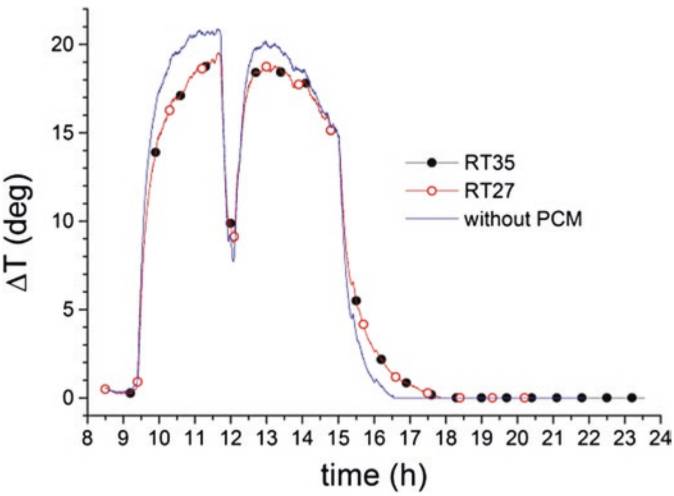


Fig. 5.9 Time variation of the air temperature increase ΔT in unglased thermal collector for 19 January 2018 with a nearly clear sky. With PCM plates made of RT27 and RT35 and without PCM [10]

5.4.3 *Solar Air Collectors Integrated in the Building Architecture*

As seen in the previous paragraphs, in Romania, solar energy can be capitalized with good results, to improve the thermal comfort of building, for heating or cooling of residential, office or industrial buildings. Hybrid systems consisting of thermo-solar and electric collector can be integrated in the building architecture on vertical wall or on the roof, in different climatic zones.

From combining engineering research activities in the field of solar energy with the activity of architects in integrating solar collectors in the design of buildings, the use of thermo-solar collectors or hybrid systems in residential or office buildings is constantly expanding. In this context, solar energy has been collected and used successfully in Romania for the past few years.

5.5 Conclusion

The chapter integrates the authors' research on solar energy and the thermo-solar collectors of air.

From the aspects presented above – statistical data and experimental measurements – the following are the results:

- Bucharest is well ranked among European cities regarding the solar energy potential.
- Romania, especially the southern zone – Bucharest, Craiova and Constanta – has a solar potential above the average values that of other European cities.
- Global solar radiation is over the average values in all seasons; however, the frequency of solar radiation maximal value is different – for Bucharest, it is about 5–6 years.
- Sunshine duration is very different during different seasons; in all seasons, Bucharest ranks over this average sunshine duration.
- Solar energy capture in air collectors is significantly influenced by the sunshine number (ssn) and solar stability number (sssn).
- The performance of thermo-solar collectors is influenced by the solar irradiation, wind intensity and phase changing material for storing their energy.
- In this regard, the storage duration was extended with more than 1 hour even for a day during winter.
- Integration of solar panels in the buildings' architecture is important in order to extend their use to all types of buildings – offices, industrial and residential.

Acknowledgement The experimental research was made with the support of Ilinca Nastase and Cristiana Croitoru from Technical University of Civil Engineering of Bucharest.

References

1. https://ec.europa.eu/eurostat/statisticsexplained/index.php?title=Renewable_energy_statistics/ro
2. WRDC *World Radiation Data Centre,* wrdc.mgo.rssi.ru/
3. R.S. Briggs, R.G. Lucas, Z.T. Taylor, *Climate Classification for Building Energy Codes and Standards*. Technical Paper, Pacific NW National Laboratory, March 26, 2002, http://www.energycodes.gov/implement/pdfs/climate_paper_review_draft_rev.pdf
4. R.S. Briggs, R.G. Lucas, T. Taylor, *Climate Classification for Building Energy Codes and Standards: Part 1* – Development Process, Technical and Symposium Papers, ASHRAE Winter Meeting, Chicago, January, (2003)
5. R.S. Briggs, R.G. Lucas, T. Taylor, *Climate Classification for Building Energy Codes and Standards: Part 2 – Zone Definitions, Maps and Comparisons*, Technical and Symposium Papers, ASHRAE Winter Meeting, Chicago, January, (2003)
6. NASA, (2015), NASA Prediction of Worldwide Energy Resource (POWER) Climatology Resource for Sustainable Buildings and DOE/ASHRAE Building Climate Parameters, http://power.larc.nasa.gov/cgi-bin/building.cgi?susbuild@larc.nasa.gov. Accessed July 2018
7. V. Badescu, S. Budea, How significant is the stability of the radiative regime when the best operation of solar DHW systems is evaluated? Renew. Energy **88**, 346–358 (2016)
8. M. Paulescu, V. Badescu, New approach to measure the stability of the solar, radiative regime. Theor. Appl. Climatol. **103**, 459–470 (2011)
9. S. Budea, V. Bădescu, A. Ciocănea, C. V. Croitoru, I. Năstase, The stability of the radiative regime in Bucharest during 2017–2018, E3S Web of Conferences 85, 04001 (2019) https://doi.org/10.1051/e3sconf/20198504001, EENVIRO 2018
10. V. Badescu, A. Ciocanea, S. Budea, I. Soriga, Regularizing the operation of unglazed transpired collectors by incorporating phase change materials. Energy Convers. Manag. **184**, 681–708 (2019)
11. S. Budea, V. Badescu, A. Ciocanea, I. Soriga, *Literature Review on Thermo Solar Air Collectors for Conditioning of Space in Buildings*, Energia si mediul in context contemporan, ("Ion Mincu" University Press, Bucharest, 2018), pp. 18–39
12. A. Shukla et al., A state of art review on the performance of transpired solar collector. Renew. Sust. Energ. Rev. **16**, 3975–3985 (2012)
13. M.R. Poole, S.B. Shah, M.D. Boyette, L.F. Stikeleather, T. Cleveland, Performance of a coupled transpired solar collector – Phase change material –based thermal energy storage system. Energy Build. **161**, 72–79 (2018)
14. B.A. Fleck et al., A field study of the wind effects on the performance of an unglazed transpired solar collector. Sol. Energy **73**(3), 209–216 (2002)
15. S. Budea, Solar air collector for space heating and ventilation applications – Performance and case studies in Romania Climatic Conditions. Energies **7**, 3781–3792 (2014)

Part II
Building with the Nature

Chapter 6
Parallel (Hi)Stories: A Subjective Approach to Energy-Efficient Design

Ana-Maria Dabija

6.1 Introduction

The beginning of the twenty-first century is marked by the declared awareness of the impact that the human civilization and activities have on the environment and planet in general. *Our Common Future*[1] was the starting point of many theories that developed into models, strategies, examples of good practice, etc.

Sustainability can be defined as the capacity of a system to be maintained at a certain level or rate for an indefinite period of time. As the definition can apply to mostly anything, under the term "sustainability," declarations and approaches in most all fields influenced by human activities arise, broadening the application of the term, from environmental sciences to economic and social sciences.

In the past (more or less) 35 years since the Brundtland Report was presented, the problematics of sustainability were dealt with at highest (political) level, the most recent High-level Political Forum (HLPF) being scheduled under the 74th session of the General Assembly of the United Nations, at the end of 2019, with the aim of cutting ways to implement the 17 Sustainable Development Goals adopted in 2015 by the General Assembly of the UN. The main target of the most recent agenda focuses on the principle of *leaving no one behind*, and the 17 goals touch all aspects

[1] Also known as "the Brundtland Report," it was elaborated by the World Commission on Environment and Development (WCED) and was published in 1987 by the United Nations, 1 year after the Chernobyl accident in the USSR [2].

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of the pillars of sustainability,[2] thus spanning from no poverty, zero hunger and good health through gender equality, quality education to clean water, clean energy, and life on land and under water and concluding with peace and justice strong institutions. As the level of the impact of the buildings on the natural and anthropic environment, one may notice the rising of – apparently – new trends in the approach of building design: from the principle of sustainability to resilience, from eco-technology to NZEB, and from biomimicry to bioclimatic.

In this vortex of terms, declarations, goals, and commitments, a brief look toward the past may bring some interesting and unexpected observation. At the level of principles, we are moving in circles: many inventions were there, invented long time ago and forgotten. Future and past are connected through present, and space may, sometimes, disappear.

6.2 The Perennial of the Vernacular

Traditional architecture is perennial: the same principles of construction have been used for centuries: location, neighborhoods, orientation, climatic agents (water, soil, wind, rain/snow), vegetation, and building materials; all have been taken into account for centuries, in the design of buildings, and what's fascinating is that they are used in the same way, anywhere in the world, if some conditions meet: same building materials and same geographic characteristics that lead to similar architectural and technological results. Therefore, we present two examples of vernacular architecture separated by more or less 10,000 km: a traditional Romanian house and a traditional Japanese house. In a climate with heavy rain and dazzling sun, the pitched roofs and the porches that filter the light are common architectural features (see Fig. 6.1).

The same local building materials – stone, wood, reed, and earth (adobe) – are installed with the same traditional techniques in comparable environmental conditions: sloped roofs are required, made with thick reed grove that is abundant in the delta or on the banks of lakes; in areas with forests, the building material of the walls is wood; and in the plains, adobe made with earth, straw, and wooden structure is appropriate for walls. Stone foundations that rise above the soil protect the floor against flooding, where appropriate (Fig. 6.2).

Increasing the physical distance and going below the Equator, in Australia, one finds the porch as what it represents everywhere in the world: an intermediate space between in and out of the building that protects against sun and wind. The wooden structures of the roof, the depth of the porch, the orientation (facing the equator), and the simple geometry of the house (a simple rectangle) prove that the constructor – Romanian, Japanese, and Australian – built the house according to the same principles and as a response to the environmental conditions (Fig. 6.3).

[2] People–Planet–Profit: In other words, the societal, environmental, and economic pillars that developed into four and then five pillars, with the rising of specific problems: safety and cultural issues

Fig. 6.1 Traditional houses in Romania and Japan

Fig. 6.2 Traditional wooden buildings in Romania and Japan

Fig. 6.3 The porch/prispa/engawa in wooden vernacular houses from Australia/Romania/Japan

When seeing vernacular architecture throughout the world, distances are sometimes dissolved, time is contracting, so occasionally we can talk about a "déjà vu" on a historical scale.

Taking a critical look at the principles of architectural design of building components (technological), throughout history, we find that there is a periodical rediscovery and a reinterpretation of the principles approached from different angles. The buildings are clearly different from those of other epochs, and their subassemblies at the first glance are also totally different, but going to the core, we find that "discovery" has been discovered sometime and what is "new" for us was also new a thousand years ago, for example. The history of construction systems is full of examples of construction principles that "come back to fashion" with the formulation of a new technical or functional requirement.

6.3 Bioclimatic: A Heritage of the Vernacular

Bioclimatic architecture defined itself as a style somewhere in the mid-twentieth century, related to the energy crisis of the 1970s. The term "bioclimatic approach" was defined a little earlier, by the two Olgyay brothers, Victor and Aladar, in *Design with Climate: Bioclimatic Approach to Architectural Regionalism* [3]. Although written almost 60 years ago, the aspects taken into consideration are still valid: beside hygrothermal analysis and calculations, wind forces, site and the recommended position, and shape of the building, the study of the sun and solar control are, even today, essential chapters for researchers and architects, when it comes to passive (solar) gain.

However, the bioclimatic approach so well theoreticized by the Olgyay brothers was not a premiere in practice, as throughout history architects remembered the lesson of the vernacular, in fact of taking nature as a partner and not as a force that must be defeated and subdued. In this context, Antonio Gaudi's architecture in Barcelona serves as example of the architect's approach of over a century ago. To illustrate the statement, we present some aspects of the Guell Park and the Casa Batllo.

The Guell Park uses all the natural building materials and shapes, to conceive the human intervention: columns and porticos resemble tree trunks, alleys follow the natural slopes, and vegetation invades all the built environment. Even the urban furniture has organic shapes that emphasize the image of a perfect connection with nature. Furthermore, in the construction of the Guell Park, Gaudi uses natural materials – stone, clay, and vegetation – as well as recycled materials coming from the earth (ceramics) outgoing the contemporary principle of the "cradle to cradle" concept and the requirement of sustainable use of natural resources[3] [4] (Fig. 6.4).

[3] According to the Regulation (EU) No. 305/2011 of the European Parliament and of the Council, "The construction works must be designed, built and demolished in such a way that the use of natural resources is sustainable and in particular ensure the following:

(a) Reuse or recyclability of the construction works, their materials and parts after demolition;

(b) Durability of the construction works;

(c) Use of environmentally compatible raw and secondary materials in the construction works."

Fig. 6.4 Antonio Gaudi – Guell Park built in 1900–1904. Columns, porches, and walls built with natural materials and integrated in nature. (Photo: Ana-Maria Dabija)

Fig. 6.5 Antonio Gaudi – cross-ventilation in Casa Batllo, designed in1904. The house is provided with windows and parapets that allow opening and closing of the acir being evacuated in the central "well", in fact an inner courtyard. (Photos: Ana-Maria Dabija)

The sophisticated and refined Casa Batllo (Fig. 6.5) has a revolutionary cross ventilation system that today, more than one century later, proves to be a correct and feasible solution in an arid hot climate, thus providing thermal comfort during the summer. We would say, today, that such systems are saving energy consumption, by using less HVAC.

The main features of the bioclimatic approach include passive design concepts, carried out in order to accomplish the comfort required by contemporary demands while reducing through intelligent design the overall energy balance of the building in use. These concepts span from the site analysis, the orientation of the house/building, the geometry of the building to the sun and light control, ventilation, thermal insulation, and use of vegetation winds and water. Like in the case of the vernacular, the use of local materials is boosted, as well as the use of local workers. These last two requirements occupy important positions today, on the scale of measuring sustainability in the process of design and build.

The builders passed the skills (the know-how) from one generation to another, the discoveries being carried out through time, while the failures (as there must have been) were lessons to remember and avoid. No written scientific theories stand behind the way vernacular homes are built, except the transmitted knowledge, from one generation to the next.

6.4 Old or New Facades

The energy crisis of the 1970s led to the reconsideration of energy sources and therefore identified the need to find ways to integrate alternative energy sources into architecture. The most accessible energy source was – is – the sun, so most research was focusing on finding the means to use this resource. Solar architecture flourished, mainly using passive gain (although active thermal solar and photovoltaic systems began to be developed on a larger scale also).

Energy crises have happened before in history; if we look at the past century only, at least two of them had major implications in the construction industry: The end of the Second World War that left a poor society behind that needed to save energy rather than spend it and the well-known crises of the 1970s, with the awareness of the termination of the petroleum resources at the same time with the rising of the petroleum prices. Both of them pushed the effort of scientific research toward finding ways of using energy from alternative sources.

In both cases, along with the effort of scientists to discover – or rediscover – patents, products, and elements and use them in building materials, architects discovered, or rediscovered, the simple truths of the forgotten vernacular. In the United States, catalogues and books on solar houses were published, where the use of the sun was maximized by the architectural design.

6.4.1 Trombe Walls

Among the systems that periodically come in fashion in architecture are the Trombe walls. They are technological assemblies that include a glass element toward the exterior environment and a (thick) wall with vents at the base and at the upper part, toward the inner environment – the room – separated by an air layer. The whole assembly is oriented toward the equator (South for the Northern Hemisphere, North for the Southern Hemisphere). The sun radiation passes through the glass and becomes longer-wavelength infrared radiation. At the contact with all the other surfaces, the energy is re-emitted into longer wavelength radiation, thus heat becoming trapped into this buffer space. The effect increases if the surface of the wall that is oriented to the glass is painted in black. The air gaps placed on the lower and on the upper part of the wall provide a convection loop that permanently provides warm air from the buffer space into the room – from the superior vents – and cool(er) air into the buffer space, from the room.

Trombe walls have been included in the architectural concept of residential buildings in the 1970s and 1980s. However, these systems were not new. The first registered system belongs to Edward Sylvester Morse and was patented in 1881 [5] as "air heater" (US246626 A). The principle was rediscovered and adapted in the 1960s by Felix Trombe and Jacques Michel and was widely used as a means to diminish the energy consumption for thermal needs of homes.

Morse's system (Fig. 6.6) consists of a glazed box with a dark absorbing construction element, a buffer space, and two sets of holes from the top and bottom to the outside air and the interior of the house, resulting in a system that functions in the winter, by heating the buffer space and from there, through the vents, the interior of the house as well as in summer, by the opening of the vents in contact with the exterior, resulting in the transformation of the buffer space into a chimney that absorbs and eliminates warm(er) air from the room. The current of air is in fact a convective loop that introduces cold air in the buffer space, through the vents at the base of the wall, and warm air from the buffer space to the room, through the upper vents. The whole assembly must be oriented toward the equator (south for the Northern Hemisphere, north for the Southern Hemisphere).

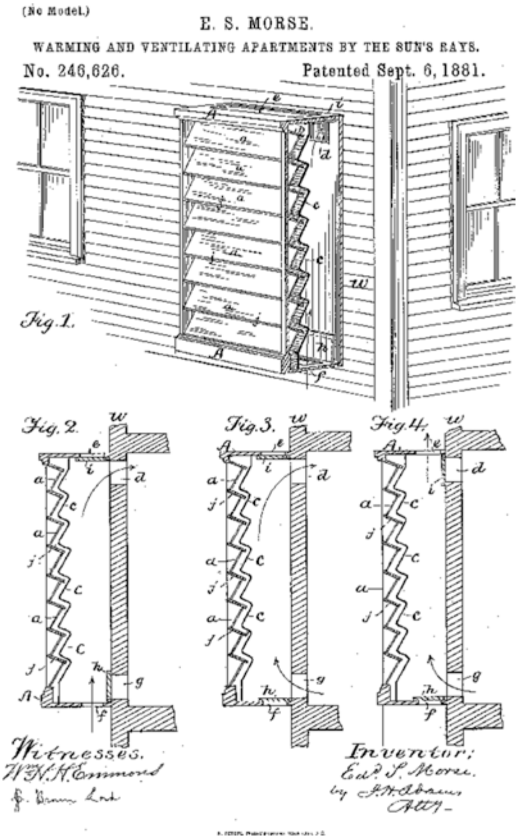

Fig. 6.6 The air heater – as patented by Edward Sylvester Morse in September 6, 1881. (https://www.google.com/patents/US246626)

In recent years, research is carried out [6] to achieve thermal comfort in summer (or semiarid climates, as the authors of the research state), by cooling the indoor air, with specific architectural detailing of the Trombe wall assembly. Also, at the level of detailing, steps have been taken to decrease the thickness of the assembly, by using contemporary "smart" materials, like aerogel or PCMs [7].

6.4.2 Solar Facades

While the Trombe walls are a passive approach in energy savings in buildings, the use of the solar energy, in BIPV and thermal solar panels, is active means.

In 1956, the Bridgers and Paxton Building was constructed according to the requirements of the two mechanical engineers Frank Bridgers and Don Paxton and the design of a local architecture company Stanley and Wright. It is allegedly the world's first building to use active solar collectors for heating purposes. In the nineteenth century, scientists and engineers were preoccupied by the use of the sun in order to decrease energy consumption: In 1885, Charles Tellier set on the roof of his house what is said to be the first solar installation for domestic hot water production. In 1891, Kemp patented a way to combine the old practice of exposing metal tanks to the sun with the scientific principle of the hot box, thereby increasing the tanks' capability to collect and retain solar heat. It was called Climax Solar Water Heater [8] (Fig. 6.7).

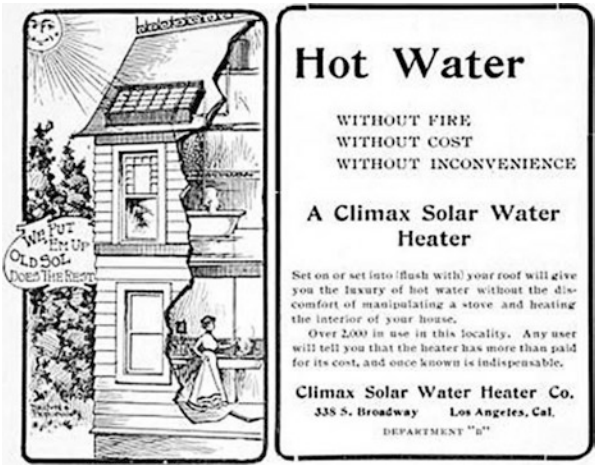

Fig. 6.7 Kemp's Climax Solar Water Heater advertisement dating 1902

6.4.3 Living Facades

A generic type of facade very fashionable on today's world market is the living facade. Living walls/vegetal facades make an important contribution to the greening of our cities, the reduction of the city's pollution, and the purification of the air. They are referred to as means of environmental interventions in the approaches for the smart cities or in the measures of diminishing the heat island effect at the urban scale. The benefits of the green facades and roofs are emphasized and promoted for some decades now, in the effort of integrating them in the assemblies of the building envelope. Plants provide better air quality by the process of evapotranspiration that lowers the temperature of the environment, by absorbing electromagnetic radiation and carbon dioxide while producing oxygen [9]. Their use in the buildings may represent not only energy savings (as the extra layers represent thermal insulation), but by the specific choice of plants, they can provide food in urban farms, as some more or less visionary architectural designs propose (thus adding an extra function to the opaque part of the envelope: food provider).

Few people, however, know that these facade systems, well-known by famous botanists such as Patrick Blanc (Fig. 6.8), are not new inventions, but also "old-fashioned" patents, forgotten in pale yellow and dusty catalogues.

In 1938, architect and American professor Stanley Hart White filed the documentation for a patent [10] proposing a structural support system for vegetation with an architectural role (US2113523).

The following lines are extracted from the patent's description: *The underlying principle of the present invention is to provide the architectural profession and related industries with an efficient and inexpensive method and means for utilizing a novel medium for ornamental and useful architectonic construction, in various forms of units and compounds having vegetation-bearing surfaces. For example one purpose of these surfaces may be to build decorative backgrounds or screens for masking eyesores or for concealing people or properties in such a way as to avoid painted camouflage or the heavy cost of ordinary hedges [...]. The essential idea therefore is to avoid planting the growing material in the open ground [...] and to provide instead*

(a) *a wall enclosed by reticular material supported by reinforcing members,*
(b) *a wall or compound built up of units of reticular material so that the structure would stand like a dry wall of masonry, or,*
(c) *a wall or compound built of interfitting portable and replaceable reticular units in a skeleton supporting frame designed to control the shape and dimensions of the completed compound.*

Contemporary urban structures covered with plants are assembled in many cities of the world (Fig. 6.9), not linked to buildings but close to Stanley Hart White's vision of the invention (Fig. 6.10) defined as a method *for producing an architectonic structure of any buildable size, shape or height, whose visible or exposed surfaces may present a permanently growing covering of vegetation* [10].

Fig. 6.8 Musée du quai Branly – Arch. Jean Nouvel, bot. Patrick Blanc. (Photo: courtesy of Prof. Dr. Arch. Ioan Lucăcel)

The visionary architect even saw, with his mind, the possibility of creating a ventilated facade with units that include plants. The design – excepting the rather exaggerated dimensions of the structure (which, on the other hand, are obtained from the available metal profiles) – is in principle similar to the current systems of modules attached to a structure (Fig. 6.11).

6.4.4 Double-Skin Facades

An interesting facade system is the double-skin facade. In facades of the latest generation, often with a dynamic response to the action of natural and anthropic environmental agents, with double layers of glass, a combination of transparent and opaque skins, or even a living, exterior skin, they also have a story and a history that goes back more than 150 years.

By 1849, Jean-Baptiste Jobard, at that time director of the Industrial Museum in Brussels, proposes a revolutionary facade system consisting of several layers and that was mechanically ventilated, allowing warm air to circulate in winter and cold

Fig. 6.9 Square in front of Umeda Building in Osaka, Japan, with planted structure that resembles Hart's description (Fig. 6.9)

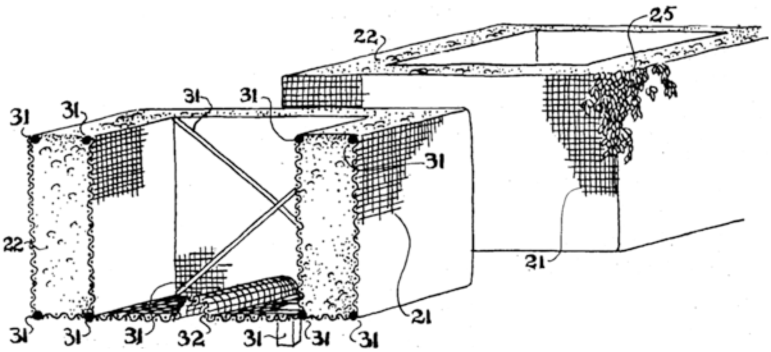

Fig. 6.10 Extract from Hart's description of the wall built up of units of reticular material (see also Fig. 6.8)

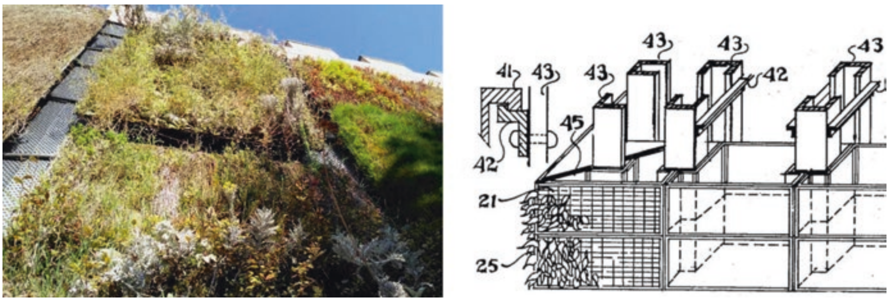

Fig. 6.11 Modular living wall in Florence (Photo: Ana-Maria Dabija) and original sketch of Hart's patent

air in the summer between the glass delimiters [11]. However, the first documented double-skin facade seems to have been constructed in Germany, in 1903, at the Margarete Steiff toy factory in Giengen, Germany. Ms. Steiff needed a building with a maximum solar intake, in a tough climate, with strong winds and low tem-

Fig. 6.12 Osthalle in Giengen, 1903. Zacharias L. CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=6423343

peratures. The solution was a three-story building (storage on the ground floor, working areas on the rest of the floors), where the extra facade system consisted of a steel frame that supported glass sheets (Fig. 6.12). It happened in 1903. The extensions of the factory made in 1904 and 1908 used the same principle but on a wooden frame which lowered the cost of the intervention. It seems that all three buildings are still in use [12].

6.5 Hanging Gardens of Semiramis or Eco-Roofs

One of the means to reduce the heat islands is to return the green spaces displaced by buildings to the city. The easiest way to do it is by providing green envelopes, facades, and roofs. Well designed and installed, they also represent effective protection of the roof waterproof system.

The first rooftop gardens are not a recent invention, although the architecture of Modernist period of the twentieth century has emphasized them, not due to the benefits that the plants give at the city scale but, mostly, for the peace and pleasure that the savoir vivre of the period represented. Modern rooftop gardens were "invented" by a German roof installer, H. Koch [13], in the nineteenth century, as a means to avoid fire hazards in the cheap, new residential urban areas developed for workers, that followed industrial expansion of the period. Dwellings were covered with tar and highly combustible, and Koch protected the tar with gravel and sand, usually brought from riverbanks. In a few weeks, the vegetation began to grow, creating another problem: the waterproof system was being penetrated by the roots of the plants. So, one step after the other, the modern green roofs were developed, with the essential layers that have not changed ever since: root barrier, drain layer, filter layer, substrate, and vegetation. The types of green/planted roofs were eventually defined, from extensive roofing to intensive roofing (where the rooftop gardens represent the most expensive and elegant system), with the explicit specific features required by the substrate and the plants. The terraces of the garden have been fashionable since the 1930s of the last century: The Rockefeller Center (Fig. 6.13), designed by Raymond Hood (1930–1939), is also famous for the planted terraces under which waterproofing is protected since 1939 [14].

The (hi)story of the green roofs, however, is very much older, splitting into two different directions: the cold areas of Europe influenced by the Viking civilization and the ancient Middle Eastern Babylon where – again – roof terraces were a common solution (it seems).

In the cold and windy areas of the North, the need to stabilize and protect the roof from being blown away was to cover the wooden shingles with a vegetal layer cut from the pastures, in "tiles" about 30 cm wide [15]. The whole assembly also provided additional thermal insulation (the sod and vegetation layer representing an important extra thickness). Since the Viking period, no essential changes have been made to the structure of the protection layer, represented by the green assembly.

Rooftop gardens were common in the Ancient Babylon. The Hanging Gardens of Semiramis was considered one of the Seven Wonders of the World because of the

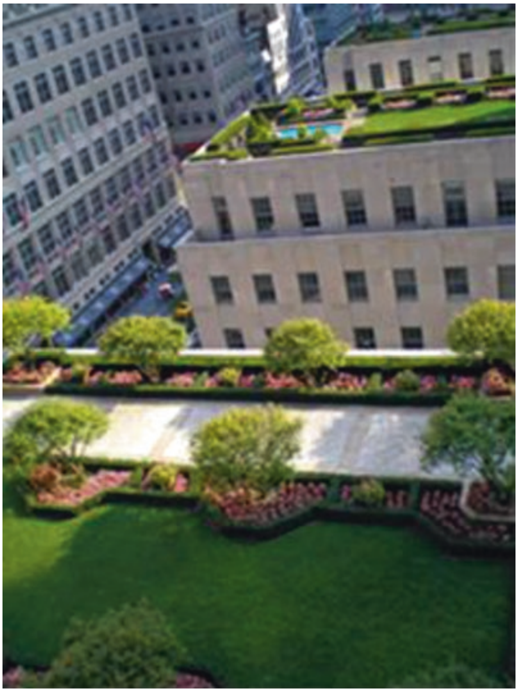

Fig. 6.13 Rockefeller Center, Arch. Raymond Hood, 1930–1939. (Photo: David Shankbone CC BY 2.5)

unicity of the grandeur, not due to a revolutionary building system although, yes, the engineering solutions were spectacular and novel for that period (and astonishing for what we know about the ancient world). “The garden is quadrangular in shape, and each side is four plethra in length. It consists of arched vaults, which are situated, one after another, on checkered, cube-like foundations. The checkered foundations, which are hollowed out, are covered so deep with earth that they admit of the largest of trees, having been constructed of baked brick and asphalt – the foundations themselves and the vaults and the arches. The ascent to the uppermost terrace-roofs is made by a stairway; and alongside these stairs there were screws, through which the water was continually conducted up into the garden from the Euphrates by those appointed for this purpose. For the river, a stadium in width, flows through the middle of the city; and the garden is on the bank of the river” [16]. Furthermore, the materials and the structure of the roof are – in principle – correct (from a contemporary point of view) as there is “reinforced” tar and lead for hydro-insulation and root barrier (preventing the root penetration within the structure of the roof), as well as a system that provides water for the plants [17]. The developed water management engineering system of ancient Mesopotamia (that included canals, weirs, dams, bridge-like aqueducts) goes back to the eleventh century BC, during Tiglath-Pileser I’s time [18] and through Sennacherib’s period – the seventh century B.C, explaining the invention and evolution of the suspended gardens of the ancient Middle East.

Planted terraces are an extension of the rooftop gardens: while respecting the structure of the living/vegetal roof, they are a part of the building facade and gained new roles, from the substitution of the original vegetation, destroyed by the construction of the building(s), to a more sophisticated and generous role, of urban farming. The Bosco Verticale (Fig. 6.14), for instance, declares [19] that the two residential towers host “800 trees (each measuring 3, 6, or 9 meters), 4500 shrubs and 15,000 plants from a wide range of shrubs and floral plants distributed according to the sun exposure of the facade. On flat land, each Vertical Forest equals, in amount of trees, an area of 20,000 square meters of forest.”

6.6 Conclusions

The simplest conclusion of presenting these parallel histories is that many of the things we discover now have been previously discovered sometime, somewhere. New technologies tune in but do not bring news in the building principles. Walter Gropius said that “Architecture begins where engineering ends.” Engineering discoveries are interpreted by interdisciplinary teams and integrated into architectural subassemblies by architects in the effort of meeting current demands with technological possibilities. New needs, new architecture programs, and new functions materialize in buildings where constructive subassemblies align and still respond to the laws of nature. Still, one thing has to be understood and respected: technology

Fig. 6.14 Bosco Verticale, Milano, Italy, Arch. Stefano Boeri. (Photo: Ana-Maria Dabija)

by itself doesn't make architecture; integrating new or old technologies into the building material, building assembly, or building component provides a new product – usually an active system – that can be used in a specific way, with specific requirements and limits. Creating a volumetry of a building that follows the laws of Nature is one larger step, as passive design stands for as long as the building stands, sometimes for thousands of years. Perhaps, looking back, we understand better where and how should we move ahead.

References

1. O. Lyons, The Ice is Melting (2004), https://centerforneweconomics.org/publications/the-ice-is-melting/. Accessed 31 July 2019
2. Report of the World Commission on Environment and Development: Our Common Future, https://sustainabledevelopment.un.org/content/documents/5987our-common-future.pdf. Accessed 8 July 2019
3. V. Olgyay, A. Olyay, *Design with Climate. Bioclimatic Approach to Architectural Regionalism* (Princeton University Press, Princeton, 1962)
4. Regulation (EU) No 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC, https://eur-lex.europa.eu/legal-content/RO/TXT/?uri=celex%3A32011R0305. Accessed 5 Jun 2019
5. Warming and ventilating apartments by the sun's rays Inventor: Edward S. Morse, (1881), https://www.google.com/patents/US246626. Accessed 12 Aug 2019

6. M. Dabaieh, A. Elbably, Ventilated Trombe wall as a passive solar heating and cooling retrofitting approach; a low-tech design for off-grid settlements in semi-arid climates. Sol. Energy **122**, 820–833. https://doi.org/10.1016/j.solener.2015.10.005
7. https://www.tudelft.nl/en/architecture-and-the-built-environment/research/research-stories/modern-trombe-wall-saves-loads-of-energy/. Accessed 12 Aug 2019
8. http://www.greendiary.com/interesting-historic-facts-renewable-energy.html
9. D. Marasco, B. Hunter, P. Culligan, S. Gaffin, W. McGillis, Quantifying evapotranspiration from urban green roofs: A comparison of chamber measurements with commonly used predictive methods. Environ. Sci. Technol. **48**, 10273 (2014)
10. Vegetation-bearing architectonic structure and system Inventor White Stanley Hart, (1937), https://www.google.com/patents/US2113523. Accessed in 2019
11. W. Streicher, et al., On the typology, costs, energy performance, environmental quality and operational characteristics of double skin facades in European buildings, in *Advances in Building Energy Research*, Volume 1, ed. M. Santamouris (2007), p. 3
12. H. Poirazis, Double skin facades, in A Report of IEA SHC Task 34 ECBCS Annex 43, p. 29, Lund Institute of Technology, (2006). Accessed 12 Aug 2019
13. J. Magill, A History And Definition Of Green Roof Technology With Recommendations For Future Research, Graduate School Southern Illinois University Carbondale April 2011, http://opensiuc.lib.siu.edu/cgi/viewcontent.cgi?article=1132&context=gs_rp
14. C.G. Wark, W.W. Wark, Green Roof Specifications and Standards. Establishing an emerging technology The Construction Specifier, August 2003, Vol. 56, No.8, http://www.fussypainting.com/pdf/GreenRoof.pdf
15. FLL Guideline for the Planning, Execution and Upkeep of Green-Roof Sites
16. Strabo, "Geography XVI.1.5", published in Vol. VII Loeb Classical Library edition, 1932, http://penelope.uchicago.edu/Thayer/E/Roman/Texts/Strabo/16A∗.html#1.5translation. Accessed March 2018
17. J.G. Macqueen, *Babylon* (Frederick A. Praeger, Inc., Publishers, New York, 1965), p. 158
18. S. Dalley, *The Mystery of the Hanging Garden of Babylon. An Elusive World Wonder Traced* (Oxford University Press, Oxford, 2013)
19. https://www.stefanoboeriarchitetti.net/en/project/vertical-forest/. Accessed 19 Aug 2019

Chapter 7
Traditional Semi-Buried House

Eugenia Valerica Potenchi

7.1 Introduction

In the context of climate change, solutions are sought worldwide for the construction of homes that consume as little energy as possible and which do not pollute the surrounding environment. From this point of view, the traditional houses in Romania are a very good model. Of these, semi-buried homes attract our attention due to the proven thermal efficiency over thousands of years.

When studying the traditional semi-buried houses, it is necessary to understand the reasons why this type of housing was built and what were the technical solutions used in different climatic areas.

After a thorough study of the "bordei," the advantages and disadvantages of these structures will be discussed, and solutions will be proposed to solve the identified problems. Finally, a modernization of the traditional "bordei" in Romania will be developed, which will respond to the demands of modern housing.

7.2 The "Bordei"

Buildings of a buried or semi-buried type existed over time and were spread widely in different areas of the globe. Some were dug in the stone or in the slopes of hills; for others, pits were dug that were protected by a wooden roof structure covered with a layer of soil or straw.

The differences in the form and constructive system of these constructions are given by three elements:

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- The materials that could be found in the area
- The climatic conditions specific to the area
- The way of living: permanently or temporarily

On the territory of Romania, this type of semi-buried construction has the name of “bordei.” As the definition of the word shows in the dictionary, the “bordei” is a “peasant dwelling deep in the ground and covered with earth or reed” [1].

In the southeastern area of Europe, traditional constructions were made, similar to those in Romania, with the names of “bordej” in Rusyn (an Ukrainian dialect), “burdely” in Serbian, “burdei” and “bordei” in Bulgarian, and “bordej” and “bordely” in Hungarian, these words being linguistically related to the word “bordei” [2].

There is evidence to prove the existence of semi-buried buildings since ancient times throughout Europe. The oldest constructions of the “bordei” type in our country were discovered both in the Cucuteni culture and the Gumelniţa culture, dating from the beginning of the Neolithic period. The “bordei” was recorded by researchers until the twelfth century. Some constructions of this kind have resisted until the beginning of the twentieth century in the southern part of the country [3].

During these ages, the semi-buried house was in a continuous transformation adapting to the needs of the people, evolving from a rudimentary construction to an advanced one, built with great skill. The historian Constantin C. Giurescu remembers in his book *The History of Bucharest from the Earliest Times to the Present Day* that in the nineteenth century, there were still “bordei” houses even in Bucharest, with a greater spread in the area on the suburbs of the city [4].

The “bordei” existed at the same time as the surface houses, representing a permanent way of living. Three of the last ones that existed in the middle of the nineteenth century were moved to museums.

Two of these “bordei” houses are located in the National Museum of the village “Dimitrie Gusti” in Bucharest: the “bordei” with four rooms in the village of Castranova (Fig. 7.1), Dolj County, built in the middle of the nineteenth century, was transferred to the museum in 1949, and the “bordei” with three rooms from Drăghiceni (Fig. 7.2) Olt County, which was built around 1800, was transferred to the museum in 1949 [5].

A smaller “bordei” is located in the Fruit and Wine Museum in Golești, Ştefănești, Argeș County: “bordei” with three rooms (Fig. 7.3) from the Puţuri village, Castranova, Dolj County [6].

At the beginning, this type of house was built also for defense reasons, being known that the settlements in the area south and southeast of Romania up to the Carpathian Mountains were repeatedly destroyed, first by the nomadic people and later by the neighboring peoples. Even the churches and the boyar houses of that time were made by the same construction system like the “bordei.” A traditional semi-buried church is on display at the Museum of the Boian Plain by “Traian Zorzoliu” in Drăgănești-Olt [7]. Under these conditions, the advantage of the “bordei” was that they could not be discovered from a distance, but only the smoke coming out of the roof, the houses integrating perfectly into the landscape. When the danger appeared, people retreated to the villages that had a more remote position

Fig. 7.1 “Bordei” with four rooms in the village of Castranova, Dolj County

Fig. 7.2 “Bordei” in the village of Drăghiceni, Olt County, built around 1800

Fig. 7.3 "Bordei" from the Puţuri village, Castranova, Dolj County. In the left, image with the access; on the right, the facade with windows

in the forested areas on the hills. The reconstruction of the houses after the passage of the invaders was quite easy to accomplish [8].

Another advantage of this type of construction is the perfect adaptation to the climate of the south and southeast of Romania bordered on the north by the Carpathian Mountains and on the south by the Danube River. Here the plains have temperate continental climate with some Mediterranean influences and with hot summers and very harsh winters. In the winter, a cold and strong wind from the northeast, called "crivăţ," is prevalent. Over time, the houses of this type proved to be cool during summer and easy to warm up in winter, thus solving the problem of fuel (wood) which was limited in some areas.

Compared to the surface houses, the semi-buried houses provide a much better insulation against the winter wind—the "crivăţ." It can also be observed that the houses are oriented so that they are protected to the north and the northeast and the entrance mostly on the south or west side.

In the medieval period, the building system of the "bordei" becomes more elaborated, craftsmen using with great skill construction techniques that they knew very well. The system from the Neolithic period involved sticking tree trunks in the four corners of the pit and fixing a cone ore wedge-shaped roof covered with branches with leaves, reef, or earth. Later the system is completed with walls made of horizontal planks that are fixed in special slots of the corner poles [9].

For the construction of some "bordei" houses, wood material was used in a very large quantity, about 25 tons, equivalent to the quantity of wood used for a surface house. This leads to the conclusion that these were no cheap houses, so the main reason for the construction type was that of the thermal efficiency given by the ratio between the buried area and the one above ground level. The volume below ground level is often higher than the above one.

Archaeologist Nicolae Constantinescu researched in the Coconi village in the south plains 74 houses of this type from the fourteenth century and detailed the construction systems of that period.

The depth of the pit varies from 40 cm to 150–185 cm but most falls between 80 and 130 cm [10]. Those that have a depth between 40 and 100 cm have been called "half-bordei."

As far as shape is concerned, the "bordei" houses of the Neolithic period were made up of a single room with an oval, rectangular, or square shape. In this room, all the activities necessary for living took place. People's activities, at that time, were mostly outside the house.

Over time, semi-buried houses have evolved by adding, on both sides of the initial "ogeac," fire room, a sleeping room called "soba," and one for storing tools or food called "celar" (Fig. 7.4). Thus, the houses became larger with one to three and even five rooms, square or rectangular, giving up the oval shape.

In the archaeological site of Coconi, the shapes and dimensions vary greatly from 3.25 × 2.90 m to 9.15 × 4.00 m or 6.30 × 6.00 m. The most common ones are a rectangle with sides from 3.00 m to 5.00 m [10].

Access to the main room is made through "gârlici." This is a buffer room in which the passage is made from the ground level to the floor of the house through a smooth slope or sometimes with steps [12].

We distinguish the "bordei" houses from the Dobrogea area, in the southeastern part of Romania, where the access to the house was made directly through the space

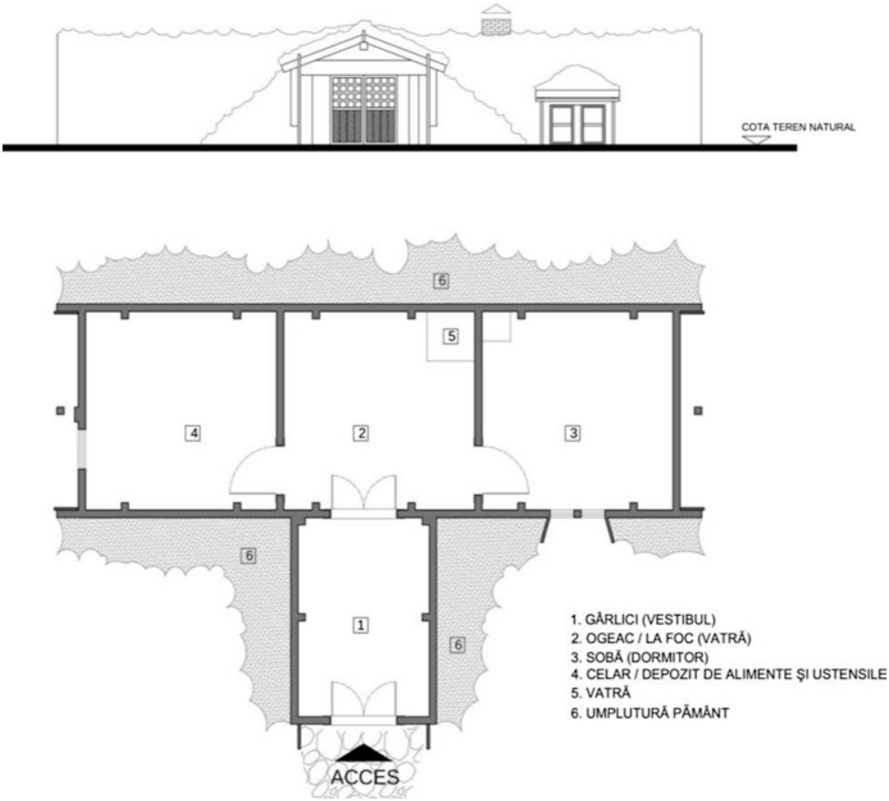

Fig. 7.4 "Bordei" with four rooms in the Castranova village, Dolj County. Plan and the main facade [11]

where the fireplace was arranged. The bedroom was placed on the side or at the bottom of this room. In the second case, the access was made along the axis of the house.

At first, the walls were plastered all with clay or with clay mixed with straw or wheat straw; later two types of walls were observed:

- The first and most widespread system consists of lining the earth walls with horizontal or vertical planks of wood. The walls made of wooden interior continued either above the ground, or they continued with walls made from interweaving of branches plastered with clay.
- The second system involved the lining of the perimeter walls with stones. This system was found in some pits of the semi-buried houses identified in the archaeological sites of the former Geto-Dacic-fortified center Capidava.

In the settlements discovered in the Gumelnița culture, the walls of the "bordei" houses were decorated with geometric drawings made of parallel lines of different thicknesses or white spirals on red background.

The roof with two slopes had a wooden frame. A thick layer of reed, straw, or soil layers was laid over the wood, depending on the materials existing in the area. At the house from Castranova, the roof is made by layers of reed, straw, and earth, while the one from Puţuri has the roof made only from layers of straw and earth.

"Vatra" (Fig. 7.5) was used both for cooking and for heating the interior space. It was located in the corner opposite to the entrance, thus creating a draw of air between the access area in the house and the chimney. "Vatra" was initially made of boulders placed vertically along three sides of a 20 × 20 cm square. The wood was

Fig. 7.5 "Vatra" from the house Puţuri village, Castranova, Dolj County

introduced from the open side. A horizontal stone plate was held up by the vertical ones. In some cases, in front of the fireplace, there was a small hole of about 8–10 cm in which the food was probably cooked during summer. In some houses, there were primitive vaulted stoves set on a layer of gravel or ceramic fragments glued with clay [10].

The floor was made of battered earth, or massive wooden planks were placed perpendicular to the long axis of the room, over which two layers were done, one thicker, of mixed clay and straw, and a thinner one, of fine clay [13].

The semi-buried constructions made with solid wood have proven resistant over time, those found in the Oltenia area between 150 and 200 years old [14].

7.2.1 Problems of in the Traditional "Bordei" House Concept

7.2.1.1 Moisture

Water from rainfall is easily infiltrated in the walls built above the level of the ground. There is a danger that water from heavy rainfall penetrates through the covers made only of layers of soil.

Moisture from the ground up can occur due to seasonal variations in the level of groundwater or in years with significant rainfall. This can moist the underground part of the walls and the floor, leading to high humidity of the indoor air. In conventional constructions, excessive moisture combined with poor ventilation can lead to the appearance of mold. At the same time, the thermal insulating capacity is greatly reduced due to the infiltrating water, through capillaries, in the walls of the building.

In the case of the "bordei" house, the appearance of the mold is mostly reduced by using the earth as a building material for walls, the floor, and the oven. It is known that the earth has the ability to adjust the humidity of an interior space. The wooden structure, on the other hand, is affected by humidity and mold.

7.2.1.2 Floods

A "bordei" house, being a construction with the floor below ground level, is permanently in danger of being flooded. Water can enter the house through the entrance or the windows which are only a few centimeters higher than ground level. In traditional houses, there is no water drainage system. At the same time, the walls made of clay are not resistant to direct contact with water.

7.2.1.3 Difficult Access

Although the room called "gârlici" is a good protection in the entrance area, like a vestibule, access is quite difficult. The door at the entrance is quite low. This height results from the space left between the roof and the natural terrain. Immediately next to the door, a fairly large step descends, after which a slope or more steps lead to the access door in the house.

7.2.1.4 Insufficient Natural Lighting

Natural light in traditional "bordei" houses does not meet current hygiene requirements. The windows of the traditional "bordei" were of small size because, at that time, the natural light in interior spaces was not considered important. People's activities took place more outside the house. On the other hand, we must take into account the fact that glass was expensive and difficult to procure until the twentieth century.

For example, in the case of the Castranova "bordei," the living room has an area of approximately 14.5 square meters with the natural illumination provided by a glazed surface of 0.96 square meters. The ratio of the surface of the room to the surface of windows is 1/15. There are no windows in the other room (the one with the fireplace); the natural light comes through neighboring spaces.

In the case of the house in the village of Puţuri (Fig. 7.6), the living room has a surface of approximately 6.76 square meters and the lighting realized through two windows with a total surface of 0.98 square meters. The ratio of room surface to window surface is 1/7.

Fig. 7.6 The room called "soba" from the Puţuri village Castranova, Dolj County

7.2.1.5 Poor Ventilation of the Interior Space

Although the access door and the chimney were placed diagonally to achieve a natural ventilation of the interior space, this is not sufficient. There is a high humidity in the interior.

7.2.1.6 Heat Losses

There are some sensitive areas where thermal losses occur: the outer walls and the floor. The walls above ground level are made of solid wood or a network of branches plastered with clay.

The calculation of the thermal resistance of a wall is done with the formula:

$$R = R_i + R_e + \sum R_k$$

where

R_i – the thermal resistance of the inner surface Ri = 0.125 m^{2}K/W
R_e – thermal resistance of the outer surface R_e = 0.042 m^{2}K/W
$\sum R_k$ – the sum of the thermal resistance of each layer of the outer wall

The thermal resistance of each layer k is.

$$R_k = d_k / \lambda_k \left[\mathrm{m^2K / W}\right]$$

where

d_k – layer thickness k [m]
λ_k – thermal conductivity of the layer [W/mK]

Thermal resistance of a 25 cm wood wall plastered on both sides with 5 cm clay is.

$$R_{ext\,\mathrm{wood}} = 0.125 + 0.042 + R_{\mathrm{clay1}} + R_{\mathrm{wood}} + R_{\mathrm{clay2}}$$

$$R_{\mathrm{wood}} = 0.25 \div 0.37 = 0.68\,\mathrm{m^2K / W}$$

$$R_{\mathrm{clay}} = 0.05 \div 0.60 = 0.08\,\mathrm{m^2K / W}$$

$$R_{ext\,\mathrm{wood}} = 0.125 + 0.042 + 0.08 + 0.68 + 0.08 = 1.00\ \mathrm{m^2K / W}$$

Thermal resistance of a sliding wall formed by a layer of plasters branch network with an average thickness of 2.5 cm and two layers of clay and straw mixture with a thickness of 15 cm is.

$$R_{\text{plastered network}} = 0.125 + 0.042 + R_{\text{clay}1} + R_{\text{network}} + R_{\text{clay}2}$$

$$R_{\text{network}} = 0.25 \div 0.28 = 0.09\,\text{m}^2\text{K}/\text{W}$$

$$R_{\text{clay}} = 0.15 \div 0.60 = 0.25\,\text{m}^2\text{K}/\text{W}$$

$$R_{\text{plastered network}} = 0.125 + 0.042 + 0.25 + 0.09 + 0.25 = 0.76\,\text{m}^2\text{K}/\text{W}$$

In conclusion, none of the two systems meet current thermal insulation requirements.

7.2.2 "Bordei" House Advantages

7.2.2.1 Organic Building

All material used to build the house such as stone, earth, wood, straw, or reed are recyclable. These can be reintroduced into the natural circuit in a proportion of 100%. The technique of construction with traditional wood in Romania allowed connecting wooden elements without metallic parts. Joints were used and sometimes wooden nails.

7.2.2.2 It Was Built with Materials from the Area: Wood, Earth, and Clay

The materials were the ones that people found in the area. Where wood was sufficient, wood would predominate in the construction of houses. In the southeastern area of Romania, in Dobrogea, the wood is used less since the stone is used more than in the other areas. Clay is available in all areas.

7.2.2.3 Low-Energy Consumption During the Construction Period

For the construction of this type of house, no special equipment is needed.

The materials being the ones found in the area, the cost of manufacture and transport is reduced.

7.2.2.4 Orientation Toward the Cardinal Points

In general, the traditional houses in Romania were placed taking into account the cardinal points. The houses had to be protected from the winter northeast-blowing wind, so most of the time, the houses had on the north or northeast side the annexes with a roof that went almost down to earth. The entrance and the windows were facing south or east, thus receiving solar heat in winter.

7.2.2.5 The Floor Below Ground Level

It is known that at a depth of 6 m below the ground, a temperature of 7°C is relatively constant in spite of variations of the outside air temperature.

Or, at the depth of 3 m, we have a temperature approximately equal to the average air temperature for 6 months. An experiment presented online shows that we can obtain a constant relative temperature even at lower depths [15]:

During the winter	T_{ext} range from −2 °C to 8 °C
	0.7 M → T_{int} = 5 °C
	1.5 M → T_{int} = 7 °C
During the summer	T_{ext} varies from 19 °C to 37 °C
	0.7 M → T_{int} = 20 °C
	1.5 M → T_{int} = 17 °C
During the autumn	T_{ext} varies between 11 °C up to 27 °C
	0.7 M → T_{int} = 20 °C
	1.5 M → T_{int} = 17 °C

Thus, we can say that in the interior space of the traditional "bordei" with a depth between 1.5 m and 1.85 m varies between 5 °C in winter and 20 °C in summer. The temperature obtained during the summer falls within the comfort limits. In winter, the temperature is low, but it does not have significant variations when the outside temperature drops even to −20 °C; 5 °C is a convenient start value for heating the space with less resources than the conventional houses.

7.2.2.6 Thermal Insulation

By making the coverings from alternative layers of soil and straw, very good thermal insulation is obtained. The use of straw layers leads to the increased thermal resistance of the covers. Knowing that the straws have thermal conductivity λ = 0.042 W/mK, we can calculate the cumulative thickness of the layers of straw needed to achieve the minimum thermal resistance for the roof R_{min} = 5.00 m²K/W [16]:

$$R_{straw} = 0.125 + 0.042 + d / 0.042 = 5.00 \ \text{m}^2\text{K} / \text{W}$$
$$d > (5.0 - 0.167) \times 0.042$$
$$d > 0.20 \ \text{m}$$

So a layer of 20 cm straw is sufficient.

The reed roofs are very light and soundproof and have good thermal insulation. These have to be fitted on a slope of 45° to prevent infiltration during rainfall. Given that the reed has a thermal conductivity $\lambda = 0.056$ W/mK, a layer of 30 cm thick is sufficient and will have a resistance of.

$$R_{\text{reed}} = 0.125 + 0.042 + d \div 0.056 = 0.167 + 0.30 \div 0.056 = 5.52\,\text{m}^2\text{K} / \text{W}.$$

7.2.2.7 The High Thermal Mass of the Earth Elements and the Existence of an Earth Stove

The use of earth for floors, partition walls, or finishing the exterior wooden walls is an advantage. The earth has a high thermal mass. It accumulates the heat from the fireplace and releases it for a long time in the interior space. Thus, the interior space is easily heated during winter, provided that the moisture is kept under control.

7.2.2.8 Capacity to Regulate Humidity

Tests carried out by Martin Rauch in his house in Schlins showed that the humidity of the air in houses made from earth is almost constant, ranging from 50% to 60%, unlike the conventional constructions where the humidity increases and decreases more depending on the humidity of the outside air. In a rainy period in which the external humidity increased to 100%, internal humidity of 70% was recorded in conventional homes, this being uncomfortable. If the underground portion of a "bordei" house is protected against moisture, the favorable case described above will apply.

7.3 Proposals for Modernizing a "Bordei" House

A modernization will be achieved by keeping the favorable elements and solving the problems mentioned above in order to obtain environmentally friendly, energy-efficient, and cheap housing, which will integrate very well and protect the environment.

7.3.1 Moisture Reduction

In order to reduce moisture in the soil layers adjacent to the construction, the principle of the "protective umbrella" can be used. This is achieved by mounting underground horizontally a waterproof foil with a length of about 4–5 m from the walls of the house. This way the humidity decreases by 50% in the area near the house [15].

The construction of a roof with large overhangs will lead to the protection of the exterior walls from the weather. This is necessary if the outer walls are made of earth or finished with clay.

It is necessary to have a waterproofing layer in the roof covering. A classic “bordei” roof or a “green” roof (with living plants) can be done above the membrane.

The protection of the construction against the groundwater must be achieved by waterproofing the floor and a layer of gravel with the role of capillarity break.

7.3.2 Avoiding Flood Zones

A leveling of the plot can be carried out and the house can be built on higher ground. The construction of drains of gravel and drainage pipes around the building will help in case of heavy rain. Water can be driven through a system of pipes to an area of the garden with plants and trees that require intensive watering.

7.3.3 Making the Entrance Easy to Use

The roof can be raised at the entrance so the door can be higher and access will be comfortable. The difference between ground level and the floor of the house can be taken in two stages, in two following rooms.

On the other hand, one can improve the type without vestibule, as they were done in Dobrogea. In this case, it is necessary to raise the land near the construction and to protect the access door with a generous overhang, so that the house is protected from heavy rains. The access will be made directly in the house and then by climbing down some standard stairs to the floor level. The staircase can be placed in a vestibule that is integrated in the space of the house as in the case of some modern houses.

7.3.4 Natural Light According to the Norms

In order to meet the needs of the modern society, where many activities of people take place inside the home, natural light is necessary and depends on the type of interior area. According to the norm regarding the design of residential buildings (revision NP 016–96), indicative NP 057–02 of 24.09.2002, Ministry of Public Works, Transport, and Housing, Article 3.4. (E).1.2., the glazed surfaces are dimensioned by calculating the ratio between window area and floor area. This ratio should be 1/6–1/8 for usual rooms and 1/8–1/10 for the other rooms (annexes) [17].

As we have shown in previous section (see Sect. 7.2.1.4), the ratio for the living room is 1/15 in case of Castranova and 1/7 at the house in Puţuri. In order to ensure the 1/6 ratio required by the norm, the surface of the windows should be supplemented up to 2.42 sqm in the case of the Castranova "bordei" house. The ratio calculated for the second house is within the normative values. Here the fact that the windows are positioned on the side has made it possible to make larger windows.

In this sense, it is necessary to increase the glazed surfaces to as long as the surfaces of outer walls allow. If this is not possible, tubes for lighting or skylights installed on the roof can also be used; this can also be done for areas that are mostly underground.

It must be taken into account that by increasing the glazed surface, the thermal resistance of the building envelope is reduced, the glazed areas having a lower thermal resistance than the opaque elements. Therefore it is necessary to use insulated windows with wooden joinery and have a thermal resistance of $R = 0.77$ m^{2}K/W.

7.3.5 Ensuring Sufficient Ventilation

As the glass surfaces are enlarged for better natural lighting, natural ventilation of the interior space is also improved. Apart from the size of the windows, it is important to position them on opposite walls so that by opening, they will create an air flow.

If the surface of the windows is not sufficient for ventilation, alternative ventilation systems can be used. Slots can be provided in the walls, with adjustable flaps.

7.3.6 Correct Thermal Insulation of the Outer Shell

According to the provisions of C 107/1, the minimum thermal resistance of an outer wall must be $R_{\min} = 1.80$ m^{2}K/W; the floor at the bottom of the basements, or of heated basements, below ground level $R_{\min} = 4.80$ m^{2}K/W; and exterior underground walls in heated basements $R_{\min} = 2.90$ m^{2}K/W [16].

Because of the thermal resistance of an outer wall of solid wood, 25 cm thick and plastered on both sides with a layer of 5 cm clay, to be greater than $R_{\min} = 1.80$ m^{2}K/W, we will do the following calculation:

$$R_{ext\,\mathrm{wood}} = 0.125 + 0.042 + 0.08 + 0.68 + 0.08 + R_{\mathrm{hemp}} = 1.80\,\mathrm{m}^2\mathrm{K}/\mathrm{W}$$

$$R_{ext\,\mathrm{wood}} = 0.125 + 0.042 + 0.08 + 0.68 + 0.08 + X/0.04 = 1.80\,\mathrm{m}^2\mathrm{K}/\mathrm{W}$$

$$X = (1.80 - 1.00) \times 0.04 = 0.032\,\mathrm{m}$$

For the thermal resistance of the outer wall formed by a network of woven branches with an average thickness of 2.5 cm and two layers of earth mixed with straw with a thickness of 15 cm, to be greater than $R_{\min} = 1.80$ m^{2}K/W, we will do the following calculation:

$$R_{\text{plastered network}} = 0.125 + 0.042 + 0.25 + 0.09 + 0.25 + R_{\text{hemp}} = 1.80\,\text{m}^2\text{K / W}$$

$$R_{\text{plastered network}} = 0.125 + 0.042 + 0.25 + 0.09 + 0.25 + X / 0.04 = 1.80\,\text{m}^2\text{K / W}$$

$$X = (1.80 - 0.76) \times 0.04 = 0.04\,\text{m}$$

For the two traditional systems, it is necessary to insulate with an additional 5 cm layer of hemp tiles or other natural materials that allow the parts made of earth to breathe.

The first traditional wall system would not make much sense in a modern house; the amount of wood used would be far too high. The second one, however, with the network of woven branches would be economical and environmentally friendly.

By making the last layer of the roof out of soil that will allow plants to grow on the entire roof, a higher insulation will be obtained and at the same time a perfect integration into the environment and landscape. This layer can be a continuation of the grassland around the building allowing nature to coexist with human occupants on practically the entire surface of the house.

7.4 Conclusions

This type of constructions on the Romanian territory has been built over time for two reasons: defense and adaptation to the climatic conditions in the south and southeast of the country. During the study, I found that this type of construction, because of its shape and the materials used, has a number of important advantages such as energy efficiency, environmentally friendliness, low construction cost, and small fuel consumption.

Although the traditional semi-buried constructions have a number of weak points that do not correspond to modern living standards, we have shown that there are constructive and conceptual solutions to solve these problems.

The use of the “protective umbrella” made of PVC foil on a distance of about 4–5 m leads to the diminution of the moisture from the ground which represents a danger to the traditional “bordei” house.

Places where the outer walls rise above the ground level are prone to water infiltration. Choosing a suitable land far from the flood areas of rivers and the level planning in the vicinity of the house together with the installation of a drainage system will protect the structure from the damage that could occur during heavy rains and floods.

Facilitating entering the house is easily solved by lifting the roof in the entrance area.

To meet the needs of modern housing, it is sufficient to resize the glazed areas according to current regulations. At the same time, the larger surface of windows can solve the problem of ventilation of the interior space.

Current norms lead us to design constructions that use as little energy as possible. In order to obtain this, the houses must be better protected against the temperature variations of the outside air. Traditional “bordei”-type houses should be protected with thermal insulation panels of at least 5 cm thick, made of natural materials so as to allow the walls to breathe.

Moreover, there are a number of concepts that can improve the structures like “bordei” houses, leading to the realization of NZEB houses, that is to say constructions with almost zero energy consumption, which are the target of the new laws in the field of constructions.

An important element is the use of the land from the excavations to make the house. The vegetal layer is not good for construction but can be reused as a top layer for the roof of the construction, thus improving the thermal resistance of the outer shell and at the same time the air quality in the immediate vicinity. The rest of the land is traditionally used to raise the exterior and interior walls, floors, stoves, and some furniture. The interior elements of the earth are very important because they help to maintain a constant humidity and to regulate the temperature of the interior space. The resulting land surplus will be used to raise the land near the house. Thus, a slope can be created to protect the house from the water.

If possible, by orientating large windows to the south and southeast, heat from the sun can be captured during winter. The shape of the roof is important; the overhang can be shaped so that it shades the windows during summer allowing the sun to directly hit them in winter. Such a building is well suited to use systems typical for passive buildings (e.g., greenhouses to capture sun heat or the Trombe-Michel system).

Using modern materials in addition to traditional ones and using some modern techniques to solve problems, we can make modern homes that meet comfort requirements for modern living. These will be low-cost houses during the construction period and during use. They are thermally efficient constructions, which integrate into the natural environment, protecting it.

References

1. L. Șăineanu, Dicționar universal al limbei române, ediția a VI-a, Ed. Editura, (1929)
2. A. Cioranescu, Dictionarul etimologic al limbii romane, ed. Saeculum, (2000)
3. G. Stoica, Arhitectura populară românească, Ed. Meridiane, București, (1989), pp. 32–38
4. C. Constantin. Giurescu, Istoria bucureştilor din cele mai vechi timpuri pînă în zilele noastre, Ed. pentru literatură, Bucureşti, (1966), p. 27
5. https://muzeul-satului.ro
6. https://www.muzeulgolesti.ro/home
7. https://www.gds.ro/Local/2015-10-14/arheoparcul-muzeului-campia-boianului-unic-europa/
8. H. Stahl, P. Stahl, Civilizația vechilor sate românești, Ed. Stiințifică, (1968), pp. 5–10 si pp. 50–51
9. I. Godea, Locuinţa străveche (secolele XII–XV): aspecte arheologice şi etnografice, in revista Buridava studii si materiale VIII, Ed. Offsetcolor, Râmnicu Vâlcea, (2010), pp. 372–389

10. R. Florescu, Bordeiul medio-bizantin de la Capidava si rolul sau in viata familiilor de stratiotai, publicata in volumul reunind sesiunile desfasurate la Sibiu din anii 1999–2001, Sibiu, (2004), pp. 253–261
11. G. Ionescu, Arhitectura populară romînească, Ed. tehnică, București, (1957), pp. 21–24
12. Locuința sătescă în România, studii de arhitectură tradițională în vederea conservării și valorificării prin tipizare, Studiu coordonat de ICCPDC, Ediție revizuită și completată, București, (1989), p. 23
13. Constantin Preda, Enciclopedia arheologiei și istoriei vechi a României (volumul II, literele DL), Ed. Enciclopedică, (1996), pp. 319–326
14. V. Butură, Etnografia poporului român, Ed. Dacia, Cluj Napoca, (1978), pp. 81–86
15. https://www.homeintheearth.com/?s=soil+temperature&submit=Search
16. Normativ privind calculul termotehnic al elementelor de construcție ale clădirilor, indicativ C 107/1 din 29.11.2005 Ministerul Transporturilor, Construcțiilor și Turismului, cu modificările şi completările ulterioare
17. Normativul privind proiectarea clădirilor de locuințe (revizuire NP 016-96), indicativ NP 057–02 din 24.09.2002 Ministerul Lucrărilor Publice, Transporturilor și Locuinței

Chapter 8
Using Agricultural By-products for Creating Innovative Technologies and Materials

Dora Francese

8.1 Introduction: Energy and Recycling

The question of energy within the building sector has been, in the last century and at the beginning of this, covered by a great number of studies and researches, as well as regulations, legislations, and standards. This process has led to a great improvement in the efficiency of the indoor space comfort as well as to a reduction of energy consumption derived by fossil fuels.

This is for sure a great achievement and a victory for the whole sector of energy, as well as for the health and comfort of users in various countries, mainly where the rigid and cold temperatures actually led users to an high consumption of fossil fuels, as well as financial weight to their economic budget, aimed at heating up the internal spaces during the long winters.

The situation can then be considered solved from the comfort and money-saving points of view, since the thick layers of insulating materials provided to the new, as well as to the existing – when possible – buildings, could allow great levels of thermal resistance.

But a great problem starts to arise lately when, for providing indeed these high levels of insulation to walls, roof, and in general to the envelope, the products employed were mainly manufactured with synthetic prime matters. The most common materials employed for these insulating layers are very often the polyurethane or the polystyrene; the latest can be considered the most polluting materials among the building products, for their low level of naturality, completely artificial manufacturing, no bioregional location, and mainly the great contribution that the production processes provide to the ozone depletion effect.

The problem can then be so identified: more insulation to envelope means more energy consumption, rather than fossil fuel saving. It is only the site of consumption

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that is moved from the house running sector to the industrial market in the building sector, where the energy is consumed and where the pollution effects are provided in order to produce the artificial insulating products.

These notes are useful for introducing the subject of the research we have been dealing with in the latest years, which is the use of sustainable materials in construction. In particular our studies and researches at the Department of Architecture in the University of Naples Federico II (interacting with the research center Cittam-Interdepartmental research Centre for the study of the Traditional Techniques in the Mediterranean Area) are aimed at defining possible changes in the production processes, mainly those which provide–as final manufacture-, building materials, and components. The conceptual approach of the general research, which started in 2008 with a study on bamboo and other vegetable materials [10], is that of reclaiming the need of transforming the linear processes which actually invest all the sectors of human activity and thus also the building one and trying to revolutionize the stages as well as the single steps, by making the process circular. This should start from the first prime matter supply which should prefer materials and resources at high naturality, at low energy inlet, and at very frequent availability on Earth, and last but not least, they should be accessible on site or very close. This first step of the cycle of the chain is important because it takes into account the bioregionalism [25], as means of social, environmental, and cultural knowledge as well as respect of the local region. This approach tries to save the identity of the place as far as resources and social establishments are concerned and can actually be considered as the more suitable to be applied when the existing place has values and human consistence [3]. The theory of bioregionalism actually takes into account also the question of waste, as well as those of transportation pollution and energy consumption, and others [23]. Although this approach has been often compared with the well-known idiomatic sentence “at-Zero-Km,” nevertheless it involves also some other fields of human action and sensitivity, rather than only the logistical issue of finding prime matters in a very close site. In fact bioregionalism [4] represents a holistic approach and a way of living and working in a place, which takes into account and tries to solve other problems such as those of material and physical as well as of spiritual and physiological nature [7]. Designing with the bioregionalist *Spirit of the Place* means to try to get in harmony with the bioregion itself, to collaborate rather than to transform and brutalize the landscape, and to improve social, sensitive, and natural milieu, trying to save the feeling of belonging [11].

Given the need of approaching building process by means of a circular chain, the other steps of the production should consider the level of naturality.

According in fact to the blue economy [21], it is possible to trace future scenarios with concrete entrepreneurial solutions and to overcome in a constructive way the crisis starting from the environment and from land requalification. Returning to the concept of being conscious of the ecosystem, more materials at low price would be available than it would be possible to imagine, and the entrepreneurial initiatives could be multiplied, so creating a new spread employment, which will be respectful of territory as well as of people’s dignity.

And as Gunter Pauli states, prime matters of the blue economy are local, in cascade, and part of an integrated system, employed in a most efficient way: for this reason, they result more competitive than the conventional ones. The author also underlines the need of a cultural change that should cross the whole society, placing in the center no longer the single product, pushed by great global industries, but the territories and their specific ecosystems, so as to valorize the landscape, and to find a way for allowing a better life even in conditions at limited availability of water, to transform areas in the process of desertification into zones rich in vegetation and prime matters for man [2].

Therefore, if the circular economy is to be applied, what can be more important than using some recycled products which are also natural and thus recyclable never-ending times?

On one hand country wastes are in fact a load and a discomfort for the farmers as well as for the cultural environment in which the greenery is often considered as dirty (imagine if there was no maintenance in a city where parks are located); on the other hand, recycling agricultural wastes can provide to the new products – made up with second-hand materials – a long life, a nonpolluting impact, and low energy systems.

Therefore another big question has to be briefly outlined as introduction, i.e., the fact that, since the building sector largely employs virgin prime matters and natural resources, it becomes important to investigate about the chance of recuperating the so-called C&D (Construction and Demolition) wastes, so as to address the management of such wastes toward a minimization of buildings' environmental impacts on ecosystem but mainly to offer new economic potential for arranging the products destined to disposal [13]. In order to recuperate and re-employ the C&D wastes, the selective demolition should be preferred, so allowing the reduction of their amount as well as designing architectural fabrics in a different way; choosing in fact components and products for building process according to the end-of-life approach requires to take into consideration the disposal stage, so previewing the end-of-life scenario already during the first stages of the design procedure [20]. According to the Life Cycle Thinking Concept, the needed steps for a good management of C&D wastes are the following: de-composing the elements; separating the various matters; recycling the product; reusing; biodegrading; and finally employing it as fertilizer [18] (Fig. 8.1).

8.2 Bio-Based Products and Wastes

The latest considerations introduce the potential of bio-based materials and products. In fact, not only the C&D wastes are manufactured in a great amount all over Europe but also the agricultural sector contributes to spread high quantities of materials into the landfills. The employment of some bio-based materials, known in literature as bio-composites, such as the WPC (Wood Plastic Composites), can produce immediate benefits within their whole life cycle: the

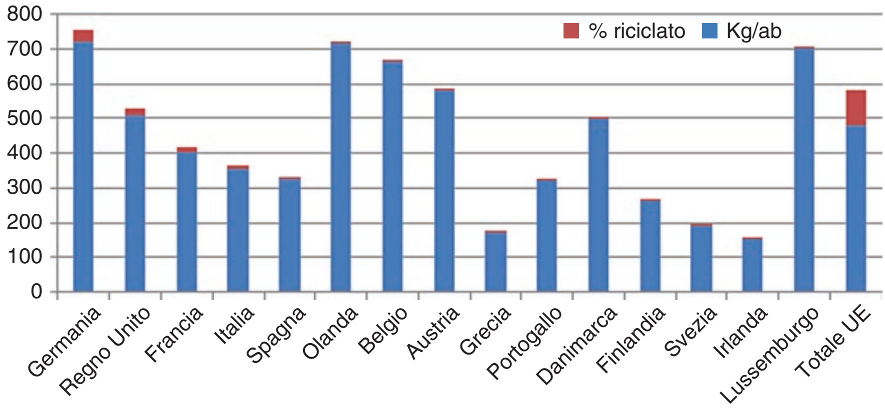


Fig. 8.1 Wastes produced in the European countries/% of recycled products (thousands of tons) [9]

requirement of virgin prime matters' extraction will be reduced, and some closed-loop disposal paths can be promoted. In fact, by previewing non-artificial prime matters, a more "natural and biological" product disposal can be thought, thanks to the principle of biodegradability of the building elements: these products would provide a lower ecological footprint to Earth [1]. A number of European projects have been carried out, aimed at innovating the building market with products at high naturality and recycled from agricultural wastes; according to the data of one of this, the Life project APPRICOD (Assessing the Potential of Plastic Recycling in the Construction and Demolition Activities), the C&D wastes produced in Europe represent 30% of the whole trash and are enumerated in 180 ton millions a year, which represents more than 480 Kg per person a year, of which only 28% is actually reused, while the rest is still destined to the landfill [14]. The C&D wastes can come from the following activities: legal C&D, squatting C&D, small housing retrofitting, and others. In conformity to the European Waste Catalogue, the building scraps are indicated with the code 179. Table 8.1 reports a classification of C&D wastes, according to their origin.

Therefore, a necessary action for reducing the environmental impacts due to the building process and mainly promoting the use of eco-oriented products and materials requires to activate processes of transformation and conversion of the waste resource. As most common goods which compose the C&D wastes in Italy are the ceramic building materials (Fig. 8.2), then substituting the vertical closure made up in ceramics with alternative solutions can contribute to reduce the wastes themselves [11].

One of these alternative solutions can be found in the straw prefabricated panels. For demonstrating the potential of good performances that they show, we carried out a step of the research aimed at comparing the LCA values of two different building components for vertical closures, one in conventional brickwork and the other in straw.

Table 8.1 Classification and origin of C&D wastes coming from various activities

Typology	Origin	Wasted materials
Construction wastes	Wastes coming from maintenance sites, from building constructions, civil infrastructures	Concrete (normal or precast) Cement and various mortars Conglomerates and mixed bituminous Bricks, tiles, and blocks Excavation earth Timber Paper, cellulose, and polyurethane Metals Plastic Gypsy Ceramics Glass Asbestos
Demolition wastes	Wastes coming from maintenance and/or partial or total demolition of buildings and civil infrastructures	
Wastes from streets' construction and demolition	Wastes coming from streets' maintenance and construction sites	Conglomerates and mixed bituminous Excavation earth Concrete Timber Metals Plastic
Earth and rocks from digging	Wastes coming from soil movements for completion of civil and digging works	Excavation earth Timber

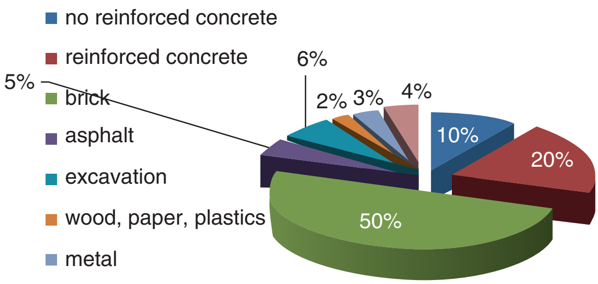


Fig. 8.2 Goods' composition of C&D wastes

8.3 LCA Comparison Between Two Products for Vertical Closures

This research is in fact aimed at looking for alternative solutions to the ceramic and concrete components for buildings, which can be useful for both reducing the polluting impact due to their end-of-life stage and promoting the employment of agricultural or other sectors' wastes.

The first part of the research started in fact to investigate upon different fields of human activity in which the waste disposal is a problem. For example, the marine vegetation, which in a natural ecosystem would be useful for a lot of various flora and fauna creatures, as home or food, or only protection, when instead it is found in the waterfront areas near humanized territories, it becomes a problem. We studied the *Posidonia oceanica* seegrass, which increases its production in the South Italian marine shores due to artificial actions. The macerated *Posidonia* parts create bad smell and discomfort for people using the beaches, as well as a problem for the security of the waterfronts. Approaching the problem with a blue economy vision, the *Posidonia* could be re-employed for two classes of application: as biomass for producing renewable energy systems and as fiber for creating innovating bio-composite products for the building sector.

Making comparison between ceramics and other bio-based materials, the vegetable ones become very competitive. The LCA assessment method had been employed [6], with the final scores which define the impacts. The scores are actually measured in eco-points (Pt): "… the value of 1 Pt (eco-point) is representative for one thousandth of the yearly environmental load of one average European inhabitant. It is calculated by dividing the total environmental load in Europe by the number of inhabitants and multiplying it with 1000" [22].

In fact literature data demonstrated that during the LCA assessments [17], the ceramic materials present a high value of damage, which is variable according to the layers' composition; for example, a brick wall of 38 cm can have the score of 0.5 Pt, while a wall made up by two bricks and insulation can be valued as 2.75 Pt; moreover the artificiality of the layers' arrangement leads to a great variable range of impacts toward both the categories of men and resources [5].

According to the data reported by ICE (Inventory of Carbon and Energy) database, the embodied energies of bricks are 3 MJ/kg and 0.24 kg of CO_2 eq./kg for the generic ceramic (general simple baked clay products; general clay brick) and 6.5 MJ/kg and 0.48 kg of CO_2 eq./kg for the cooked tiles [12].

As far as the second term of comparison is concerned, LCA assessments have been made on an innovative component, developed by our research team and deeply studied within a PhD thesis by N. Mastrangelo. In this research a prefabricated straw panel (so-called ModCell) has been proposed as technological solutions for the vertical walls in buildings. Comparing the mentioned embodied energy of bricks with that of the ModCell, some benefits are shown: in fact according to the data reported in the technical sheet, during its life cycle, this product saves 1400 carbon equivalent kg (Table 8.2).

From these considerations, the environmental advantages in substituting the ceramics with straw bales become clear: according to a study promoted by the Tuscana region, if 100,000 tons of straw are destined to building use, an amount of carbon equivalent of 158,000 tons can be retained, during the operation stage of the architectural fabric [24]. Moreover, the use of straw could compensate the greenhouse gases emissions up to 45,000 tons of gasoline (which means 3.5 carbon equivalent Kg per each kg of gasoline).

The straw bales, besides storing the carbon within the culms of the cereals, avoid also some environmental loads: in fact for completing 1 sqm of ceramic wall, almost 134 bricks are needed, whose medium emissions are 0.4 carbon equivalent Kg for each Kg of product, while with the straw wall with the same insulating performances (U value of 0.09 W/sqm °C), the loads to be subtracted are in negative: it is equal to 147.4 carbon equivalent Kg for each square meter, which means that its original culm provides oxygen, like – as we know – any other plant does.

According to the costs, it can be seen that the closure with straw in comparison with that of bricks allows a reduction from 10% to 15% of the wall cost; the building envelope in straw, for a construction of 100 sqm, costs around 4000 or 5000 euros: Edilpaglia (the Italian straw-building society) declares that the straw bales, in comparison with other materials with the same thermal performances, allow to save from 50% to 75% of wall cost [16].

Another comparison, found in literature, can be here outlined between LCA of vertical closures in straw and those in brick. The bricks perform a damage index much higher than that of the straw walls: bricks have a score of 36.9 Pt, while the straw panels are evaluated as 1.41 Pt, thus demonstrating that the straw is 16 times lower.

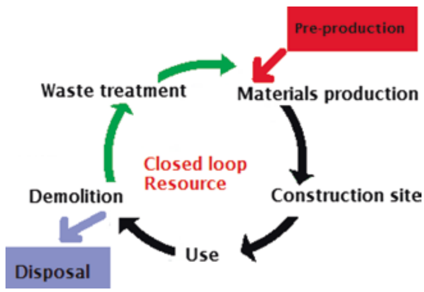
The investigation had in fact considered different stages of the building elements' life cycle: the pre-production, the production, and the disposal (Fig. 8.3).

In the present research, a similar process of investigation has been carried out, aimed at comparing the environmental loads of the life cycle of two classes of building component: the ceramic one with its specific thickness and components and the innovative systems employing straw as the main second prime matter. Both

Table 8.2 Embodied energy analysis of ModCell panels [15]

	Wood	Straw bales	Plaster	Total
Materials of ModCell lime straw 3 × 8 bale panel	**369.**1 ft	271.75 kg	0,483 m^3	
Embodied energy in ModCell lime straw 3 × 8 bale panel (MJ)	1031	198.2	973.2	2084.4
Average energy embodied **for 1** × **2.**4 section of ModCell lime straw 3 × 8 bale panel (MJ)	257.8	49.55	243.3	550.7

Fig. 8.3 Format of the investigation on the LCA stages



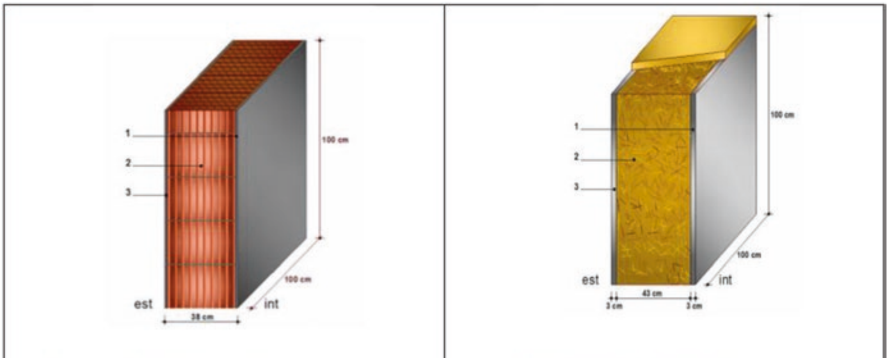


Fig. 8.4 Comparison between the two types and their U values. (Source: [19])

can be utilized as vertical closure for the envelope of a good insulated building. The characteristics, chosen for the two systems in a similar typology, are the following: the first (Type A) is made up with porous ceramic of 38 cm and civil internal and external plaster of 0.2 cm; the second (Type B) is instead composed by a cross-laminated timber frame and then a 43 cm thickness of straw and is finished with civil plaster of 0.3 cm, both internal and external. The comparison of thermal transmittances (U value) for both the types is shown in Fig. 8.4.

The analysis and evaluation of the two samples have been made over one square meter of surface, as functional unit of vertical closure. It has to be remembered that the bricks' production undergoes to fabrication processes on national scale, while the straw panels' production follows a local and regional strategy: in fact the prime matters are coming from local context and are assembled in suitable spaces located very near to the site of construction, so the final product made up with these prime matters can be classified as a system at Zero-Km.

As shown in Fig. 8.5, the impacts of the ceramic production are great, since the fabrication and transformation processes from the prime matters require great amount of resources, while for the prefabricated cross-laminated and straw panel, the higher incidence is due to the acquisition of the semi-components to be assembled so as to complete the modular system. The impact percentage in the production and construction stages, which occur during the ceramic fabrication, results around half of the whole impact factor. The damage is, therefore, mainly linked to the production of the single elements and their transportation. By assessing the two solutions, it can be seen that the bricks are always the more affecting: in fact for the voice "Resources" the bricks' data are equal to 3.68 Pt, in comparison with the straw panel of 0.785 Pt; and finally the validity of the straw solution is demonstrated by the fact that a great advantage is provided by the damages in the category of "Human health"; here the bricks reach the value of 3.92 Pt, while the straw panel is still lower than 0.22 Pt (Fig. 8.6), thus meaning that the straw type creates less negative effects on men.

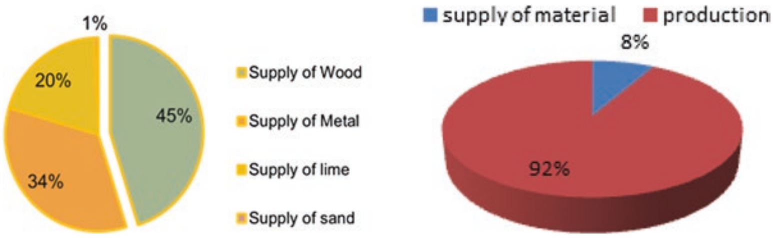


Fig. 8.5 Comparison between pre-production and production stages of the investigated two types of vertical closures (Type B, straw panel on the left, and Type A, brick wall on the right)

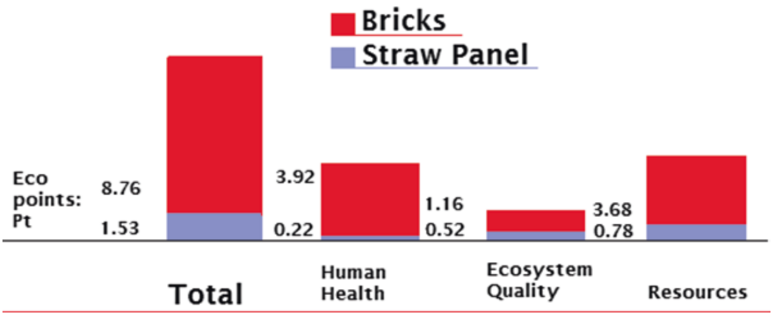
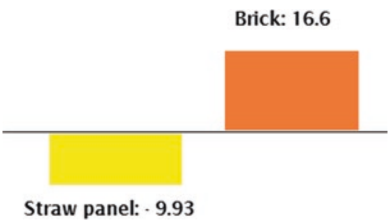


Fig. 8.6 Comparison between the processes according to Eco-indicator 99 (E) V2.03/Europe EI 99 E/E / single score. (Remake from LCA literature)

Fig. 8.7 Comparison between impacts for end-of-life phase of the analyzed solutions. (Remake from LCA literature)



As far as the end-of-life scenario is concerned, according to the studies, the bricks affect 16% of the whole LCA value, while the straw panels get even negative score: this difference is due to the easy demounting suitability of the pre-fabricated component and to the chance of reusing both the single materials and components into other processes and the whole element in the same building process, when they are still good performing and intact (Fig. 8.7).

8.4 Conclusion

Although a correct management of bricks in the disposal stage would reduce the amount of wastes, which could become SPM (second prime matter) for manufacturing new inertial materials and would be greatly valuable, nevertheless the promotion and use of straw panels in the Italian Building sector has not yet become a habit (Table 8.3).

Although presently the agricultural process for producing the straw bales for construction is not yet located in the national territory, nevertheless a productive chain addressed to designing and commercializing systems built with straw could guarantee to the agricultural farms a plus-value for the wasted by-products. This strategy could moreover promote the use of eco-sustainable and bio-compatible building materials, re-employed both in the productive cycle of the construction sector (by molding the rammed earth or reusing the straw for new panels) and in the agricultural cycle (as animals' litter or for protecting the grown harvest from high solar radiation): and finally this component could be processed naturally for biodegradable disposal which would not produce any gas, liquid, or solid polluter.

We can conclude with a sentence from Ciribini, who said about the memory that "…so surfacing is not then sign and change or quoting to archive or harvest in the museums, … and neither re-memorization nor com-memoration, but rather alive memory, as a reactivation of knowledge, of its present production, of memory as

Table 8.3 Comparison between management of straw panels and bricks in the disposal phase

Management of straw panels' disposal phase	Management of bricks' disposal phase
New production chain for straw in sustainable buildings	Reducing the quantity of waste products
Implementation of reusable construction cycle (kneading with clay or reusing straw for new panels)	Implementing the production of the second prime matter in the production of inert materials
Reuse of straw in agricultural cycle (as bedding for animals or mulch)	
Recycling ecological products for composting straw (a biodegradable material) with no generation of pollutants	

unveiling:" [8] this idea can corroborate the use of by-products also as a peculiar means of remembering the soil importance of a place and providing to buildings erected with straw the right to be part of the cultural as well as natural environmental and in the ultimate place as a bioregionalist system of constructing and recycling.

References

1. AAVV, *Ecological Footprint – Un approfondimento sull'impronta ecologica dell'edilizia residenziale in Italia, Documenti IAED nr*, 8th edn. (Papageno, Palermo, 2004)
2. S. Achim, K. Ashok, *Foreword in Pauli G., "The Blue Economy: 10 Years, 100 Innovations, 100 Million Jobs" Report to the Club of Rome* (Paradigm Publications, Taos, 2010)
3. P. Berg, Welcome Speech from the First Bioregional Congress of North America, (1984)
4. P. Berg, R. Dasmann, Reinhabiting California. The Ecologist **7**(10) (1977)
5. A. Campioli, M. Lavagna, Misurare la sostenibilità: il laterizio. Costruire in laterizio **143**, 65–71 (2011)
6. E. Cangelli, A. Paolella, *Il progetto ambientale degli edifici. LCA. EMAS, Ecolabel, gli standard ISO applicati al processo edilizio* (Alinea, Firenze, 2001)
7. R. Carson, *Silent spring* (Penguin books, London, 2000)
8. Ciribini G. (1989), Forward to: AAVV "Tecnologia del Recupero edilizio", Utet, Torino.
9. A. Di Lauro, S. Sicher Short, D. Grimaldi, (editors) Guidelines on industrial C&D Waste:ARPA Liguria. https://docplayer.it/1912961-Linee-guida-sui-rifiuti-speciali.html
10. C. Filagrossi, D. Francese, I. Orefice, Vegetable materials in architecture, in *"11th Durability of Building Materials and Components" SET International conference on Sustainable Energy Technologies*, (Istanbul, 2008)
11. D. Francese, *Technologies for Sustainable Urban Design and Bioregionalist Regeneration* (Routledge, London, 2016)
12. C.T. Hendrickson, L.B. Lave, H.S. Matthews, A. Horvath, *Environmental life cycle assessment of goods and services: an input-output approach* (Resources for the Future Press, USA, 2006)
13. http://annuario.isprambiente.it/sites/default/files/pdf/2012/annuario/10.RIFIUTI_2.pdf
14. http://ec.europa.eu/eurostat/statistics-explained/index.php/Waste_statistics
15. https://qspace.library.queensu.ca/bitstream/1974/5409/1/Offin_Maria_201001_MES.pdf
16. https://www.edilportale.com/search/notizie/edilpaglia
17. M. Lavagna, *Life cycle assessment. Progettare e costruire in una prospettiva di sostenibilità ambientale* (Hoepli, Milano, 2008)
18. A. Masullo, *Qualità verso quantità. Dalla decrescita ad una nuova economia* (Lit.ed, Rome, 2013)
19. P. Milano, Environment assessment of products in raw earth. SMC J. (www. sustainablemediterraneanconstruction.eu) **1**, 63–69 (2014)
20. A. Passaro, *Costruire e dismettere. Nuove strategie per il riciclaggio in edilizia* (Arte Tipografica, Napoli, 1996)
21. G. Pauli, *Blue Economy: Milano* (Edizioni Ambiente, 2010)
22. M. Soedkoop, S. Affhing, M. Collignon, *The Eco-indicator 99. Manual for Designers* (Ministry of Housing Spatial Planning Publication, Netherlands, 2000)
23. F. Stevenson, A bioregional approach to climate change design, in ARC 307, 327, 377, Environment and Technology 5 (2013)
24. M.C. Torricelli, C. Gargari, E. Palumbo, Valutazione ambientale nel ciclo di vita dei prodotti in laterizio. Costruire in laterizio **116**, 60–67 (2007)
25. A. Van Newkirk, Bioregions: Towards bio regional strategy for human cultures, in Environmental Conservation /Cambridge Journals on line/Volume 2/Issue 02 (2009)

Part III
Case Studies

Chapter 9
Les conditions de la nature sont retrouvèe: The Tower of Shadow in Chandigarh and Other Le Corbusier's Masterpieces

Stefano Perego

9.1 Introduction

The relationship between form and light constitutes a properly architectural research issue in which the theme of solar control in architecture is fully inserted. Architecture reveals itself under the light; it is the *wise play of volumes under light*. The plastic properties of architecture are emphasized by light and shadow. For Henri Focillon [1], "Light does not only illuminate the internal mass, but also collaborates with architecture to give it its shape. Indeed, it is itself form, since its rays, sprinkled by determined points, are compressed, thinned and tense, so that they come to strike the parts of the structure, more or less gathered, underlined or not by ridges, in order to calm, or to let the light play." The famous painter Edward Hopper puts his personal research on light saying "All I ever wanted to do was paint sunlight on the wall of a house." This thought states the value of the research on the theme of light and the need to face it in a patient way. Differently to a painting, the research on light in architecture includes the variable of the time described by the sun during the day, the seasonal variations that mark the rhythm of our life. And architects need to face the issue of *necessity* (in terms of use) and the character of architecture that makes this research even more complex and fascinating.

An Ernst H. Gombrich [2] essay entitled *Shadows* is an interesting discussion on the value of the shadow through some significant episodes in the history of art. Through the revival of some legends, Gombrich maintains that the search about the shadow indicates an awareness of reality. The presence of shadow certifies the existence of an element, a body, a tree, and, of course, an architecture. It assumes that the very element that generates it is placed under the light of the sun and that its parts, in turn, generate shadows on the parts themselves that make up the element.

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In *De pictura*, Alberti writes that the light and the shadow make the sensed things appear. In architecture, the shadow reveals its form.

But today, the idea that solar control in architecture is restricted in a functional point of view detach from architectural composition is still present in our scientific community, an attitude that has confined many interesting experiences, major and minor without distinction, in the context of functionalism.

For that reason, it is important to include the theme in a broader reflection concerning the relationship between architecture and nature as highlighted by Aldo Rossi in his introduction to Boullée's *Architecture, Essay on the Art*. The research on light and shadow in architecture, as understood by Boullée, is firstly insert in the field of observation of nature where the architect finds the compositional principles for design activity.

Looking to the works by Le Corbusier, it is possible to recognize this kind of sight that concerns in an admirable synthesis the scientific and poetic aspects that today still represent a milestone in architectural panorama. In order to understand this synthesis, the Tower of Shadows represents a very clear *manifesto* from which it is possible to start to read other important experiences by Le Corbusier and, generally, a way to face this magnificent argument that fascinates architects from the beginning of times. This kind of analysis of the works – in this case some Le Corbusier works – could be didactic for students because they surely face, more than what is done, a return to the nature, in a changed world where *le condition de la nature sont retrouvèe* [3].

9.2 Results and Discussions

9.2.1 The Tower of Shadows, Chandigarh[1]

One of the building within *La Fosse de la Considération* in Chandigarh, a complex of demonstrative buildings, is the Tower of Shadows. The denomination "tower" does not correspond to the real character of the building. This name finds an ancient reference in the Tower of the Winds in Athens, and it can be compared to the tradition of Indian's astronomical buildings. It is made by reinforced concrete, and it is composed of two parts with squared bases. Its four sides are oriented toward the cardinal points, but just three of them are built, on east, south, and west while the north side is unbuilt.

The tower of Chandigarh stages the theatre of shadows in architecture. The upper part is rotated toward northeast, southeast, southwest, and northwest, and inside the building is completely empty and is occupied just by structural elements, nine circular pillars. The lower part, 15.5 m side, is divided by height, with a 2.26 m of

[1]About the *Tower of Shadow*, the author of this paper participated in the conference *Cities in Transformation* on June 2012 starting from the results discussed during his Ph.D in architectural composition in Politecnico di Milano. From the proceedings of this Conference: Perego [6].

span, with three levels of horizontal planes measuring 1.55 m depth and on which the *brise-soleil* are posed according to clear relationships. The characteristics of the *brise-soleil* depend to the orientation.

On the east façade, the vertical elements on every floor seem like concrete blades rotated of 45°. On the south side, instead, the vertical elements have just the function to support the horizontal planes. On the south, differently to east and west side, Le Corbusier inserts another level of horizontal planes that have the role of shielding the sun in the hours around noon. The shading elements on the west side, very similar to the east ones, present a different inclination in order to protect more the inside from the hot sun in the afternoon during the summer season. They are a real barrier for the sun. Le Corbusier, according to his proportioning method, decreasing the size of the *brise-soleil* and their mutual distance, aims to highlight the strong relationship between the single element (the *brise-soleil*) and the general design of the façade. In order to determine the shape and arrangement of these elements, Le Corbusier used the typical tools of representation of our own discipline, through the elements of descriptive geometry and of the theory of shadows. Nowadays with the progress in the field of informatics, verifications once carried out by hand can be more precise thanks to some software that output a virtual image of the project in relation to the natural conditions of the place where it is in. Thanks to these new possibilities, the author of this chapter has carried out some simulations in order to understand the reasons of the solutions adopted by Le Corbusier and also to grasp the critical aspects on this demonstrative building in Chandigarh. For the definition of these representations, the author followed an already known classical method in order to compare the conditions in three very significant periods: the solstices and equinoxes. For these comparisons, the author decides to use five different times of the day. Another important element to take in account is the geographical position of Chandigarh that is located with a short distance from the northern tropic. This fact provides a fundamental input about the solar passage at this latitude and gives a first indication about the position of the building in relation to cardinal points.

From the variation of the shadows on the winter solstice (December 21), the spring equinox (March 21), and the summer solstice (June 21), it emerges that during the coolest period, the vertical elements on east and west side allowed the light to illuminate and heat the inner parts of the building. Around the spring equinox, the average temperatures in the morning reach relatively high values, the days becomes longer than the nights, and when the sun approaches the zenith, the vertical elements and the horizontal ones exclude the solar radiations from the inner spaces. This configuration of the shading elements is adequate to this place. In fact, this system in a continental climate will demonstrate the inadequacy of such solutions where, in the middle seasons, spring and autumn, it is necessary to allow the penetration of light and heat inside the building in order to bring benefit in terms of comfort [4, 5].

In particular, the reasons why there are different inclination of the *brise-soleil* on the west side, more closed than the east façade, are also very important. The reasons for this closure are to be found in the phenomenon that has already been investigated relatively to the relationship between solar radiation and temperature. The heat load on the west is different compared to the east. The higher temperature in the

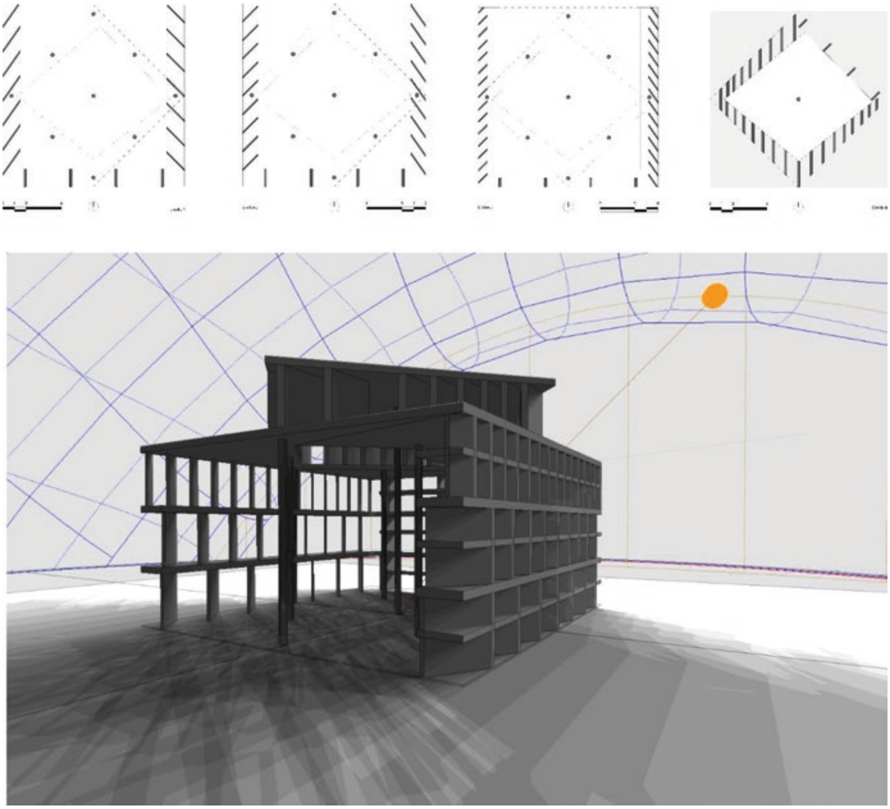

Fig. 9.1 The Tower of Shadows. Plans and 3D model studied with the solar path (By S. Perego, 2012)

afternoon together with the direct solar radiation creates a discomfort in the rooms facing west. It is therefore necessary to close more tightly the façade. This inclination, at such latitudes, provides also the refraction of the light that bounces between the *brise-soleils*, decreases its energy, and spreads in the inner parts, role also played by the horizontal *brise-soleil*.

The Tower of Shadows in Chandigarh represents an emblematic example in the studies of solar control and with its clear principles and reasons that are at the base of the relationship between architecture and nature (Fig. 9.1).

9.2.2 Palais de l'Association des Filateurs

The building in Ahmedabad built in 1954, in India, is one of the works that best expresses Le Corbusier's attention to the climatic aspects and the relationship with the elements of nature.

The concrete parallelepiped is located on the bank of the river that flows through the great city of northern India in an easily accessible place, in the middle of a garden. This choice allowed the association to meet in the assembly and to concentrate the administration activities within it. From the openings on the east side of the building, it was possible to see in the river the men immersed in water intent on washing clothes and collected cotton.

The building, also intended for various common and public activities, often in the evenings, was designed as a large space of significant civil value. The entrance to the building from the main north–south road is possible thanks to a large external staircase and a ramp that leads directly to the first level. The representative plan, with a major height than the others, is on the third level where an auditorium and a small café are located.

The supporting structure is in reinforced concrete, and the no-bearing wall has been made with local bricks that recall the buildings of Chandigarh whose construction is coeval with the building in Ahmedabad. In addition to some characteristic elements of Le Corbusier's work, there are extremely interesting solutions, especially those concerning the relationship with the climate and nature. Its situation and the architectural choices that derive from it depend very much on the relationship that the building establishes between the city and the river; for this reason, in fact, the opening of the east and west elevations, against a total closure of the north and south elevations (with a small exception for the south elevation), highlights the relationship between the city and the river (Fig. 9.2).

The east elevation is much more open and is made by vertical and horizontal elements in relation to the supporting structure of the building; the west elevation, on the other hand, is defined by vertical elements arranged with a smaller pitch (half compared to the step that structures the east elements) inclined at 45° to the façade.

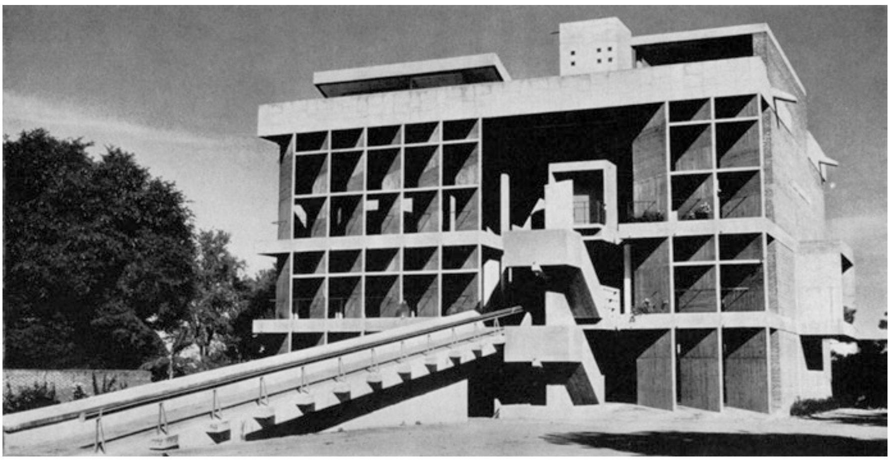

Fig. 9.2 Palais de l'Association des Filateurs

The city of Ahmedabad is located at the latitude of the northern tropic. The solar path corresponding to this latitude clearly shows that on the day of the summer solstice, June 21, the midday sun is at the zenith; the sun's rays are perpendicular to the earth's surface. In the period in which the sun takes the short path, *related* to the winter solstice, the inclination of the sun's rays with respect to the earth's surface is approximately 45°. The south wall of solid bricks is almost totally blind. This choice stems from the need to exclude to the direct solar radiation the parts of the building located in the southern part which, in the period from the winter solstice to the summer, would be exposed to a considerable amount of radiation that would make activities difficult. It is also possible to assume that this wall has the purpose of imprisoning the heat in the bricks of which it is built, to release it inside during the evening when the temperature drops considerably.

We have had already the occasion to underline, in general terms, the difference that exists between a façade facing east that is hit by the sun in the morning and one facing west that is hit by radiation during the afternoon. In these considerations, we find a further explanation of the different composition of the fronts. The most evident closure of the west elevation and the inclination of the vertical elements with respect to the east façade arise from the need to exclude direct sunlight during the afternoon but, at the same time, to ensure that they penetrate inside during the less hot periods of the year. The two different sunshade elements also differ in their depth. The *brise-soleils* of the west elevation are more than one and a half deeper than those to the east for the reasons already highlighted above.

The reinforced concrete grids have both, at the same level as the building's floors, basins with vegetable soil in which small shrubs are planted which, even if only minimally, contribute to the mitigation of sunlight. These solutions, now taken up as "modern invention," are present in the best experiences of modern architecture but, above all, proposed with criteria. Here, in fact, the humid climate guarantees the life of this vegetation; they have a reason for being here.

The inclination can also be explained with regard to interior lighting (it will be seen later in connection with the Unité d'habitation). The refraction that is generated thanks to their position and their clear colors causes an indirect light to spread in the large interior spaces. The solutions adopted by Le Corbusier for the two fronts depend at the same time, as well as on the relationship with the place, also with the climatic characteristics. First of all, the relationship is built with the prevailing winds. For the specific reasons of the area, there is a dominant wind that blows from west/southwest to east/northeast. The opening of the two fronts to the east and to the west guarantees the passage of the breezes that keep the internal parts always ventilated, guaranteeing an adequate control of the high temperature during the day. The narrow span of the inclined elements also has the task of decreasing the wind speed which would otherwise be annoying for the activities that take place in the building.

9.2.3 Two European Experiences: La Tourette Convent and the Unité d'Habitation

In 1951, the Dominican friars of Lyon under the guide of Father Couturier called Le Corbusier to draft the new convent project in Eveux-sur-l'Arbresle, 25 km from Lyon. The area is located on a small hill near a castle. Following the road beyond the castle, you reach a slight slope that opens toward the hilly landscape to the west.

The topography – therefore the position of the area and the elements of nature – together with the program studied together with the Dominican friars is for Le Corbusier the data through which to build their own project idea. It is a building that harks back to the architectural tradition of convents, not just Dominicans, of which Le Corbusier reinterprets the elements.

The friars' cells, around one hundred, are placed on the first and second level. The common areas such as the refectory, the library, and the meeting rooms are at the entrance level.

The levels of the cells are characterized by the loggias that crown the entire building on the east, south, and west elevations. The loggias are configured as elements applied to the body of the cells, a character also accentuated by the prefabricated elements which, presenting a rough surface obtained with the insert of river cobbles, put differences from the reinforced concrete surface behind.

Each cell, therefore, finds its extension in nature thanks to the loggia by identifying a portion of it. The connection with nature is sought inside a visual relationship, unlike what we find, for example, in other religious places where this relationship is physical. If we look at the Certosa di Pavia, each cell has a small vegetable garden. This relationship is certainly also due to the Cistercian rule in which the prayer alternates with manual work on nature. In the same way, Eveux's cells are a small world that, thanks to the loggia, framed a portion of nature. This fact constitutes the character of this important building.

The only element that separates the loggia from the cell is the glass partition with a wooden structure, whose elegant design strictly depends on the daily gestures that are performed inside: study, prayer, and rest. The loggia is also a solar control element. It is an element that we often find in Le Corbusier's work, as we will see in the Unité d'habitation. It is also true that this characterizing element does not always take on a positive role in terms of solar control. In the convent of Eveux, the loggia is present indistinctly on the three elevations and with the same characteristics. It thus confers a unity on the whole building as happens in the Unité, where the loggia gives shape to the elevations. However, we are aware of the fact that the thermal load deriving from solar rays is not always the same on the different exposures. An east elevation does not receive the same solar radiation as that to the west even though, with a geometric approach to a solar paper, we would be inclined to consider the two identical exposures. This deduction would be true if we consider just the light. But, considering the thermal aspect, we cannot reach the conclusion that

Fig. 9.3 Le Corbusier, La Tourette. Light in a cell. (By S. Perego)

the two exposures are equivalent. The cells to the west – in addition to being 43 cm wider than the rooms to the south and east (because there is space for the library that the students do not have) – in summer are overheated due to the incidence of solar radiation whose inclination is such that the sun's rays penetrate into the loggia up to the innermost part of the cell (Fig. 9.3).

This situation, it is clear, is related to a limited period of the year, corresponding to the warmer one and is a negative aspect. La Tourette convent is located in a very windy area and takes advantage of its position to cool, even in summer, thanks to the light breezes that are generated between the forest and the valley. This aspect has been the subject studied by Le Corbusier, who was very fascinated not only to light control but also to ventilation in buildings. Each cell, by the way, has two vertical wooden doors that give one on the loggia and the other in the corridor leading to the rooms. Their reciprocity creates, when these are open, inner micro-ventilation that has the task to cooling the air and allowing to change it.

A different reflection is instead to be made on the common parts. They are identified by a glass wall marked by vertical concrete elements; the common rooms, the rooms for lessons, the chapter room, the library, and the refectory are thus defined. They are located in different parts of the convent, each with its own specific reason. Take the refectory as an example. It has its largest side, completely glazed, toward the splendid view of the hills of the countryside of Lyon.

The orientation is west, with a slight inclination to the north. On the façade of the refectory, as is well known, many discussions have taken place concerning the scanning of the vertical parts which coincides, as is known, with a musical composition by Xenakis. Almost nothing has been said from the energy point of view. This fact, as it is easily understandable, generates microclimatic differences, in the same refectory, in the different periods of the year. If in the spring season, the conformation of the façade guarantees a slight increase in the temperature inside the refectory; in the summer, it generates a greenhouse effect that is not easily controlled. Not so much the steel-tilting elements makes for the air circulation, in relationship with the same elements placed on the glass façade facing the inner courtyard. In this, La Tourette certainly presents a problem that today – in front of a climatic condition characterized by overheating in progress – should be solved and that indicates a way that today can no longer be pursued. In a similar situation, today, there would be those who would close that façade with a low-emission glass. Others, instead, following a purely architectural process, would study the possibility of managing the large window with specific elements. And it is not to be excluded that Le Corbusier, in the face of energy problems, would consider that solution again.

The considerations made so far in one of Le Corbusier's most didactic and best-known buildings, as Aldo Rossi pointed out in the article published in 1960 on Casabella, do not aim to diminish its scope and architectural quality. Here, we want to "indicate in Le Corbusier's work a connection of very important and truly modern problems." In the overall framework of the choices, it represents one of the best works of Le Corbusier, also and above all for that sought-after relationship with nature, which will also be found in other works by Le Corbusier, for example, the Unité d'habitation.

The orientation of the building in Marseille, as well as for the different units designed and built, is north-south. The apartments therefore face their largest share to the east and west. In addition, in the southern portion of the building, there are other apartments that follow a similar conformation of the accommodations located on the east and west sides.

The building section clarifies the entrance and joint system of the apartments, as well as highlighting the organization of spaces and services: the position of the bathrooms and kitchens, located in the center of the house, is shown as a rational solution that leaves the relationship with the exterior mediated by the loggia to the living room and bedrooms. The apartments are on two levels with an internal staircase that guarantees the connection between the parts of the house. The distribution, rationalized thanks to the ingenious system of joints, takes place through the corridors. Both the apartments represented in section have therefore a double exposure to east and west, articulation that it is possible to recognize also in the composition of the elevation. This composition generates double-height parts where living rooms and kitchens are located, environments that require a greater amount of light for a very long period of time.

Le Corbusier's research on illumination is represented by some interesting diagrams entitled *Ensoleillement de la cellule*. The principle of the *brise-soleil* is to stand respect to the winter and summer solar path, guaranteeing for the first the penetration of the sunrays into the depth of the housing and for the second the shelter from the summer sun rays. At the famous section sketch, Le Corbusier supports a scientific drawing with which he demonstrates the characteristics of the loggias in relation with the solar paths of the solstices and equinoxes in correspondence of these with the domestic environments of which they are the extension toward the outside. The double-height parts of the house correspond to a loggia, which is also double-height, interrupted by a horizontal element in reinforced concrete which, in addition to bringing back the internal height of the loggia to a value that can be found in the internal heights of the apartments and to give it such a dimension as to define a cosy place, of rest and reflection, has the task to shield more in the summer periods.

La forme tubulaire of each Unité apartment, which has a width-to-depth ratio of 1:5 (excluding the loggias), together with the double-facing east–west, generates, at different times of the day, soft air movements accentuated precisely from the narrow and elongated shape of the individual dwellings. The principle is proper of the fluid mechanics; in fact, the air moves from a warmer point to a colder one. The lecorbusierian scheme shows how the difference in temperature of the air in contact with the surface hit by the sun and that of the air in contact with the shaded surface generates the phenomenon described above.

In addition to ventilation, internal lighting is also guaranteed, thanks to the shape of the individual housing units, even in the most central parts of the home such as services. The close relationship between the white side walls of the house accentuates the reflection of the light that comes thus also in the points far from the lodges.

The search for this phenomenon is all centered around the morphological type choice of the Unité. This aspect is not trivial because it further highlights how aspects of solar control and ventilation already belong to architecture in the initial reflections. The work and the research by Le Corbusier have in this a profound educational value because they still outline a valid path of research capable in front of the nowadays problems (Fig. 9.4).

9.3 Conclusions

Among the few studies on the *Tower of Shadows*, a small book by Francesco Venezia published in 1978 represents a significant reference for this short chapter. The approach proposed here moves, unlike those years, from the need to face the question of the relationship with the sun in the face of a constant removal of architecture from the natural elements, in particular for the consequences that this loss means in terms of energy consumption that correspond to a general flattening of the architectural characters and, generally, a flattening related to the design process.

The research carried out in the Architectural Composition PhD course is in continuity with the study of Francesco Venezia [7] investigating in more depth what the Tower of Shadows offers with respect to the questions concerning the good orientation of the buildings in order to guarantee suitable conditions of living. These aspects are known and investigated by Le Corbusier over the course of his long theoretical and architectural production.

The opportunity to publish these studies allows me to underline an inseparable relationship between *architecture of real appearances* as Venezia calls it and the studies on solar orientation of energy derivation. The Tower of Shadows stands as an emblematic and clarifying experience that permit to understand, as I tried to do

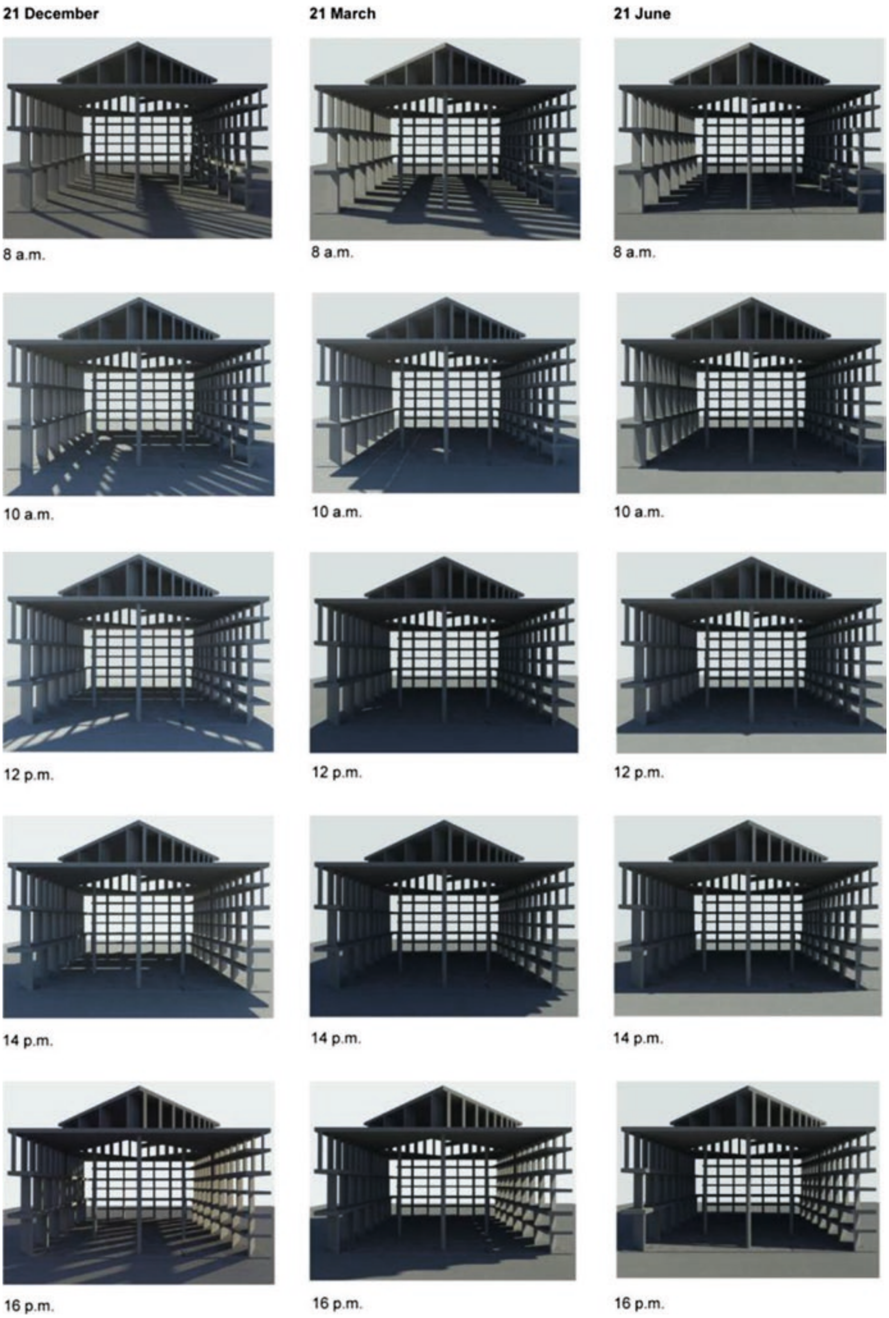

Fig. 9.4 Tower of Shadows. Winter Solstice, Equinox, Summer Solstice. (By S. Perego)

in this small text, the architectural reasons of other buildings, not only designed by Le Corbusier. On several occasion of discussions, the attention to the aspects of energetic nature and more generally to the sustainability in architecture has been read as a *positivist* approach referring with this definition to the criticism moved to the studies of the modern movement on the theme of orientation. Today's challenge is to reach the synthesis mentioned earlier.

References

1. H Focillon, Vie des formes. Parigi: Ernest Leroux, 1943; transl. it., *Vita delle forme*. In Id. *Scultura e pittura romanica in Francia*, ed. by S. Bettini, (Einaudi, Torino, 1972)
2. E.N. Gombrich, *Ombre* (Einaudi, Torino, 1996)
3. L. Corbusier, *OEuvre complète 1910-69* (Les Editions d'Architecture Artémis, Zurich, 1986)
4. A. Olgyay, V. Olgyay, *Solar Control and Shading Devices* (Princeton University Press, Princeton, 1957)
5. V. Olgyay, *Design with Climate: Bioclimatic Approach to Architectural Regionalism* (Princeton University Press, Princeton, 1963)
6. S. Perego, Solar control in architectural composition, in *Cities in Transformation*, ed. by M. Bovati, M. Caja, G. Floridi, M. Landsberger, (Il Poligrafo, 2014)., ISBN: 978-88-711-5829-7
7. F. Venezia, *La torre d'ombre o l'architettura delle apparenze reali* (Fiorentino editrice, Napoli, 1978)

Chapter 10
Sustainability and Energy Efficiency Design in Hospital Buildings

Fani Vavili and Artemis Kyrkou

10.1 Introduction

Hippocrates, about 2500 years ago in his work called *On Air, Waters and Places*, highlights the connection and the effect of the physical environment and the climate on health of all living organisms (plants, animals and humans) [1]. Starting from the ancient times, a historical overview on the "ecology" of hospitals is a rather interesting topic. It appears that hospitals in ancient times and sanatoriums later on are not found in natural environment by chance, but the location was carefully chosen under the criterion of exploitation of favourable parameters of the natural environment [2]. The ancient medical world was unaware of the causes of many diseases and attempted to ensure for their hospitals the best possible environmental conditions.

This trend continued until the discovery of the causes of communicable diseases. Currently, the wide knowledge and vast technological advances in the medical field have resulted in a tremendous interaction of multiple factors on the design of hospitals in order to simultaneously satisfy the complex needs of users and staff. In addition, the use of new materials and technologies implies new problems as the

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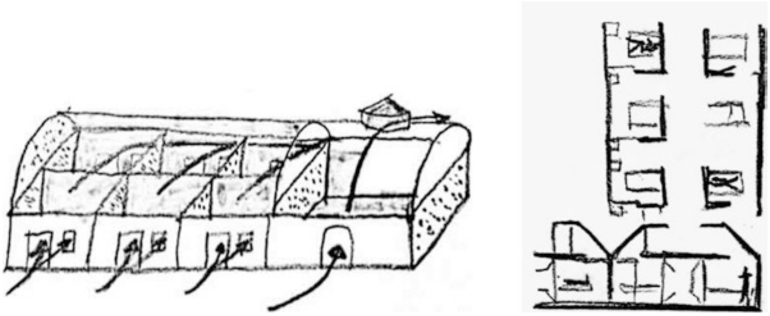

Fig. 10.1 Hand sketches by A. Kyrkou based on Thompson and Goldin (1975, pp.56–57), layout and isometric of Salpetriere pavilion by architect Francois Viel (left) and on the Le Corbusier "Venice Hospital" 1965 (right)

so-called sick building syndrome.[1] Among the symptoms (way finding, growth and change, institutionalism, etc.) of a poor hospital environment are natural light, ventilation and sustainability techniques. Ironically, very often hospitals are the sickest buildings, considering production gasses and CO2, engagement with the surroundings and the local environment, material use, recycling, etc. Presently, we are the first generation that will hand the planet to our children in a worse condition than we inherited it. Buildings generate 48% of the CO_2 emissions that are creating disorder in the ecosystems, and hospitals are among the most unsustainable buildings [3].

The ancient approach for the healthcare settings could be compared to the present holistic approach of health that has gained many followers in everyday life and its impact in modern architecture. "Health" is presently pursued in everyday human expression, and its meaning has changed tremendously over the years, starting from seeking the "healthy" way of living to a "healthy" built environment that consists of "healthy" buildings [4]. Healthcare architecture today is utterly affected by all this shift of meaning. The past decades the public face and the role of the hospitals have gradually changed a lot to more friendly (both to users and the environment) and patient-centred places that offers with respect medical care in a supportive and healing environment. Therefore, nowadays, in order to have a more complete and correct view when designing modern healthcare buildings, an interdisciplinary approach (apart from architects, civil engineers, energy planning specialists, doctors, psychologists, financial healthcare managers, etc.) is considered to be mandatory (Fig. 10.1).

[1] The sick building syndrome (SBS) describes the condition that occurs when a number of a building's occupants have a constellation of nonspecific symptoms without a specific identifiable cause including nausea, headaches, dizziness, skin irritation, etc. These symptoms should be temporally related to being in the building, resolve when the person is not in the building and be found in a number of individuals within the building. Although it is not exactly clear what causes the SBS, it is probably due to a combination of factors including poor ventilation (e.g. poorly maintained air conditioning system), indoor air quality and lighting quality. The SBS is common in open plan-type buildings (e.g. offices), but one can get it in any other building type.

10.2 Defining Sustainability and Energy Efficiency in Modern Healthcare Buildings

In the context of healthy living and due to the environmental crisis and the unpredictable climate change, sustainability is considered to be a strategic priority, especially for the European "Energy Union" [5] that promotes as first principle "energy efficiency". The term "sustainable" describes [6] methods that do not harm the environment so that natural resources will still be available in the future, and therefore "sustainability" (especially sustainable development) refers to meeting the needs of the present without compromising the ability of future generations to meet their needs. In a few words, it is necessary for us to be thoughtful with the resources currently available and not deplete them for generations of people beyond us. Resources, both renewable and non-renewable, must be carefully considered in sustainable development models.

Energy efficiency refers to the amount of output that can be produced with a given input of energy. However, other kinds of output can also be used. The EU Energy Efficiency Directive uses a very broad definition: "energy efficiency" means the ratio of output of performance, service, goods or energy, to input of energy [7]. An important parameter for energy saving in the buildings sector is the high efficiency of the energy infrastructures [8], which requires excellent quality of the relevant equipment installed, as well as the compliance with all the requirements set by the legislation. Particularly in hospitals, energy-saving measures can play a significant role for lowering energy consumption and energy costs, as well as for environmental protection.[2] Hospitals are the ideal buildings to learn from about energy saving due to their 24-h continuous operation (e.g. 24-h need for lighting, heating, air conditioning and electricity consumption), the big surface of the buildings, the need for hot water, thermal comfort, sterilization supplies and energy-consuming machines and equipment. Pilot studies and practices of the past have presently given architects a large area and enough data for rethinking and re-evaluating hospital design priorities.

Over the past years, many design guidelines and strategies for energy-saving methods have been published and applied to newly built healthcare facilities and in major renovation healthcare projects. Energy-saving measures can be applied to either the shell of the building or at the electromechanical installations; the main energy-saving measures are divided in three basic categories regarding the investment[3] [9]:

[2] Energy consumption is responsible for the CO_2 emissions to the atmosphere that contributes to the "greenhouse effect".

[3] Based on the energy consumption of the building (e.g. shell, heating, lighting, etc.) and on the investment that is required for their implementation.

- Simple measures that do not require special financing or capital investment (often related with the change of behaviour of the users of the building or the maintenance of the building)
- Low cost measures (e.g. actions that are taken once and financed by the administrator of the building – their cost may often be returned to the investor within the same administrative year and usually in less than 2 years)
- Reconstruction actions (measures that require capital investment, and usually a techno-economic study is needed in order to examine the viability of the investment)

A number of architects over time have created their own idea on the way architectural and interior design can influence the healing process of the patients. Powell and Moya's Wexham Park Hospital, (Slough, 1965) is a horizontal layout hospital (plus the administrative tower) known for its human scale, due to the architects' conviction that a hospital – as a building itself – has the duty to provide psychological support to patients, staff and visitors. Additionally, the horizontal hospital (the wards, arranged around lawns with natural light and ventilation, were in one-storey pavilions) reduces vertical movements and the dependency to elevators (Fig. 10.2). The teaching hospital at Aachen has a different design approach, as a known example of a flexible and technically adaptive building, able to expand by creating simultaneously a unique morphology for healthcare buildings [10] (Fig. 10.2).

The control of the energy consumption and the high operating costs of acute care hospitals, since the 1970s, has been a high priority in the USA, the UK (NHS), and other countries. The case of St Mary's Hospital, Isle of White, UK, in 1991, is an early important project of such an approach. Designed by Ahrends, Burton and

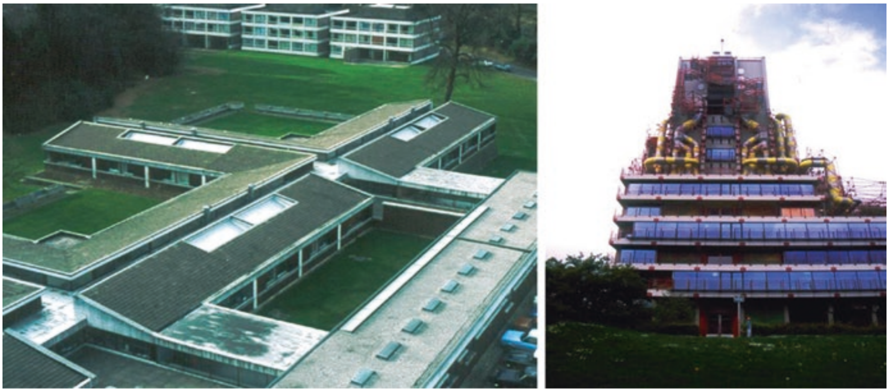

Fig. 10.2 At Wexham Park Hospital by Powell and Moya (1966), the natural landscape and sun played a significant role in the overall design of the hospital. The horizontal layout of the hospital was based on the concept for each patient to have access to natural light, ventilation and interesting views. On the right, the teaching hospital of Aachen, in Germany (in the 1980s designed by Weber and Brand), is a remarkable paradigm of the huge industrial part of a hospital – showing its bulk energy needs. The extensive visible pipes at the hospital's facades formulate an industrial morphology (high-tech architecture) of the building, reminding an oil refinery. (Photo: F. Vavili)

Fig. 10.3 At St. Mary's Hospital (1991), ABK architects, Isle of White, UK, the sustainable approach (low energy) played also a fundamental role on the facades of the building and the overall exterior appearance of the hospital. (Photo: A. Kyrkou)

Koralek (ABK) Architects, it was considered to be the first hospital of "low energy" or "low operating cost" based on control of all design parameters by computer systems (Fig. 10.3). In this hospital of 17.400 m^2, a 50% savings in fuel was achieved since the third year of operation. The radial plan minimizes the basic amenities and transport routes of heat from the central unit. The design includes (1) integration and control of heat generated naturally, (2) lighting and ventilation with the introduction of heat recovery systems from air and water and (3) use of energy management techniques to ensure the maximum benefit (with proper operation of these systems). A strategy based on convenience, safety and cost of maintenance of the building and the systems was considered as an essential part of the design. Furthermore, the above choices created unique facades, so one could say that this sustainable approach played a fundamental role in the exterior look of the hospital building.

On the other hand though, according to a recent research project (2014) that was supported by the Norwegian Research Council (NRC) [11] about low energy hospitals and how they could reduce the energy uses by 50%, the activity data clearly showed that hospitals are not operated 24 h 7 days a week. Only a small percentage of the floor area is used around the clock, and more than half of hospital area follows normal office hours. Even during active hours, the simultaneous occupancy level was relatively low. This activity demand was not reflected in the energy data, which showed a large and continuous baseload for electrical and ventilation energy. A review of the design data confirmed how hospitals differ from all other building categories: (1) larger interior from hospital-specific equipment using high-value electricity, whose waste heat also demands cooling energy, and (2) large ventilation demand coupled with lower rate of heat recovery due to unnecessarily strict hygiene requirements. The research conclusion was that hospital equipment and ventilation designs did not allow energy supply to follow the actual demand from activity and that the reduction potential is about 50%, so activity modelling was proposed as an integrated design method to evaluate new designs for demand control of hospital equipment and ventilation energy. According to the WHO, in hospitals, the use of alternative forms of energy, such as solar panels, wind turbines and energy-saving lamps, and organic food supplies from local producers are expected measures in order to become more environmentally friendly buildings.

At this point, the parameter of the local climate has to be stressed as a crucial indicator for the overall design of the hospital building and the choices of the energy saving measures. Some countries – being pioneers in hospital design studies – realized that the climate change has utterly affected the temperature variations and that healthcare buildings have to adapt to this new reality. For example, in London, where the weather during the summer is relatively cool, it is concluded [12] that thermally lightweight, well-insulated, naturally ventilated hospital wards can be using low energy but are at risk of overheating in the summer conditions, and this needs to be addressed before such buildings can be recommended for wider adoption. At Evelina London Children's Hospital, the atrium area is covered by a glass curved façade that, due to the big free interior height, acts as a natural ventilation mechanism for the hospital, which adds in energy saving (Fig. 10.4). Unfortunately though, during the summer of 2006, due to the extreme and unpredictable temperature changes, the temperature was so high in London, and because there was not a mechanical air conditioning system in the atrium area, the high temperature was spread to the whole hospital building, exposing patients to danger [13]. Accordingly, at the overall design of Great Ormond Street Hospital (GOSH) hospital in London (Fig. 10.4), the part of the glass building volume offers a buffer zone (from the sun heat) that simultaneously helps in the ventilation.

The interaction between buildings, climate and functional activities is diverse, variable and complex manifestations of relatively simple physical processes – heat transfer, fluid dynamics and radiation interchanges [14]. Some basic elements of a climate-friendly hospital are based on:

- The reduction of hospital energy consumption and costs through efficiency and conservation measures
- The construction that responses to local climate conditions and is optimized for reducing energy and resource demands
- The production and/or consumption of clean, renewable energy on-site to ensure reliable and resilient operation

The local climate in combination with the unique characteristics of the local natural environment (e.g. amount of sun, wind, local greenery, etc.) can also play a fundamental role in hospital design and energy efficiency. At Meyer Children's Hospital in Florence, Italy, at the atrium area, the façade is covered with a unique type of curved glass with attached micro-solar panels that help in collecting energy but also acts as a buffer zone and perfect insulation area for the rest of the hospital

Fig. 10.4 On the left, the curved glass roof of Evelina London Children's Hospital that due to the absence of mechanical air conditioning system and the high temperature during in the summer of 2006, the whole hospital building was overheated, putting patients in danger. On the right, the glass building volume of Great Ormond Street Hospital in London helps in the ventilation of the hospital and simultaneously reduces energy consumption. (Photos: A. Kyrkou)

Fig. 10.5 At Meyer Children's Hospital in Florence Italy, the "greenhouse" atrium area and the detail of the micro-solar panels that are attached on the curved glass façade on the left figures help in energy saving. On the right, the solar tubes that offer natural sunlight in the interior spaces. (Photos: A. Kyrkos)

building during winter (Fig. 10.5). Moreover, due to the unique local environmental characteristics and – more specifically – the amount and the quality of sunlight, a unique way of using the natural light was created on the green roofs of the hospital. Forty-seven "Pinocchio hats", as they are called, dot the roof (Fig. 10.5) – these are actually solar tubes that feed natural light into the building. The complex was developed under the European Union's Energy Program and has successfully reduced its energy consumption by a whopping 62% for HVAC and 80% for electricity compared to a typical hospital [15]. Also, the surrounding greenery of the Florentine landscape played an essential role in the use of glass (for interesting natural views), the creation of the greenhouse area ("serra" in Italian) in the main reception, the atrium area and the overall design of the hospital.

In a typical Mediterranean local climate, a unique attempt was made in Papageorgiou General Hospital of Thessaloniki, Greece. Its design focuses on energy saving and bioclimatic strategies. Due to the Mediterranean sunlight, there was a special research that focused on the hospital's microclimate in combination with the lighting and the ventilation systems. Window test models, 1:1 in scale, were assembled and examined in the actual conditions (orientation, sunshine, rain, wind, etc.) of the hospital site, in order to have the best possible results in shading, functionality and interior temperature. The microclimate of the building, the interior lighting, ventilation and temperature were all subjects of deeper scientific research and design focus. The lighting result of this research has ensured that in the patients' wings, there is enough natural light (from 9:00 to 17:00), which is also due to the building's orientation. A combination of natural and artificial ventilation and lighting was applied in all patients' rooms. The operable windows of the room have a very discreet safety lock (Fig. 10.6), so in this way, fresh air flows directly into the room [16]. At the same time, the operable upper part of the window, in combination with the window on the upper part of the patient's room door, and the ceiling fan help in renewing indoor air and providing thermal comfort to the patient. Inside the room, a transparent surface on the wall made out of glass bricks helps in giving more light to the bathroom during daytime (Fig. 10.6).

International design competitions presently include design requirements for sustainability and energy saving – especially for hospitals. Recently, the architects from Henning Larsen Architects recently won a design award for a hospital pro-

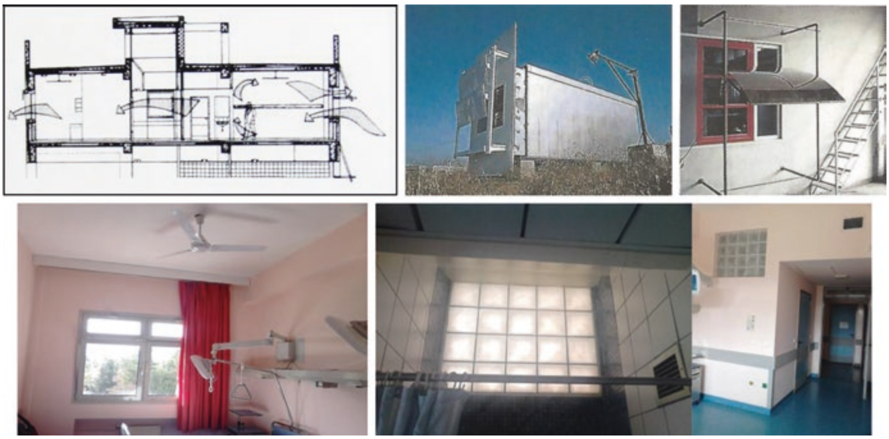

Fig. 10.6 The ventilation and lighting of the hospital were an important parameter in the design process of Papageorgiou General Hospital (1999), Thessaloniki, Greece. (Photos: A. Kyrkou)

posal of low energy consumption. Their architectural proposal of the new University Hospital, Odense (OUH), Denmark, will be built near the city centre in a picturesque old forest with dense vegetation, for the effective treatment of its patients offering views of the magnificent countryside as the buildings of the hospital are clustered in a circle. The whole installation integrates nature in every opportunity so as to create an environment that will be dominated by peace and tranquillity. The glass skin of the hospital buildings is also used to collect rainwater, enhancing the water of the lakes of the region and surrounding croplands. It should be stressed here that ecology in modern architecture is also an important design parameter as in the OUH project. The Nuovo Ospedale di Mestre by E. Ambasz (2008) in Venice is another characteristic project where glass has a leading role. The 660-ft-long southwest facade, dubbed the "glass sail", consists of 11,000 trapezoidal panes of different dimensions, held in aluminium frames over a grid steel structure. The main aim is to save on energy by making the most of natural ventilation. Seven hundred mechanized openings, connected to temperature sensors, are placed at the bottom and top of the glazed facade. In all of the patient rooms, full-height window walls are fitted with a "smart glass" system that regulates ventilation and heat dispersion. The windows not only suffuse the rooms with natural light but allow patients to look out on the atrium's palm trees or the cotoneaster and yellow primrose on the exterior balconies.

According to NHS and SDU,[4] the key area for action is on energy saving and carbon management. More specifically, it is suggested that each agency:

– Should review its energy policies and carbon management at the board level
– Increase the use of renewable energy sources where appropriate
– Make measurements in order to monitor the building throughout its life cycle based on cost
– Ensure proper behaviour by encouraging each user of the facility and the entire organization (hospital)

10.3 The WHO Calls for More "Green Hospitals" and the Quest for the ZERO Waste Hospital

According to S. Verderber, since 2008, when the global economic crisis begun, hospitals were the first buildings utterly affected by it [14]. "Green design" consists of modern design guidelines that are friendlier to the environment and aim in minimizing the negative consequences of it. In this context, energy saving and renewable energy sources are design strategies that support this goal. Green design principles

[4] Sustainable Development Unit was established in 2008. The Unit is jointly funded by, and accountable to, NHS England and Public Health England to ensure that the health and care system fulfils its potential as a leading sustainable and low carbon service.

are usually taken into consideration from the very early stages of design based on the following [15, 17]:

– Careful site selection (close to an existing road network, future expansion) for appropriate transportations to/from (and in) the hospital building
– Use of environmental-friendly or local building materials
– Respect the existing greenery or enhance it by replanting after the construction
– Incorporate the local natural characteristics (sunlight, wind, humidity, temperature, etc.) by the use of renewable energy sources, control of the use and the disposal of the water in order to minimize the carbon footprint of the building

Also, in several hospitals, the design focuses on flexibility in order to save energy and running costs [17]:

– Of the structure, to allow interior changes with minimum disruption
– By grouping of similar functions (e.g. patient's and consulting rooms)
– By standardizing room sizes and minimizing room types

Ideally, according to the WHO [18, 19], the quest for the time being is the "zero waste hospital"; but still hospitals and healthcare facilities are a major source of pollution and should be involved in the battle against climate change. M. Neira, the director of the Department of Public Health and Environment of the WHO, states that in many countries, the health sector ranks second in the use of coal as an energy source, along with very high energy consumption. Moreover, on a recent WHO report,[5] it was stressed that the emissions from hospitals, health centres and ambulances increase the number of cases of asthma and other respiratory diseases, contributing to the increasing numbers of visits to emergency departments. In some countries, the consumption of electricity for healthcare buildings increases the annual running costs. In the USA, for example, it rises at more than 600 million US dollars in direct costs and more than 5 billion in the indirect costs.[6]

Recent hospital design projects from around the world focus also on the so-called bioclimatic design. These design attempts are influenced by certain parameters such as local economies, social priorities, etc. It is interesting to look at the philosophy of the design awards of the Aga Khan Foundation (https://www.akdn.org/). The awarded projects focus on sustainability and energy savings (e.g. use of local materials and building techniques, environmental-friendly approaches, etc.). These factors are the basic criteria of the jury.

The awarded Salam Centre for Cardiac Surgery (2010) in Khartoum, Sudan (https://www.akdn.org/architecture/project/salam-cardiac-surgery-centre), is built as a pavilion in a garden with its primary buildings organized around large courtyards. The hospital block is of the highest technical standards with complex

[5] WHO. Climate change and health: resolution of the 61st World Health, Assembly. Geneva: WHO, 2008, pp. 27, www.who.int/gb/ebwha/pdf_files/A61/A61_R19-en.pdf

[6] WHO (2013). Healthy Hospitals – Healthy Planet – Healthy People, Addressing climate change in health care settings. A discussion draft paper published by the World Health Organization and Health Care without Harm, pp. 5.

functions (e.g. operating theatres optimally placed in relation to the diagnostic laboratories and wards). Mixed modes of ventilation and natural light enable all spaces to be homely and intimate yet secure. Additionally, the architects seeing the abandoned containers that were used to transport construction materials for the Salam Centre for Cardiac Surgery were so inspired by them that they reused them to house the centre's staff. It is important to mention that insulation is provided through a system of 5-cm internal insulating panels and an outer skin of bamboo blinds. A solar farm powers the water-heating system (https://www.akdn.org/architecture/project/salam-cardiac-surgery-centre).

Another awarded healthcare facility, the Lepers Hospital in, Lasur, India (1995), designed by Brynildsen and Jensen, is also of great interest (https://www.akdn.org/architecture/project/lepers-hospital). Its rectangular plan, bounded by continuous linear buildings, encloses a courtyard conceived as a "paradise garden". Indigenous materials were used throughout: barrel-like vaults of brick, concrete beams for the walls, floors and windows of stones and finished roofs of white glazed tiles that reflect the sun's heat. The jury of the Aga Khan Award commended the architects for creating "an attractive and friendly sheltering enclave, within a barren and hostile environment. Out of minimal architectural form, they devised a design of simplicity that radiates calmness", together with sustainability in mind.

10.4 Hospitals in the Future and Necessary Design Needs/Goals

Summing up, some of the main design needs and goals regarding sustainability design of existing and future hospitals buildings are [4, 18–22] as follows:

- Creating "out-of-the-art" healthcare building in the current conditions.
- Regarding the existing building stock and the current resources, the operational costs need to be checked continuously at all levels.
- Implementing regulations but always under critical evaluation and constant update according to present conditions and the rapid technological advances.
- Existing hospitals are required to adapt to the current energy saving needs, or they will or close.
- The viability of the hospital as a building type will be based on sustainability aspects (human and ecological), advances in planning, design technology and aesthetics.
- Creating design proposals that are sensitive towards the landscape and the natural environment.
- Respect for the local climate and the local characteristics of the context.

Fig. 10.7 On the left, the exterior panels show the world during creation, probably on Third Day, after the addition of plant life but before the appearance of animals and humans in the triptych painting "The Garden of Earthly Delights" by Hieronymus Bosch (1410–1510), oil on oak panels, Museo del Prado, Madrid. (Figure source: Wikipedia (public domain)) https://commons.wikimedia.org/wiki/File:Hieronymus_Bosch_-_The_Garden_of_Earthly_Delights_-_Garden_of_Earthly_Delights_%28Ecclesia%27s_Paradise%29.jpg

Many efforts[7] (e.g. conventions, meetings, lectures, presentations, etc.) and symbolic actions (e.g. Earth Hour) are made by global organizations and governments in order to tackle climate change, embrace energy saving and set new goals for a viable future. Hospitals, at the time being, are being re-evaluated as a building type due to the fact that they have a demanding functional program and require large amounts of energy and costs for their operation. Nevertheless, sustainability and energy efficiency – perhaps nowadays more than ever before – still remain one of the most contemporary, challenging design topics for architects, especially in hospital and healthcare facility design due to their necessity. Respecting the valuable natural resources when creating new healthcare buildings or transforming the existing ones according to the current environmental demands is mandatory, and it is our obligation to the generations that will follow. After all, earth with all of its "delights" has always been subject of inspiration, admiration and mystery, so it is our responsibility to preserve it that way (Fig. 10.7). It seems that the values of architecture are

[7] Even the sub-theme for UIA (International Union of architects) 2014 Durban congress was resilience which was explored through several focus areas. Resilience is defined as developed life strategies by communities, critical interventions that contribute to poverty alleviation and the important role of government and its investment towards the reconfiguring of the spatial economy to the benefit of all globally in order to find voice and solutions to problems within all forms of architecture and development practices. Some main focus areas were "ecology" time, evolution, systems, processes and environment, which are intrinsically linked to the concept of time in terms of diachrony, timelessness, preservation, energy control and climate change, as it considers processes of architectural production that acknowledges people and place and an understanding of cities as ecosystems and "values", with focus areas on architectural practice and education, in order to re-assess professional values, to interrogate the ethics associated to architectural and design practice and to establish a sense of respect through diversity and humility.

at a critical crossroad, and architects' creative approaches have to give a priority to the environment and consequently to energy consumption, materials, construction techniques and technologies.

References

1. Δ. Λυπουρλής, "Ιπποκρατική ιατρική", (Παρατηρητής, Θεσσαλονίκη 1998)
2. F. Vavili, A. Kyrkou, An overview of healing environments. World Hosp. Health Serv. Off. J. Int. Hosp. Feder. **46**(2), 27–32 (2010)
3. S. Prasad, *Changing Hospital Architecture* (RIBA Publishing, London, 2008), pp. 117–118
4. WHO, *Healthy Hospitals – Healthy Planet – Healthy People, Addressing Climate Change in Health Care Settings* (A discussion draft paper published by the World Health Organization and Health Care without Harm, 2013), p. 10
5. G. Erbach, *"Understanding Energy Efficiency", European Parliamentary Research Service (EPRS), Briefing, European Parliament* (2015), p. 2
6. https://dictionary.cambridge.org/dictionary/english/sustainable. 11 Aug 2019
7. G. Erbach, *"Understanding Energy Efficiency", European Parliamentary Research Service (EPRS), Briefing, European Parliament* (2015), p. 3
8. EPTA Ltd, *Guidelines for energy efficiency in hospitals*, "EMAS and Information Technology in Hospitals", LIFE04 ENV/GR/000114, pp. 2 (2007)
9. ibid., pp. 5–7
10. J. Willis, P. Goad, C. Logan, *Architecture and the Modern Hospital, Nosokomeion to Hygeia, Research in Architecture* (Routledge, 2018)
11. Norwegian Research Council, Activity modelling for energy-efficient design of new hospitals. Int. J. Facility Manag **5**(1), 1–17 (2014)
12. L. Fifield, K. Lomas, R. Giridharan, D. Allinson, Hospital wards and modular construction: Summertime overheating and energy efficiency. Elsevier, Build Environ J **141**, 28–44 (2018)
13. C. Hall, *Babies Swelter Off in 90F at New Hospital* (The Telegraph, Telegraph Media Group Limited, UK, 2006)
14. R. Burton, Emerging hospital design – Resource economics. Emerging approaches to hospital care and hospital architecture – Focusing on the development of hospital care and hospital architecture in Europe. Proceedings of Public Health Group, UIA, RIBA in the Pan Regional Conference of the International Hospital Federation, 20-23 October 1992, London, (1992) p. 5
15. R. Del Nord, *The culture for the future of healthcare architecture, Proceedings of 28th International Public Health Seminar, TESIS, 2009* (Alinea Editrice, 2009), p. 16
16. A. Kyrkou, Ventilation in patient's room. SMC magazine, Luciano Editore, Italy **3**, 34–37 (2016)
17. S. Verderber, *Innovations in Hospital Architecture* (Routledge, New York, 2010), p. 38
18. S. Prasad, *Changing Hospital Architecture* (RIBA publishing, London, 2008), p. 161
19. B. Hamoui, *Hospital 2020 – A Green hospital Conference* (H 2020.org, Chicago, 2015)
20. J. Karliner, R. Guenther, *A Comprehensive Environmental Health Agenda for Hospitals and Health around the World, Global Green and Healthy Hospitals* (Health Care Without Harm, Chicago, 2011), p. 2, 4, 9
21. F. Vavili, Guidelines and health care buildings. World Hosp. Health Care Serv. **39**(2), 24–31 (2003)
22. F. Vavili, *Aspects of Healing Environments* (ZITI Publ., 2009)

Chapter 11
Football Stadium: An Energy-Efficient Building and a Source of Renewable Energy for the Community

Radu Sfintes

11.1 Introduction

Football stadiums fall into the category of big-scale buildings, the construction of which assumes the allocation of substantial material and human resources, not to mention the resources consumed to keep them functional. Their role in and for local/regional/national/international communities is highly symbolic, and the experiences they shelter are meaningful at various levels. These are the main reasons that impel us to tackle the issue of sustainability on football stadiums through all its components – environmental, economic and also social sustainability – even when referring mainly to energy efficiency. The reasonable use of natural resources (as one of the aspects of environmental sustainability) considered in all the technical solutions adopted for architecture, structure and equipment may be more difficult to implement in the actual building phase given the scale of the object and the challenges and responsibilities it engenders (e.g. regarding the safety of tens of thousands of spectators). However, this only highlights the importance of implementing top sustainable solutions that reduce natural resources consumption and pollution while being functional, as well as advocating for sustainability and even helping the community/communities that are part of being sustainable. Economic sustainability is highly important not only as a way of cost saving or allowing economic growth but as a way of making sure that the investment itself is durable, that the building is being used efficiently at its full potential and, most of all, that it will not die with the potential death of its main function. Such decommission would have a great negative impact upon the built environment and the communities around it, one that they may not be able to recover from as long as even the demolition itself would entail too high costs (the most illustrative examples in this case are the Olympic venues in Athens and Rio). Social sustainability can assure the function of all the other aspects

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through use and meaning-making, but the simple existence of the building cannot guarantee its use or success. This is why we shall highlight the social significance of football stadiums for various categories of users in parallel with what the stadium itself can offer a community beyond the spectacle. The stadium can become a source of renewable energy and thus also contribute to raising the standards of living, to illustrating and, as we said before, advocating for sustainability.

A very good example of stadium which responds to sustainability issues, becoming an energy-efficient building and a source of renewable energy for the community, is *Kaohsiung World Stadium* designed by Toyo Ito & Associates, built in Kaohsiung, Taiwan, between 2006 and 2009. The stadium has a capacity of 40,000 seats. It is covered with 8844 photovoltaic panels which produce around 80% of the energy needed by the neighbourhood [1]. When the stadium is not used, the energy is sold, thus contributing to the reduction of CO_2 by 660 tons. Besides being one of the biggest stadiums that produce solar energy, it is remarkable also the fact that it has been entirely built with recyclable materials, all made in Taiwan.

This paper addresses the issue of energy efficiency in the case of football stadiums in relation to all the components of sustainability. The approach is multidisciplinary, and it takes into account various aspects that influence the implementation and success of sustainable solutions concerning energy efficiency by relating them to different categories of users. For this end, we follow the psychological and anthropological understanding of meanings along the history of the game and the stadium as both the game and the arena become important through the ideas of team play and access to the play.

An analysis of legislation helps us see how game rules and European norms and standards evolved and changed in order to align to contemporary values and norms of society – to inclusion, diversity, sustainability, etc. In the same train of thought, we debate the idea of football stadiums as energy-efficient buildings and propose different measures that address this issue in relation to the contemporary complexities of such a building.

From an architectural perspective, the general conclusion underlines the necessity of transforming the football arenas into multifunctional buildings, this having various implications beyond the arena and the spectacle itself. The necessity of proposing more and more varied spaces that would satisfy the different needs of the spectators is closely connected to the aim of bringing in and engaging a greater public. Beyond the financial implications, this relates to contemporary values of diversity, sense of community, security, accessibility (to leisure facilities), etc. Related and complementary functions contribute to assuring a unique and meaningful experience inside the sports arena for the spectators by offering various use possibilities before and after the game as well. This means keeping the supporters longer in the building, and given the great number of users it can accommodate, the sense of and conditions for security become the most important elements that need to be addressed. Football is also known for its quick-tempered fans – football hooligans – who alienated a general public from the sport, leading to a descending attendance tendency on the stadium. Making football a spectacle for the whole family thus means implementing safety measures for all categories of users, including children, and taking into account methods of achieving security like CPTED – crime prevention through environmental design. All these attributes – from proposing multiple functions inside the same space to making football a sport for the whole family – also extend the symbolic value of the building which becomes meaningful for various communities, not only for those of the supporters. For example, an energy-efficient stadium building can contribute to informing and educating the surrounding community about sustainability, sustainable systems and measures, sustainable use as well as become a source of renewable energy for the community, thus becoming part of the community itself not only through its landmark significance.

11.2 The Sport and the Stadium

Practicing a sport represented, in antiquity, a way of preparing for battle during peace times (the games associated with the Olympic Games). As the Greek sports competitions, "Roman spectacles were a public display of power, and that power was primarily military" [2]. In this context, acknowledging the importance of reaching a certain performance led to specialization (e.g. the gladiators).

This discussion highlights the importance of the sport and its arena, as well as the importance of spectacle and spectators. Down the centuries, we can identify, by analysing the evolution of different societies, significant transformations of the idea of a spectator, closely connected to the type of spectacle he/she attends – from spectacles addressed to the whole society to those which only members with a certain social status can attend or from organized to spontaneous shows. Contemporary society erases, in many cases, the barriers that stopped certain people from attending some events: the social class does not dictate anymore what kind of spectacles one can or cannot go to.

Referring to the game with a round ball, we cannot clearly state its place of origin, but the use of a spherical object since old times, on different continents, and with different rules demonstrates a possible independent evolution. Football itself passed through several stages and various changes in its evolution (like the emergence of professional players or setting the hours at which the plays take place, etc.). All these determined accordingly an evolution of the sports arena and of the spectacle. Modern football has its origins in the nineteenth century [3, 4]. Until then, we can speak of more or less different versions of this sport, practices in various spaces, with different game rules, the common element being the (empty or full inside) round ball.

The introduction of strict rules that separated one game from another,[1] the establishment of the *Football Association* in 1863 England and the establishment of

[1] The separation of football from rugby started around 1823

specialized clubs[2] laid the foundations of modern football. Setting a clear set of rules led to defining the characteristics of the play field as well as of the sports arena it would accommodate the game and its spectators, by responding to their specific needs and requirements. The avalanche of clubs set up immediately after the formation of the English *Football Association* led to a wave of constructions dedicated to football. Various types of sports arenas have been tested then, but few of them became models (e.g. White City and Highbury). The most notable typological difference is that between specialized stadiums (dedicated only to football) and sports arenas that could also accommodate other kinds of matches (rugby, American football, grass hockey, hurling, etc.) or other kinds of competitions (e.g. on White City athletics competitions, cycling races and dog races were also held).

In the interwar period, the use of arenas for various sports is supplemented, due to its flexibility and the great number of people it could accommodate, by using them for political gatherings: for recruiting new members in political parties [5]. These gatherings were accompanied by sports competitions before or after, thus becoming fancy spectacles. After the Second World War, in the area of the communist bloc (or in the case of totalitarian regimes), the space is also used to pay tribute to various leaders of the state. In order to hold political congresses, significant amounts of money have been invested in such stadiums, many of them being, nowadays, hardly occupied to their maximum capacity.

No matter how the stadiums were used, at a social level they always had a special significance, being spaces of discharge, of emotional release, but the fact that this release was more or less safe for the spectators makes it important to speak about the norms and legislation. In the following section, we shall highlight game-related legislation and specific sustainability issues, thus leading the way to demonstrating how the football arena can become an energy-efficient building and a source of renewable energy for the community.

11.3 Game-Related Legislation and European Norms

The tragic incidents that took place on football arenas especially in the second half of the 1980s, in different European countries, led to the introduction of various measures meant to limit the ways of expression on stadiums. By falling into the category of hooliganism, such behaviours made necessary the intervention of police forces to re-establish order and to assure the safety of the spectators. Thus, the measures proposed referred to supervising and controlling behaviour inside and outside the stadium, as well as to adapting the sports arenas to the new requirements of safety and security. In the context of responsibility for being sustainable, all these measures can and must also be related to European directives concerning sustainability and sustainability standards.

[2] In England we name: Arsenal FC London (1886), Manchester United (1878), Liverpool FC (1892); in other parts of Europe: FC Barcelona (1899), Real Madrid (1911), Juventus Torino (1923)

11.3.1 Reports and Game-Related Legislation: Impact Upon Design Norms

The role of design norms is that of satisfying the essential requirements in constructions and of responding to the requests made by the investors without compromising these minimum requirements specifically established for each architectural program – concerning comfort, safety, security, avoiding loss of human lives by design errors, etc.

Regarding football stadiums, the norms and legislation must be followed with great responsibility given the number of supporters that can attend a match, but they can be insufficient and inefficient when incidents are started by the supporters themselves. The association of football with hooliganism and precisely the hooliganism manifested on stadiums during various matches raise many challenges for the design team, for the management team, for police forces, etc. In England, for example, there have been many reports drafted after tragic events which happened on stadiums – to name some of the most important: *The Shortt Report* (1923), *The Moelwyn Hughes Report* (1946), *The Chester Report* (1966), *The Harrington Report* (1968) and *The Lang Report* (1969). These reports proposed various solutions that highlighted the need for a new design vision that would discourage antisocial behaviour.

In parallel with all the recommendations made in the various reports, in 1973 a good practice guide for sports arena designers is drafted, *Guide to Safety at Sports Grounds* [6, 7], also known as *Green Guide*. Although its implementation is not mandatory, its continuous improvement and information update makes it a basic document for designers. The scope of the *Green Guide* is that of providing guidance to the management team, to technical specialists such as architects and engineers and to representatives of all authorities involved, in order to assist them in assessing the number of spectators that can be safely hosted in a sports complex. The local design rules and standards or European norms and directives have priority, however.

Following the reports mentioned above and at the instance of the public opinion regarding the bigger and bigger problems created by hooligans on stadiums, in 1975 the *Safety of Sports Grounds Act* is adopted, which is a first document standardizing the design and authorization process for stadiums which could accommodate more than 10,000 spectators [8].

Other incidents and reports followed – *Popplewell Report* (1985), *The Taylor Report* (1990) [9] and *The Report of the Hillsborough Independent Panel* (2012) [10].

European football legislation addresses the issue of stadium requirements in two basic documents: *UEFA Guide to Quality Stadiums* [11] and FIFA *Football Stadiums: Technical recommendations and requirements* [12]. Due to the differences in value of sportsmen lots, of prestige and economic status of the club, the UEFA guide has a general character, only establishing at large the conditions that the sports arena must meet, without imposing excessive rules. The UEFA guide is a good starting point for any club wishing to invest in a new, modern arena as it presents all the phases an investor would have to follow. The requirements are loose, thus allowing to almost any stadium the possibility of accommodating matches. The

FIFA *Football Stadiums: Technical recommendations and requirements* document summarizes a series of recommendations and requirements with the purpose of building a modern stadium in which the national teams would play their international matches. As long as the new sports arenas must be able to accommodate both UEFA and FIFA competitions, both documents must be complied with.

The FIFA *Football Stadiums: Technical recommendations and requirements* document also stipulated a couple of recommendations regarding sustainability:

- Water should be used more responsibly for irrigations, and rainwater storage is advised.
- Beverage containers are recommended to be reused.
- Selective recycling is advised, as well as selling loose foods and other products in order to reduce waste.
- Renewable energy could be obtained through photovoltaic panels.
- The use of air conditioning should be diminished.
- The use of a centralized energy consumption control system is recommended.
- Use of public transport should be encouraged.

11.3.2 European Directives Concerning Sustainability and Sustainability Standards

In order to fully understand the sustainable measures proposed to be implemented on stadiums, we shall present the evolution of sustainable development thinking as it results from various events and official documents.

The beginning of sustainability is considered to be the *Report of the World Commission on Environment and Development "Our Common Future")*, known as *Brundtland Report* (1987) [13] which proposed "long-term environmental strategies for achieving sustainable development by year 2000 and beyond" [13]. One of the key statements in this report is the one that became the definition of sustainable development: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [13]. The recommendation of changing the lifestyles in industrial states in order to diminish consumption of water, energy, minerals and other resources led to a true social movement, the citizens becoming involved in leading a sustainable life.

This report and the many congresses that followed – especially the *United Nations Conference on Environment and Development* (UNCED) which took place in Rio de Janeiro on June 3–14, 1992 – had a major social impact, defining how each activity can contribute to a sustainable development. The directions set during these conferences, summits, etc. determined the European forums to pass *Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings* [14]. This document was a first step towards implementing the principles of sustainable development in the European Union.

Other documents and summits follow, promoting the production of renewable energy and energy efficiency of end users. In this context, public buildings (including stadiums) become true reference points through the way they integrate, improve and exploit different systems. The *Directive 2006/32/EC of the European parliament and of the council of 5 April 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC* [15] even state that "Member States shall ensure that the public sector fulfils an exemplary role in the context of this Directive. To this end, they shall communicate effectively the exemplary role and actions of the public sector to citizens and/or companies, as appropriate".

The influence a sports arena has at the level of the individual, the group of individuals and the society is major because of the great number of spectators it draws and because of the scale of the building and of the complex which makes possible the implementation of various sustainable systems it can make use of.

The economic crisis led to a slowing effect regarding sustainable measures; thus a long series of documents was drafted, proposing long-term plans in order to fulfil the sustainability requirements already established. This series starts with *Europe 2020 – A European strategy for smart, sustainable and inclusive growth* [16] followed by other directives on energy performance. *Europe 2020* strategy establishes as priorities smart economic growth, based on knowledge and innovation, facilitation of sustainable growth, and non-discriminatory employment. It is a first act that regards sustainable development in an all-encompassing way, referring to different activity sectors, fields of research, directions of implementation, etc. The launch of European funding programs such as *Horizon 2020* – a research and innovation program based on the *Europe 2020 Strategy* which aims to increase global competitiveness – proves the expected outcome in terms of possibilities to implement top solutions and phenomena understanding.

The same strategy is also followed by *Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)* [17] which introduces a new article (9) – nearly zero-energy buildings. As the principle is not easy to follow, the directive recommends:

- Developing a legislative frame that would encourage designing such buildings, including sanctions in case of serious deviations from minimal requirements
- The analysis of the built environment and finding of specific solutions of intervention in less flexible urban structures
- The establishment of a team of professionals (architects, engineers, sociologists, etc.) with power of decision, capable of changing mentalities
- Developing a dedicated structure capable of understanding and implementing the new requirements
- Raising awareness and responsibility among investors, beneficiaries and users

Based on *Directive 2010/31/EU*, in 2012 a new document is redacted – *Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance* *requirements for buildings and building elements Text with EEA relevance* [18]. The document supplements and establishes the limits of the *Directive 2010/31/EU*, leaving each member state responsible for deciding how they will implement the minimum requirements, according to each case and the specific macro- and microeconomic factors. These regulations try to give a sustainable development direction that would take into consideration more than just economic factors, the various realities of each member state making impossible the implementation of strict regulations as stated in previous documents.

Such a view highlights the spirit of sustainable development through a continuous reference to willingness for change and economic possibilities of the society. Taking into consideration the real potential of each country and the specific conditions framed by the site, the communities and the economic, social, political realities is very important. This is why we should keep in mind that all that follows should also be filtered, in case of implementation, and related to all those conditions.

11.4 The Sustainability of Football Stadiums

In the context of sustainable development which becomes mandatory in all aspects of contemporary society, the architect must pay great attention to passive solutions and to efficient local renewable energy production systems. This assumes, among others, looking for solutions in other domains, combining active and passive solutions and making all the stakeholders responsible. As “the owners of a facility cannot legally relieve themselves of the responsibility for providing security” by just putting a sign that says so [19], the architects remain responsible for their designs. This means taking into consideration all known aspects and even anticipate, innovate in order to respond to various challenges, even more so when speaking of buildings that accommodate a great number of persons while also being great consumers of resources. Considering the problems stated in the previous pages, in such cases crime prevention (through environment design) becomes much more important that aesthetics [20, 21], as does sustainability (through all its components).

In the following subsections, we shall see how football stadiums can respond to sustainability issues by relating them to contemporary challenges and realities around the stadium, the football play, the spectators and the spectacle itself while also proposing new measures to be implemented at different scales.

11.4.1 Economic and Environmental Sustainability

In order to respond to economic and environmental sustainability requirements, the entire design team should take into consideration the possibility of implementing various sustainable technical solutions from the design phase, relating both to construction and sustainable maintenance. For that we list a basic set of specific sustainable development solutions that can impact the building but also the sports complex.

At the scale of the building – the football stadium – renewable resources can be used for, among others, watering the field (in case of natural grass), undersoil heating[3] and artificial lighting to ensure the photosynthesis of the lawn (if the stadium is covered entirely); rainwater can be collected and used for toilets, in irrigation and for other non-potable uses.

The symbolic significance of the stadium as a landmark (at a local/regional/national level) makes the implementation of sustainable development principles even more important, thus becoming a place that can advocate for sustainability and even educate and make the communities around acknowledge what sustainability means and how it can be supported. At the scale of the sports complex, renewable resources can be used for street lighting or for powering any electrical equipment or for watering green surfaces; solar radiation can be used both for generating electric energy and for heating water. The large surface on which a sports complex stretches makes collecting rainwater notable. The same large surface makes it possible for the sports arena to generate great amounts of renewable resources which can be used beyond the complex itself and power or supply the houses of the community close by.

The most important issue raised by the stadium in the context of economic and environmental sustainability is that of being used more given the costs and resources consumed for building it and keeping it in service. The need to pay off the initial investment as well as to cover the costs of maintenance led to a diversification of events happening on the stadium. Besides the accommodation of political gatherings, the good acoustics and the great number of people that can populate the space once led to opening up the stadium to music concerts – from rock (Queen, Wembley Stadium, July 12, 1986 – 72,000 spectators) to classical music (André Rieu, Amsterdam Arena, June 11, 2011 – 85,000 spectators). Another good example, one we consider it should be taken into consideration as current practice, is using the stadium as a place that can be set up to be used in case of emergency – as was the Superdome in Louisiana during hurricane Katrina in 2005.

By linking these aspects with what economic and environmental sustainability demand by default (reasonable use of natural resources, reduction of natural resources consumption and pollution, cost-saving, allowing economic growth), we recommend the full and permanent roof covering of the arena in order to create an appropriate interior microclimate that would allow both the performance, in good conditions for the players and spectators as well, and the easy transformation of the arena in temporary accommodation/place of refuge in case of natural calamities/disasters.

11.4.2 Social Sustainability

The issues raised in the previous subsection already speak of social sustainability also. Besides measures with a social impact that follow economic and environmental sustainability, there are a couple of solutions that can lead to an almost continuous

[3] Heating the field has become a rule in some countries for specific leagues.

use of the sports complex, providing spaces for the community around and even opening the arena towards a larger public. What we advise is designing public spaces (like leisure spaces, playgrounds for children, etc.) inside the sports complex that would draw daily users. However, given the safety issues raised by hooliganism on stadiums on match days, we do recommend separating the entrances into one for the supporters attending the game and another for the general public.

Designing the public spaces according to CPTED principles would also be beneficial. Such an approach would make the grounds safe for people to use at any time, thus transforming the stadium into a true landmark that becomes part of the community it serves. CPTED assumes implementing various solutions that discourage antisocial behaviour through elements that have a subconscious impact. Among passive (non-energy consumption) CPTED solutions, we name glazing between inside and outside (so that there is always a visual connection with the exterior from certain spaces), a clear demarcation of spaces and functions, attending the unbuilt spaces, securing fast intervention routes in case of incidents, etc. Active solutions include CCTV (that diminishes crime acts through the fear of being seen, identified and brought to justice), street lighting, appropriate signage, highlighting the community spirit through caring for the built space, etc. [19–23].

Opening the sports complex to daily use can be taken further by also proposing related functions which serve the main function – that of a stadium (bars, restaurants, cafés, commercial spaces that sell sporting gear, etc.) or complementary spaces that serve the community (offices for the local firms, various commercial spaces, accommodation, cinemas, etc.).

Last but not least, football stadiums can contribute to social sustainability by cultivating supporter ethics. Stadiums can promote specific sustainable development systems, and they can present and publish technical data and results obtained through such solutions, thus educating through example and with evidence. Also, the multifunctional spaces could accommodate social activities concerning the community, and even more so, the community could be involved in decisions regarding the arena. All these measures can have a beneficial impact upon the members of the community, especially upon youngsters, making the space more easily appropriable and thus discouraging crime and law violations.

11.5 The Outcomes of Stadiums as Multifunctional Buildings

The importance of transforming stadiums into multifunctional buildings goes beyond the few expected result stated above. This is why we consider useful further developing the subject in a dedicated section.

The football stadium is a local symbol and a landmark for the local community. In this context, at which we add the effort of finding a big enough and accessible site, and the financial effort made during and after construction, confirms the recommendation of sustaining the stadium through other related and complementary functions that would assure a daily use. Using the stadium only during match days is not economically justified. Not only does the investment need to pay off, but it can become a source of economic growth by letting the community use it – freely (by using its public spaces) or by being able to rent spaces inside the sports complex (for offices, for community-related activities, etc.). Thus, the stadium generates income but also jobs, the advantages being economic as well as social.

Proposing multifunctional spaces can have great advantages on the long term, depending on the openness it is willing to promote, like a continuous use (7 days a week) which means giving continuous access to various services, an efficient use of resources (by diminishing consumption at times that do not generate income), the integration of functions that serve the community (functions – from leisure to administrative spaces – which help the community define itself, consolidate, grow, evolve) and drawing various people closer to sports and so to a healthy life.

In order for an investment into a football stadium to be sustainable, it must demonstrate its utility for the investor as well as for those living around it. This is why a contemporary arena must be multifunctional, sheltering a great variety of activities, all related to the needs of the community it serves. Designing such a building that besides the field itself and its tribunes would also offer access to cinemas, museums, etc. is a complex process, one that makes necessary a detailed research into the site, the different types of users, the community or communities around it, the phenomena involved and the realities it will be inserted into.

In the end, we would like to highlight another type of outcome that opening the stadiums towards various events allows – one with cultural significance, speaking of contemporary challenges and crossing boundaries. André Rieu – internationally renowned violinist and conductor – constantly tries to break the rules of playing with an orchestra in order to reach a broader public, one that is not necessarily made of connoisseurs of classical music. In 2011, he held a full concert on Amsterdam Arena in front of 85,000 spectators (after playing, in 2009, two pieces of classical music in front of football fans, before a match between Ajax Amsterdam and Olympique Marseille). Such a show, held in open air, raises new challenges for the artist and his team, as well as for the public, but the atmosphere, the possibility of creating a new and complex scenography, developing a unique relationship between artist and spectator, is just one of the strengths of setting up a spectacle in a non-dedicated but impressive space. Anyway, this kind of activity is part of a broader tendency of opening up various institutions towards a broader audience through programs which negotiate the relationship between (anyone's) public space and the main function inside [24].

11.6 Conclusions

The overall dimensions of football arenas underline the important role the architect has in conceiving a space that would better respond to the ever-changing needs of the final users. In the same time the architect must help and continue, through his/

her architecture, the process of eliminating communication boundaries, in the case of football arenas already basing his design on a sport that led to strong connections between supporters as they are often members of dedicated communities.

The architect and the whole design team (engineers of different professions, professionals in related domains like sociology, psychology, doctors, etc.) must come up with specific solutions that would include the new specific technologies and/or make use of/come up with innovative solutions. By doing so they must also relate to the newest realities, challenges, defining characteristics of the sport and of the society (the pursuit of dynamism, spectacle, inclusion, etc.).

The implementation of sustainable development principles in football stadiums, for example, tackles not only aspects of renewable energy but also aspects concerning the happening of various events and activities that would support the main function (Fig. 11.1).

Transforming a football stadium into a space with multiple functions can lead to a permanent use and to address to a larger public (by including museums, cinemas, commercial spaces, administrative spaces for the community, etc.). This makes even more relevant the discourse about erasing barriers and fostering communication and interaction as different functions lead to spaces being populated in the same time by different ages, different social categories. A secondary outcome of such an approach is preventing crime by exercising social acceptance, understanding others, indirect supervision, etc.

Streamlining the build space (a principle which was used at the beginning of the twentieth century also) assumes using the architectural object at its maximum potential, and this makes necessary a lesser degree of specialization. The stadium, in a future-oriented perspective, must leave behind its focus solely on football and become an arena dedicated to more sports than one, as well as a multifunctional space that would satisfy a broader range of user needs.

The possibility of post-use must not be neglected either. Once a stadium ended its purpose, it can acquire another function that would serve the community. In this regard, we mention the proposal for transforming the stadium of Arsenal FC into habitation, the Highbury Square project being emblematic for the way it keeps the memory and tradition of a renowned club alive in a contemporary context. Such a transformation sets a new light upon spaces that with time became technologically outdated.

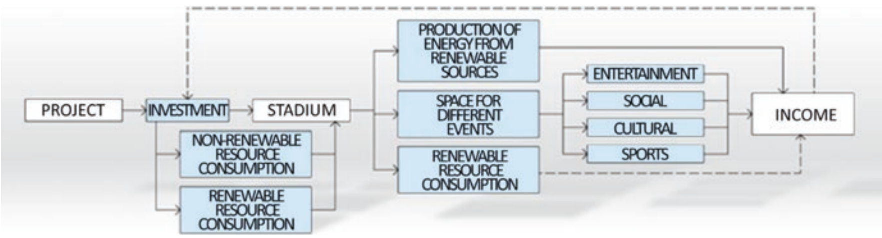

Fig. 11.1 Solutions for recovering the investment into a stadium by implementing sustainable development solutions

References

1. S. Jordana, Taiwan Solar Powered Stadium. *Archdaily*, http://www.archdaily.com/22520/taiwan-solar-powered-stadium-toyo-ito (2013, accessed 22 Aug 2015)
2. W. TEJ, *Emperors and Gladiators* (Routledge, 1992)
3. G. Carnibella, A. Fox, K. Fox, et al., *Football Violence in Europe- A report to Amsterdam Group*. The Social Issues Research Centre, www.sirc.org/publik/football_violence.pdf (July 1996, accessed 8 Mar 2015)
4. E. Dunning, *Sport Matters: Sociological Studies of Sport, Violence and Civilisation. London* (Routledge, New York, 1999)
5. R.W. Lewis, 'A civic tool of modern times': Politics, mass society, and the stadium in twentieth-century France. Fr. Hist. Stud. **34**, 155–184 (2011)
6. Home Office/Scottish Office, *Guide to Safety at Sports Grounds*. 2nd ed., http://hillsborough.independent.gov.uk/repository/docs/LJT000000810001.pdf (1986, accessed 6 Sept 2015)
7. Department for Culture, Media and Sport, *Guide to Safety at Sports Grounds*. fifth edition., http://www.safetyatsportsgrounds.org.uk/sites/default/files/publications/green-guide.pdf (2008, accessed 3 Sept 2015)
8. Fire Departament Home Office, *Safety of Sports Grounds Act* 1975, http://www.safetyatsportsgrounds.org.uk/sites/default/files/publications/150-1975.pdf (1975, accessed 2 Sept 2015)
9. J. Taylor, *The Hillsborough Stadium Disaster*. London: Home Departament, http://hillsborough.independent.gov.uk/repository/HOM000028060001.html (19 Jan 1990)
10. Hillsborough Independent Panel, The Report of the Hillsborough Independent Panel, http://hillsborough.independent.gov.uk/repository/report/HIP_report.pdf (2012, accessed 4 Sept 2015)
11. UEFA, *UEFA Guide to Quality Stadiums*, http://www.uefa.org/MultimediaFiles/Download/EuroExperience/competitions/General/01/74/38/69/1743869_DOWNLOAD.pdf (2011, accessed 28 Aug 2015)
12. FIFA, Football Stadiums – *Technical recommendations and requirements*, http://www.fifa.com/mm/document/tournament/competition/football_stadiums_technical_recommendations_and_requirements_en_8211.pdf (2007, accessed 28 Aug 2015)
13. G. Brundtland, M. Khalid, S. Agnelli, et al. *Our Common Future ('Brundtland report')*, http://www.bne-portal.de/fileadmin/unesco/de/Downloads/Hintergrundmaterial_international/Brundtlandbericht.File.pdf?linklisted=2812 (1987)
14. The European Parliament and the Council of the European Union, Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings. *Official Journal*; L001, http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32002L0091 (2003)
15. The European Parliament and the Council of the European Union, Directive 2006/32/EC of the European parliament and of the council of 5 April 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC. *Official Journal of the European Union*; L 114/64, https://eur-lex.europa.eu/legal-content/ro/TXT/?uri=CELEX:32006L0032 (2006)
16. European Commission, Europe 2020 – A European strategy for smart, sustainable and inclusive growth, https://ec.europa.eu/eu2020/pdf/COMPLET%20EN%20BARROSO%20%20%20007%20-%20Europe%202020%20-%20EN%20version.pdf (2010)
17. The European Parliament and the Council of the European Union, Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast). *Official Journal of the European Union*; L 153/13, https://eur-lex.europa.eu/legal-content/RO/ALL/?uri=CELEX%3A32010L0031 (2010)
18. European Commission, Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council on the energy performance of buildings by establishing a comparative methodology framework for calculating cost-optimal levels of minimum energy performance requirements for build-

ings and building elements Text with EEA relevance. *Official Journal of the European Union*; L 81/18, https://ec.europa.eu/eu2020/pdf/COMPLET%20EN%20BARROSO%20%20%20007%20-%20Europe%202020%20-%20EN%20version.pdf (2012)
19. R.I. Atlas, *21st Century Security and CPTED: Designing for Critical Infrastructure Protection and Crime Prevention* (CRC Press, 2008)
20. S. Geason, P. Wilson, *Designing out Crime: Crime Prevention through Environmental Design*. http://www.aic.gov.au/media_library/archive/crimprev/cpted/cpted.pdf (Australian Institute of Criminology, Canberra, 1993, accessed 12 Sept 2015).
21. D. Sanger,S. Warner, L. Hill, *Role of the architect in crime prevention through environmental design (CPTED)* (Australian Institute of Criminology, Sydney), pp. 27–34
22. R. Potts, The role of police in crime prevention through environmental design, http://www.aic.gov.au/media_library/conferences/cpted/potts.pdf (1989, accessed 11 Sept 2015)
23. T. Crowe, *Crime Prevention through Environmental Design*, 3rd edn. (Butterworth-Heinemann, Amsterdam, 2013)
24. A.-I. Sfinteş, *Spaţii limită în antropologia arhitecturală* (UAUIM Bucureşti, 2014)

Chapter 12
Passive Design Strategies in Pursuit of Architectural Identity: The New ACT Student Center

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12.1 Introduction

Frequently characterised as the "living room, or hearthstone of the campus" [1], college unions form the epicentre of student life in higher education, offering out-of-classroom experiences that serve to link people and ideas. Since the turn of the second millennium, their typology has evolved, from original precedents dating back to 1894, to encompass a variety of functions that in turn allowed them to be characterised as "fusion" buildings [2]. The brief for the architectural competition for the New ACT Student Center (NASC), launched by the American College of Thessaloniki in 2017, sought no less, specifying the creation of public areas, shops, student areas, office spaces, a fitness centre and a multifunctional space, while a phased construction programme required the design and future addition of a 500-seat auditorium and residencies.

A "fusion" typology poses enough of a programmatic challenge for its sustainable design and construction, being subject to risks pertaining to: its size and scale in relation to surrounding buildings, the need for future expansions – alterations and reappropriations of spaces – and funding [2]. However, a further challenge for the design lies within the greater context of campus greening initiatives that universities engage in since the 1990s, which have not necessarily been able to counterbalance

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their increasing need for amenities and hence the subsequent increase of their environmental footprint [3]. As aptly put by Brown and Taylor, college unions nowadays – functioning both as educational buildings and businesses – need to embrace their central role in teaching citizenship, social responsibility and leadership, which translates to them becoming *stewards* for sustainability, seeking not merely to function as energy-efficient buildings but rather as operational "models" of the sustainable world that future generations must aspire to [4].

The development of an architectural identity for the promotion of environmental "stewardship" formed the core of the design process that lasted for 2 months, seeking to address the competition brief's requirements for an aesthetically and functionally dynamic building that would (a) utilise the infrastructure of the ACT campus, (b) develop in two phases, (c) present expandability and variability, (d) integrate with the landscape and (e) adapt to the principles of sustainability. Furthermore, this endeavour was framed by the Greek financial but also societal, cultural and environmental crisis that made the question of a sustainable architectural resolution even more pertinent.

Being active both in academia and in practice, ArchSix Architecture Studio approaches every architectural competition as an opportunity for research, conducted by iterative cycles of design and analysis, which in turn not only culminates into a project but also allows for the localised renegotiation and adaptation of the architectural discourse that strives for sustainability. Included in this volume of case studies, this paper forms the second deliverable of the process, offering a perspective of the particular limitations and opportunities allowed in the fast-paced design process of a complex educational building, tracing the development of ideas and their design interpretations in the hope of informing a wider audience dealing with the environmental design of buildings and open spaces.

To aid in the better understanding of the design process, the remainder of the paper is structured in five sections. Section 12.2 delves deeper into the competition brief requirements, the site analysis and background research that informed the design development. Section 12.3 outlines the main design principles and traces the decision-making process that formed the core of the environmental architectural concept, which is further elaborated on in the fourth section of the paper that includes a detailed description of the final design proposal. The fifth section presents the environmental design analysis of the proposed scheme, enumerating its environmental performance. The paper ends with a discussion that generalises the findings of the analysis.

12.2 Brief - Site - Further Background Research

12.2.1 The Brief

Active in post-secondary education since 1981, Anatolia awarded its first 4-year baccalaureate degrees in Liberal Arts and Science in 1993. During the early 1990s, Anatolia embarked on master planning of a new campus for ACT, at an 11 acre

(45,637.10 m^2) site, situated in Pilea, a suburb of the city of Thessaloniki. The Master Plan, completed in 1992, culminated into the erection of two buildings. The ACT New Building was completed in 1994, comprising of three levels, each measuring 1249.8 m^2, with a total area of 2278.54 m^2, and currently houses educational, administration uses and a cafeteria. The second building to be completed, in 2002, was the Bissell Library, comprising of three levels, each measuring 1683.83 m^2, with a total area of 4376.19 m^2, housing one of the largest general-purpose English language libraries in Greece and also home to the Stavros S. Niarchos Technology Center. The two buildings cover 6.4% of the site, the maximum allowable coverage being 10% for educational uses developed in areas situated beyond the official city plans [5, 6] representing low density. Moreover, the built area grosses 6.654,73 m^2, which amounts to 73% of the maximum allowable built area for the specific plot.

The building program for the New ACT Student Center specified, in precise numbers, the allowances for specific functions. It provided an itinerary of spaces that were grouped into 620 m^2 of indoor communal spaces and 150 m^2 of exterior communal spaces, 360 m^2 of office spaces, a 500-seat auditorium of 700 m^2, and 140 m^2 of residential spaces (3 residences for guests) and allowed for auxiliary spaces of 150 m^2 while also making further allowances for circulation, walls, etc. Furthermore, the brief allowed the contestants very little tolerance (±3%) in deviations from the square footage assigned to each function. On the other hand, it proposed that the building could be erected utilising the available square footage allowed for the plot, under the aforementioned legal framework, but also suggested that if height, square footage, volumetric or other limitations were hindering the architectural composition, the designers could apply for a permit of exemption, which could effectively double available land coverage and built space allowances for future expansions.

12.2.2 The Site

The ACT campus approximates a rectangle (270 × 170 m) oriented along the NS axis. Its north border is facing a rural road that leads to Eleones, a connecting suburb. The road circumscribes 5118.00 m^2 that have been classified as a private (campus) forest area which partly shades the campus' main outdoor car park. At the south, it is separated by a public road from the adjacent Anatolia high school campus, while safe pedestrian communication between the two is provided by an elevated pedestrian bridge. The east and west campus boundaries are delineated by two zones of dense cypress trees, providing not only excellent views but also sun shade early in the morning and in the afternoon respectively. The competition's proposed site for the new building was indicated at the west part of the campus (north of ACT new building and west of the Bissel library) where a beach volleyball court sits today. The specific location includes several scattered pine trees and two rows of almost 15-year-old olive trees.

12.2.3 Further Background Research

While the brief specified that the designated area for development is mostly flat, presenting a low stable inclination to the north, the drawings annexed to the brief included very little detail as to the topography of the campus and the levels of the two existing buildings. A site visit revealed that this stable inclination reached a point where it became extremely steep at the north, creating a hill face of more than 6 m that was dotted with construction rubble. Upon closer examination, it transpired that the steep hill dividing the proposed site from the campus parking area is a product of land transport that took place during the past decades. The investigation of the documentation of the urban planning offices revealed that the land was initially transferred to the northwest of the plot for the creation of a football court. The construction of the new ACT building in 1993 and the Bissel library in 2000 allowed for more land transfer, culminating into the resulting unique terrain, a topographic mapping of which ultimately required several man-hours during the early design stages. The process of land transfer during the past century is illustrated in Fig. 12.1.

12.3 Environmental Concepts and Principles

The aim of the proposed project was to design a building that will embrace the existing open public area to welcome the students, providing a landmark for the campus, allowing for a dialogue with the natural environment through its morphology and adopting the principles of sustainability and accessibility, as presented in Fig. 12.2. The objectives were to design a student- and staff-friendly building, where the organisation of the uses will be easily identified and to capitalise on the opportunities provided by the unique terrain and vegetation of the site, in relation to Pilea's climate and the site's microclimate. The design principle was to provide the space quality that meets the needs of ACT, both in terms of contemporary architectural identity and functionality.

The question of an architectural identity for the promotion of environmental "stewardship", in the contexts of the local Greek crisis and the global environmental crisis, framed the design process. Respecting the landscape and the rural atmosphere of the wider area, an early decision was taken to design the building within the standard legal building permission constraints, maintaining a low-density campus, with a land cover under 10%. This in itself presented a challenge for keeping the building small and compact by minimising circulation spaces and by careful clustering of functions, relying on synergies between the required spaces. Instead of seeking for an exemption that would permit absolute architectural freedom, the design team opted to elaborate on allowances offered by the renewed building codes of 2012 [7] that match provisions for height/spatial/volumetric excess with the inclusion of passive design systems, such as planted roofs, solar chimneys, buffer or underground spaces. This meant that the design embarked on an effort to assimilate

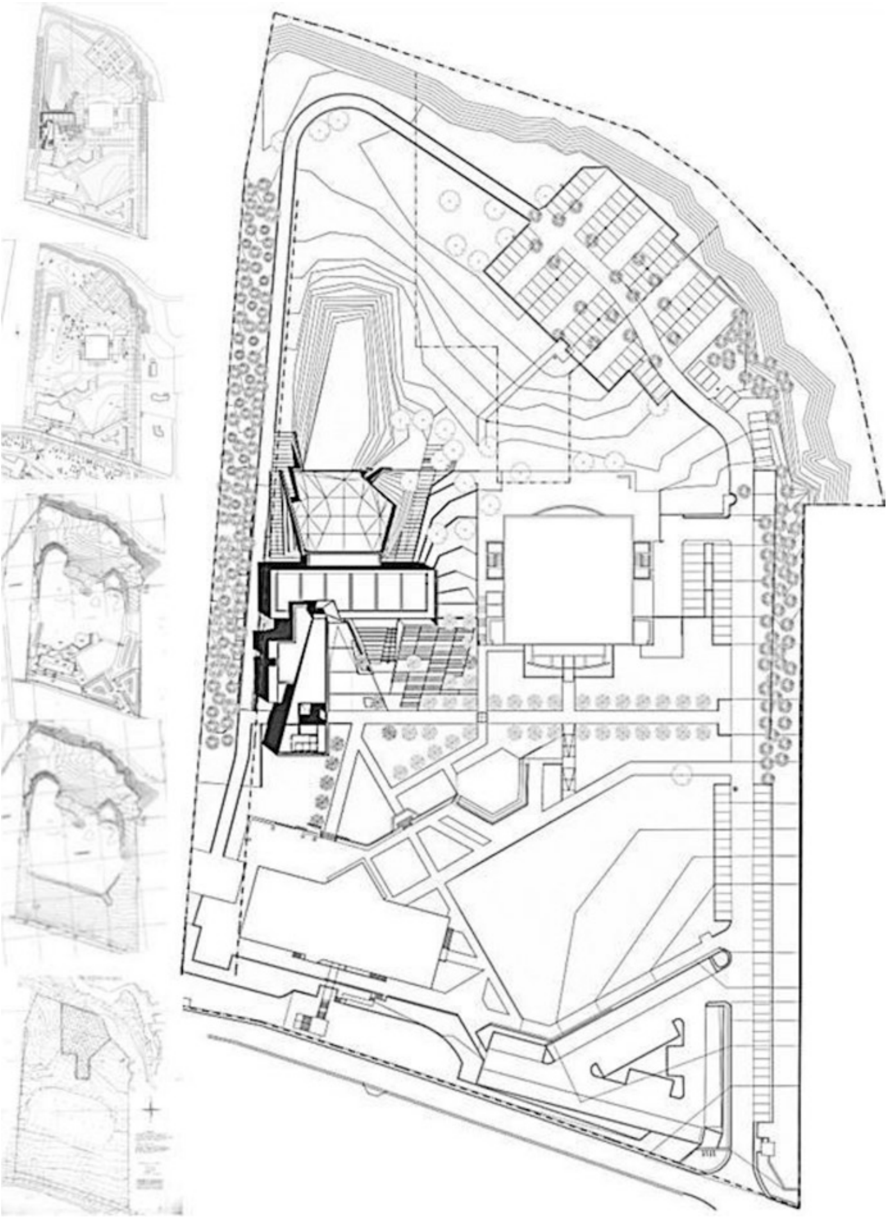

Fig. 12.1 Topographic drawings of the site, dating from 1922 (bottom left) to 2017 (top left and right)

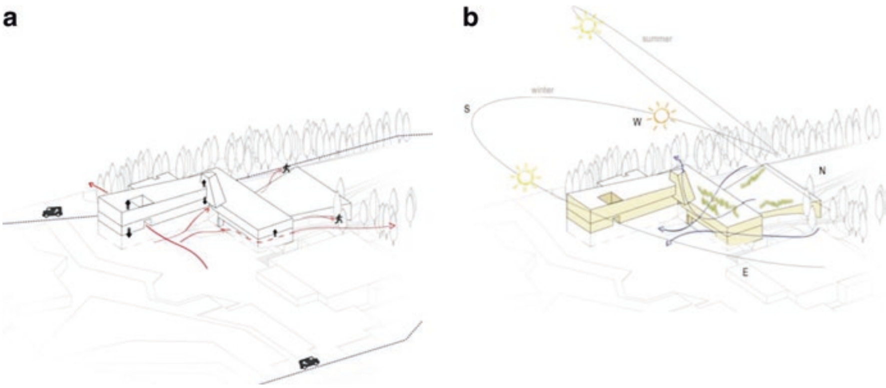

Fig. 12.2 Concept diagrams, (**a**) accessibility and (**b**) environmental design principles

a passive design idiom that could be created through simple and tested construction wet-trade techniques, which not only allow for longevity but also are within the capabilities of a construction sector in crisis. Last, but not least, the team wished to remedy the unsustainable practice of land transfer that characterised previous interventions to the site and searched for ways to address this unique land formation for the benefit of the environmental response of the building.

The need for accessibility, especially during the 2^{nd} phase of construction of the 500-seat auditorium, provided a challenge in addressing the unique land formation and exploiting the existing north parking area and the steep inclination. At the same time, the imperative need for a car-free campus provided the initiative to explore the creation of an auxiliary peripheral road that would extend the existing eastern route and, through the parking (Fig. 12.2), would lead to NASC and the ACT building, parallel to the west plot boundary.

12.3.1 Building Energy Performance Goals

The EU Directive on Building Energy Performance [8] mandates that all new buildings should consume nearly-zero energy from 2020 onwards. According to the Directive, nZEBs are high energy performance buildings that cover the low-energy requirements from on-site or nearby Renewable Energy Sources (RES). The ramifications of the EU nZEB policies on architectural design are significant as climate responsiveness will likely be mandatory to achieve low-energy status. The nZEB concept requires a holistic and systems-thinking approach to building design where the interactions between the local climate, the building envelope, the electromechanical equipment and user behaviour will need to be examined from the earliest stage of the design process.

In addition, the 2016/1318 EU recommendation [9] defines energy performance goals for different European climates. For the Mediterranean, it assumes a total primary energy consumption of around 80 kWh/m^2.y of which 60 kWh/m^2.y is covered by local RES. The Greek legislation (Decree 85251/27.11.2018) [10] equates nZEBs as buildings that are rated as A (26–74 kWh/m^2.y) or A+ (10–44 kWh/m^2.y) according to the Greek Building Energy Code (KEnAK) [11]. The aforementioned energy performance ranges correspond to tertiary sector buildings for the climatic zone of Thessaloniki and are the result of building energy assessments over the past years [12].

12.3.2 Climatic and Microclimatic Conditions

The design takes into account the potential of the climate of Thessaloniki for passive design and additionally utilises the microclimatic advantages of the local landscape. The climate of Thessaloniki – CSa class according to Koppen-Geiger classification) [13] – is characterised by dry-hot summers and mild-wet winters. The heating period starts on October 15 and ends on April 30, while the cooling period starts on June 1 and lasts until August 31 [14]. Total heating and cooling degree-days are estimated to be 2184 and 135 for base temperatures of 20 °C and 26 °C, respectively [15, 16]. Average winter cloud coverage is 60%, allowing for efficient passive solar heating and daylighting, while the significant drops in nocturnal air temperatures during summer allow for efficient night cooling. The building site is located in a lightly built area where the Urban Heat Island intensity is negligible. On the contrary, the proximity to the peri-urban forest further enhances the efficiency of summer passive cooling through natural ventilation.

12.4 Environmental Architectural Design

Based on the aim of creating an “embrace”, the proposed building is architecturally drawn with the dipole of the two basic building volumes-wings (first construction phase), one perpendicular to the other, namely, wings A and B, to optimise functionality through the creation of clusters, as seen in Fig. 12.3, and ensure the maximisation of lighting and natural ventilation and create a large outdoor patio and entrance area that integrates into the existing campus design completing its NW corner.

Wing A, oriented along the E-W axis, groups all required communal spaces. It presents an almost transparent volume, well shielded from the north and transparent to the south – the existing landscape allowing solar access for both levels – which houses the most public areas: an “agora”. Wing B is a less porous volume that opens up to the west, accommodating office spaces and residences, while allowing dedicated access to the latter. The building volumes enclose and shield the multi-level outdoor patio that can be used for recreation and open-air events, its morphology adapting to the natural inclination, while also creating the prerequisites for the addition of the auditorium at the second construction phase. A solar chimney marks the

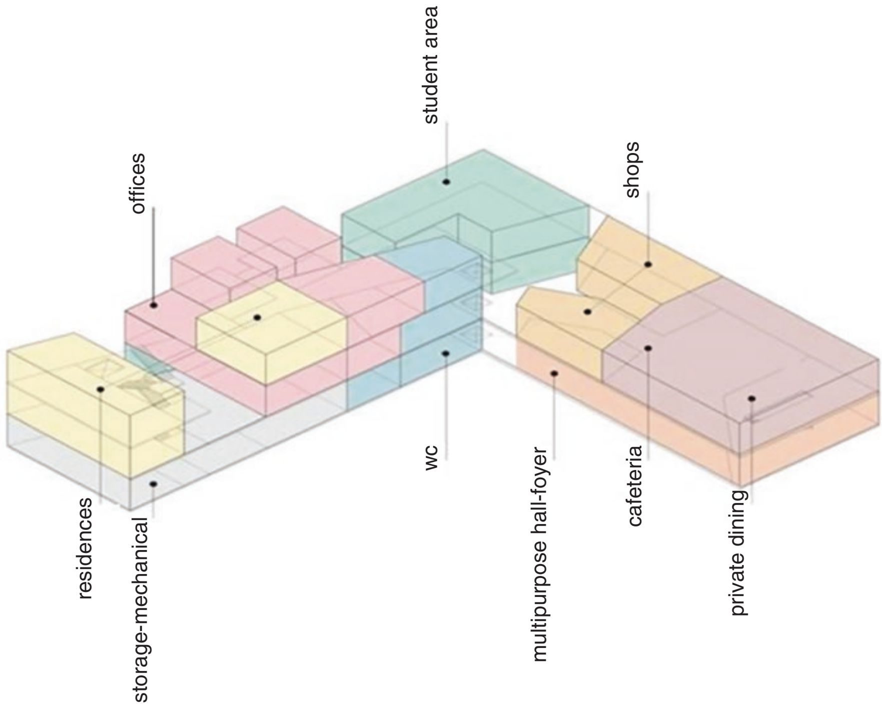

Fig. 12.3 Space allocation and functional organisation through clusters

intersection of the two wings, i.e. the main entrance to the building. More than a morphological device making reference to the works of Eduardo Souto de Moura or A. Tombazis, this feature is symbolic of the proposal's identity.

Two existing axes, derived from the adjacent buildings and the existing landscape design, are extended and incorporated into the design, to allow for south-north and east-west connections and future expandability. Through these axes, the building is also connected with the present patio at the south of the Bissell Library.

The construction of the auditorium during the second phase is unified with the above-mentioned volumes, partially inserted in the building as an extension of the multi-functional space – the auditorium foyer. The architectural design of the auditorium is based on the principles of optimised visual and acoustic design for analogous spaces, through the cardioid layout, which allows for an even distribution of direct sound, promoting intimacy. The method of theatre sightline design was used for determining the inclination of the audience seating, allowing clear view of the stage floor, which consequently creates maximum visibility for all other uses. Also, no central corridor was used to exploit the benefits of this area's seating. The seats are organised in four major groups. This provides the opportunity for future layout variability, creating at least three lecture rooms that could function simultaneously, if ACT is in need for a venue hosting parallel sessions. According to the acoustic design prerequisites, ceiling reflectors have been designed according to the image-

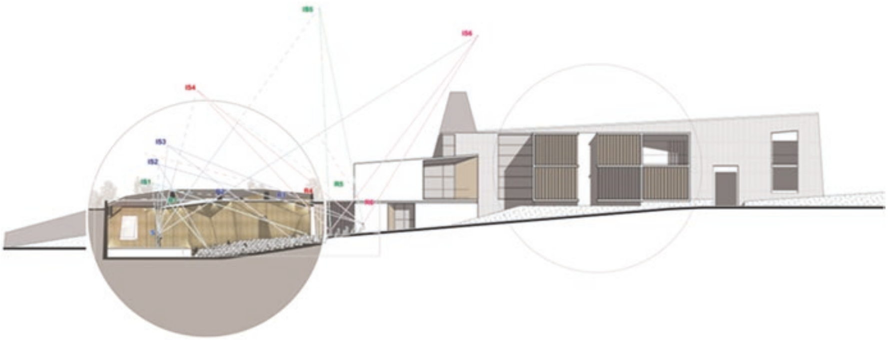

Fig. 12.4 West Elevation – Section diagram of the auditorium reflector design based on the image source method

source method, as presented in Fig. 12.4, to enhance sound, especially at the back of the auditorium. The design also makes allowances for the treatment of peripheral walls with reflective/diffusive materials, movable/rotating panels, to achieve variable acoustics, in terms of speech intelligibility, clarity, definition and reverberation time, for hosting different types of use or performance – speech, music, etc.

The proposed design, illustrated in Fig. 12.5, incorporates both passive and active energy systems to achieve nZEB status. Wing A has a clear southern orientation with extensive low-e glazed surfaces shaded by a horizontal protrusion of the inclined roof. This arrangement allows the sun to penetrate the building during winter, prevents unwanted thermal losses from glazing and provides efficient summer shade. Northern openings are significantly smaller, and storage non-conditioned spaces serve as buffer zones that further enhance building envelope insulation. Small window openings at the north and south facades of the communal/public areas take advantage of the prevailing northwestern wind of Thessaloniki for optimised cross-ventilation. The inclined roof of wing A is planted to reduce unwanted heat gains and losses and further stabilise indoor climate. The solar chimney increases vertical convective air flow and thus improves natural stack ventilation and night cooling of the thermal mass.

The eastern and western facades of wing B are protected from summer solar radiation by utilising a series of bioclimatic strategies. The double skin provides an additional protective layer of shade, while ventilation openings minimise the entrapment of hot air masses between the building façade and the second skin. The large glass surfaces of the western offices are shaded by both the existing dense row of cypress trees and a series of vertical operable blinds that can freely rotate to provide optimal shade and daylighting at any time. The auditorium intersects the volume of wing A to benefit from the passive ventilation techniques applied and is partially built below ground level to capitalise on the earth's thermal capacity. Earth sheltering minimises heat exchanges, keeps the internal temperatures stable and provides part of the necessary sound insulation. The lower parts of the auditorium's roof, above the dressing rooms, the scenery storage and other auxiliary spaces, where the

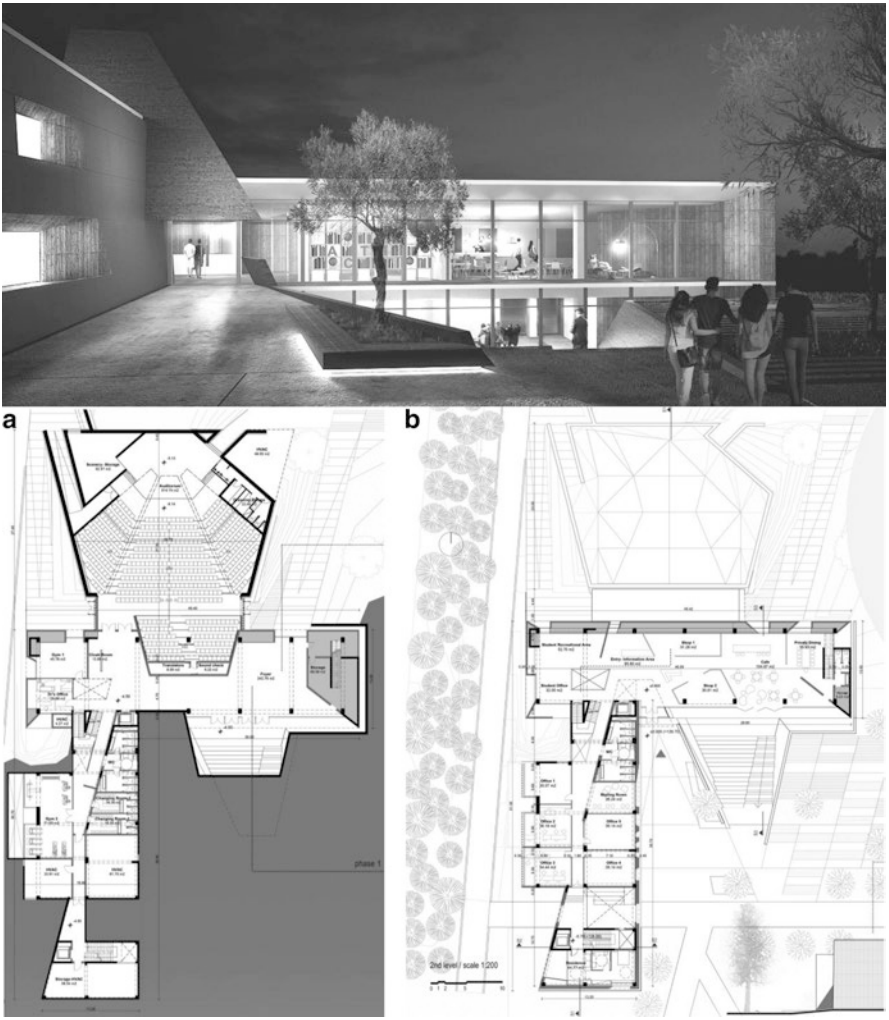

Fig. 12.5 Photo rendering of the NASC entrance and multilevel patio and plans (**a**) first and (**b**) second levels

structural constraints are less strict, are also planted, while the rest of its roof is completed through insulated composite panelling.

Building construction complies with the specifications of the Greek Building Energy Code set out for the climatic zone of Thessaloniki. Both the bearing structure made from reinforced concrete and the walls made from perforated bricks provide the necessary thermal mass to moderate the diurnal internal air temperature changes. The building is externally insulated primarily with stone wool of variable thickness and secondarily by expanded polystyrene only for locations where bearing loads are of primary concern. Stone wool is selected because it is highly recyclable and non-toxic and has good acoustic and thermal insulation properties while being resistant to fire and humidity.

The heart of the building's HVAC system is a variable refrigerant flow (VRF) high-performance heat pump with heat recovery and a dedicated outdoor air system (DOAS) for mechanical ventilation where required. The VRF system is powered by both natural gas and electricity and provides the necessary domestic heat water (DHW) as well. Artificial lighting relies on dimmable LEDs combined with motion and light detectors to conserve power. The electricity needs are partially covered by a photovoltaic (PV) array located on the roof of wing B and oriented for optimal performance. Following the initial building energy simulations, a second PV array is also proposed to be placed above the auditorium to meet the nZEB requirements.

12.5 Environmental Design Simulation

The design process was informed by sunlight exposure, daylighting and energy consumption simulations conducted using EnergyPlus and Radiance which are both validated, open source and extensively used in the industry [17, 18]. Both simulation software were operated through the DesignBuilder 4.7 user interface [19]. The initial building massing studies were guided by solar irradiation and shading analyses for the heating and cooling periods. At later stages of the design process, building energy simulations allowed the comparison of HVAC alternatives and insulation materials, the fine-tuning of shading devices according to occupancy schedules and the quantification of passive and active solar potential.

Sunlight exposure studies were found to be the most effective in quickly informing the design process as it evolves. While it is more difficult to interpret solar irradiation values and compare different time periods, sunlight exposure can be quickly calculated and is easily understood by designers and non-experts alike. Figure 12.6 demonstrates the building and outdoor space sunlight exposure for the heating and cooling periods. The sunlight exposure analysis shows the effectiveness of the building shading strategies, where openings are significantly exposed to the sun during the heating period and are sufficiently shaded during the cooling period. Furthermore, the analysis revealed the building surfaces that are most exposed and are ideal for locating PV arrays.

The energy simulation of the final proposed design showed that the total primary end-use intensity (EUI) is 46.9 kWh/m^2.y and the net EUI is 22.5 kWh/m^2.y considering the local PV electricity generation. According to the Greek building energy code, the building is rated as A+, and therefore it is considered as a nZEB. Furthermore, these consumptions are in line with the aforementioned EU recommendations for Mediterranean nZEBs. The PV contribution is estimated at 34% of the total EUI. Figure 12.7 shows the monthly and annual fuel breakdown illustrating that 27% and 24% of energy is spent on heating and cooling, respectively, while 19% is spent on lighting and 11% on DHW. The rest is spent on HVAC pumps, fans and heat rejection.

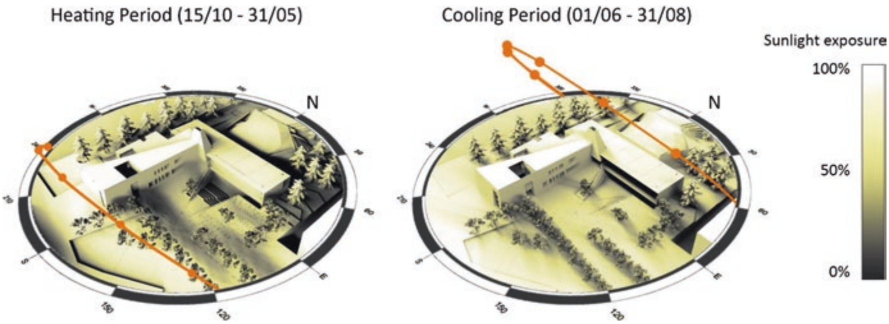

Fig. 12.6 Sunlight exposure for the heating (left) and cooling (right) periods. The orange curve and dots indicate the apparent sun trajectory during winter and summer solstices. The lighter the colour, the greater the exposure of the surface to the sun

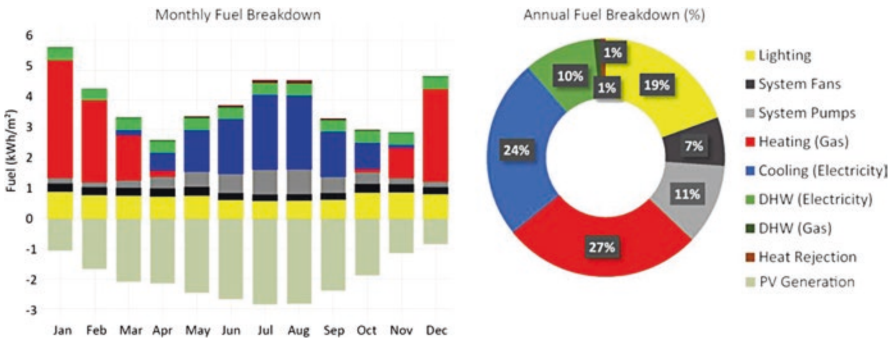

Fig. 12.7 Monthly fuel breakdown in kWh/m^2 (left) and annual fuel breakdown as percentage of total EUI (right)

The building emits approximately 10 $kgCO2/m^2.y$ which is far lower than the 2008 carbon emissions for building heating in Greece (approx. 33 $kgCO2/m^2.y$) but still larger than the respective emissions of other countries such as Norway (approx. 3 $kgCO2/m^2.y$) according to EEA [20]. Carbon emissions, however, do not only depend on building design and operation but also on the high dependence of the national electricity grid on fossil fuels.

12.6 Discussion

This paper presented the environmental architectural design proposal by ArchSix Studio for the competition for the New ACT Student Center: the decision-making process, the main design principles, the concept, the environmental design analysis and the performance evaluation. The design evolution, a process that lasted

2 months, allows for further discussion on the opportunities provided for the sustainable design of fusion building types for education:

- Building small, condensing the square footage by investigating possibilities for functional synergies and clustering of uses can provide a solid basis for the energy-efficient design, such as in the case of the NASC.
- Fusing simple, passive design strategies and features, a cantilever coupled with a large thermal mass, with accessible technological interventions, low-e glazing, can allow such buildings to function in the Mediterranean basin, minimising their needs for cooling and heating. At the same time, passive design features combined with active energy control systems are also a means for introducing resilience through the creation of system redundancy: the passive features assuring that the building can function satisfactorily in the event of a future crisis, even in extreme power-shortage conditions.
- Vernacular passive design features, such as a solar chimney, can effectively be integrated in a contemporary sustainable architecture idiom as morphological devices for accentuation and identity building.
- The inclusion of the simplest of passive design features that are common to most people in the Mediterranean basin – operable windows, glass doors allowing natural ventilation – also permits the seamless functional integration of indoors and outdoors.
- The restrictions imposed either by building codes or by unique terrain conditions can lay the foundation for a creative architectural design process, leading to a strong architectural identity.

The above points of the discussion should not be mistaken for a call to architectural conservatism for the sake of sustainability but rather as instigation for a radical rethink, re-examination, reappropriation and ultimately reform of what is actually already in our grasp.

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References

1. B.A. Jacobs, J. Kinzie, Editors' notes, in *Enhancing Sustainability Campuswide, New Directions for Student Services*, ed. by B. A. Jacobs και, J. Kinzie, vol. 137, (Published online in Wiley Online Library, Wiley, 2012), pp. 1–6
2. C. Hamilton, Fusion building: New trend with some old roots, in *Planning for Higher Education*, (2009), pp. 44–51
3. A. Rappaport, Campus greening: Behind the headlines. Environment **50**(1), 6–17 (2008)
4. P. Brown, J. Taylor, Sustainability in the union, in *Enhancing Sustainability Campuswide, New Directions for Student Services*, ed. by B. A. Jacobs, J. Kinzie, vol. 137, (Published online in Wiley Online Library, Wiley Periodicals, Inc., 2012), pp. 53–65

5. Greek Parliament, Laying down the conditions and restrictions on the construction on land beyond the urban plans of the cities and outside the boundaries of legally existing settlements before 1923, Presidential Decree 6 (5) /17.10.1978, *Greek Government Gazzette*, D'538, 1978 (in Greek)
6. Greek Parliament, Amendment of the conditions and restrictions on the construction on land beyond the urban plans of the cities and outside the boundaries of legally existing settlements before 1923, Presidential Decree 24 (1) /31.5.1985, *Greek Government Gazzette*, D'270, 1985 (in Greek)
7. Greek Parliament, New Building Regulation, Law 4067/09.04.2012, *Greek Government Gazzette*, 79/2012, pp. 2075–2112 (in Greek)
8. European Parliament, Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on “The Energy Performance of Buildings” and Directive 2012/27/EU on “Energy Efficiency” (Text with EEA relevance). Off. J. Eur. Union, 2018, Brussels
9. European Commission, Commission Recommendation (EU) 2016/1318 of 29 July 2016 on “Guidelines for the Promotion of Nearly Zero-energy Buildings and Best Practices to Ensure That by 2020, All New Buildings are Nearly Zero-energy Buildings”. Off. J. Eur. Union (2016)., Brussels
10. Greek Parliament, Approval of National Plan to Increase the Number of Buildings with Nearly Zero Energy Consumption, Ministerial Decree YPEN/DEPEA/85251/27.11.2018, *Greek Government Gazzette*, B'5447, 2018, pp. 64397–64408 (in Greek)
11. Greek Parliament, Approval of Building Energy Efficiency Code, *Greek Government Gazzette*, B'407, 2010, pp. 5333–5356 (in Greek)
12. V. Sita, National Legislation for Nearly Zero Energy Buildings – nZEB”, 10th Technical Meeting of the Panhellenic Society of Certified Energy Inspectors, Technical Chamber of Greece, 2019, Athens (in Greek)
13. M. Kottek, J. Grieser, C. Beck, B. Rudolf, F. Rubel, World map of the Köppen-Geiger climate classification updated. Meteorol. Zeitschrift **15**, 259–263 (2006)
14. Technical Chamber of Greece, *Climatic Data of Greek Areas* (Technical Chamber of Greece Publications, Athens (in Greek), 2012)
15. K. Papakostas, G. Tsilingiridis, N. Kyriakis, Cooling degree-days for 50 Greek cities. Technica Chronica, Sci. J. TCG **1**(1), 161–172 (2010). (in Greek)
16. K. Papakostas, G. Tsilingiridis, N. Kyriakis, Heating degree-days for 50 Greek cities. Technica Chronica, Sci. J. TCG **4**(1–2), 51–65 (2005). (in Greek)
17. D. B. Crawley, F.C. Winkelmann, L.K. Lawrie, C.O. Pedersen, Energyplus: New capabilities in a whole-building energy simulation program, Proceedings of the Seventh International IBPSA Conference, Rio de Janeiro, 2001, pp. 51–58
18. G. J. Ward, The RADIANCE lighting simulation and rendering system. Proceedings of the 21st annual conference on Computer graphics and interactive techniques – SIGGRAPH ‘94, 1994, pp. 459–472
19. DesignBuilder Software Ltd 2013, DesignBuilder 4.1 (software). Available from https://designbuilder.co.uk/. Last accessed 10/07/2019
20. European Environmental Agency 2012, CO2 emissions per m^2 for space heating. Available from: https://www.eea.europa.eu/data-and-maps/figures/co2-emissions-per-m2-for-1. Last accessed 10/07/2019

Chapter 13
Towards a Sustainable Refurbishment of the Hellenic Residential Building Stock

Elena G. Dascalaki, Constantinos A. Balaras, Kalliopi G. Droutsa, Simon Kontoyiannidis, and George Livanas

13.1 Introduction

The buildings sector in the European Union (EU-28) uses ~42% of the total final energy consumption or 442 million tonnes of oil equivalent (Mtoe), according to the latest officially reported data for 2017 [1]. High-energy performance buildings have been among the priorities of several EU policies and are now part of the Clean Energy for all Europeans package [2] that aims to decarbonise the EU economy by 2050 and to deliver on the EU's Paris Agreement commitments for reducing greenhouse gas (GHG) emissions. The Clean Energy Package reaffirmed the important role of buildings in meeting Europe's 2030 climate and energy targets, expecting to reach about −38% savings by 2030 [3].

Since the early 2000s, the main European Directive that supports the efforts for improving the energy performance of buildings is the EPBD [4]. National transposition efforts over the past couple of decades have significantly improved the design and construction practices for new buildings and major renovations that comply with more stringent energy requirements. The new era for nearly zero energy buildings (nZEB) has emerged as of 2019 for new public buildings, and as of 2021, it will become standard practice for all new buildings.

While it is imperative that new buildings have an improved energy performance, they will have a limited impact on the energy balance of the building stock, since the annual rate of new building construction ranges from only 1.2% down to 0.4% in some countries [5]. Apparently, it is the millions of existing, high-energy-consuming and poorly performing buildings that need to gain attention and implement effective renovation measures. Currently, annual renovation rates range from 1.6% down to 0.6% [5]. Building energy renovations also provide direct benefits for building

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occupants from lower energy operating costs, better indoor environmental quality (IEQ) and well-being, among others.

With the prevailing new construction, renovation or demolition rates, it is estimated that about 70% of the building stock in 2050 already exists today [6]. Taking this into account, EPBD [4] mandates that member states develop realistic roadmaps to encourage long-term renovations of existing buildings to nZEB levels. These efforts should select and support the implementation of specific measures that will help reach the national 2030 targets and in the long-term aim at a highly efficient and decarbonised building stock by 2050. National renovation strategies are now mandated from all EU member states to consider the building stock and define suitable action plans. This obligation was actually transferred from the Energy Efficiency Directive (2012/27/EU) to the EPBD recast in 2018 [4], integrating the national building renovation strategies into the national energy and climate plans (NECP).

As illustrated in Fig. 13.1, the total final energy consumption has increased from 1995 to 2017 by 3.5% (i.e. from 1024.1 Mtoe to 1060.0 Mtoe [1]). On the other hand, the primary energy use has slightly decreased by −0.4% (i.e. from 1567.4 Mtoe in 1995 to 1561.6 Mtoe in 2017 [1]). The most notable downward trend was observed during the period of 2005–2014 as a result of the financial and economic crisis that changed the dynamics and growth rates of the different economic sectors [7]. Looking closer to the past 4 years, there is a continuous increase of final energy use since 2014. Despite the fact that the final energy use in 2017 still remained slightly under the 2020 target (i.e. 1086 Mtoe), there are concerns that it may not be possible to finally meet this target. On the other hand, the primary energy use of 1562 Mtoe in 2017 already exceeded the 2020 primary energy target (i.e. 1483 Mtoe). These trends have motivated the adoption of more aggressive EU targets for 2030 that were recently announced for an improvement in energy efficiency of at least 32.5% (compared to the 2007 baseline), an impressive reduction of 40% in

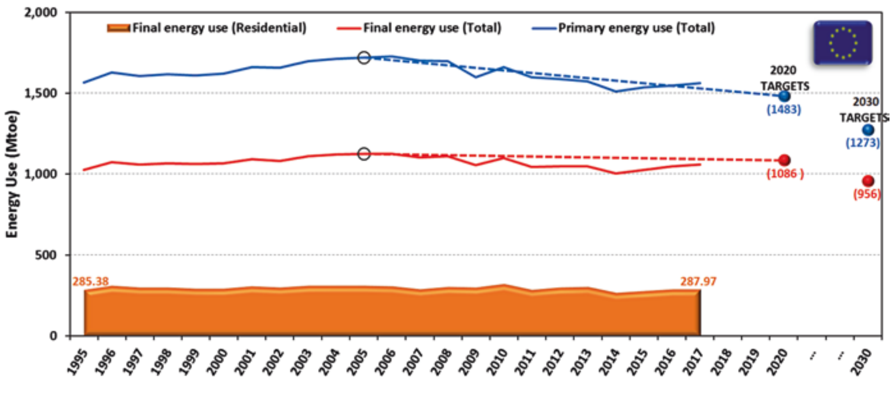

Fig. 13.1 Annual energy use in the European Union (EU-28). The dotted lines represent a linear trajectory between the 2005 actual energy use and the 2020 targets. (Data source: updated energy statistical country datasheets for 2017 [1])

GHG emissions compared to 1990 levels and a 32% share of renewables in energy use.

The buildings sector experienced an increase of the final energy use by 10.3% during the 1995–2017 period, from 400.7 Mtoe in 1995 to 442.0 Mtoe in 2017. Although new buildings are more energy efficient, it is evident that there is little progress in renovating and improving the energy performance of the existing building stock. It is evident that with the current trends, it is necessary to encourage more aggressive renovation rates to meet the new 2030 targets that translate into final energy consumption of 956 Mtoe and/or primary energy consumption of 1273 Mtoe. The new draft NECPs for the next decade that have been reviewed by the European Commission [8] reveal that the role of European buildings should be strengthened to reach the targets for energy efficiency and renewables [9].

The residential sector represents 27.2% of the total final energy or 288.0 Mtoe (Fig. 13.1) in 2017 [1]. Residential buildings exhibited an increase of the final energy use by 0.9% during the 1995–2017 period (Fig. 13.1). Residential buildings dominate the building stock with over 221 million permanently occupied private dwellings in 2017 [10], which represent ~73% of the 27 billion m^2 total building floor area, and they are projected to reach ~241 million by 2030 [10].

Over two-thirds of the European residential buildings were constructed before the 1980s (www.entranze.eu) and the widespread adoption of energy building regulations. As a result, the majority of the existing buildings do not meet today's high energy standards for the envelope thermal protection or the systems. Figure 13.2 illustrates the final energy use in European residential buildings. As expected, the member states with the largest population rank on the top with the highest energy use. Germany stands out at 56.5 Mtoe, followed by the closely grouped triad of

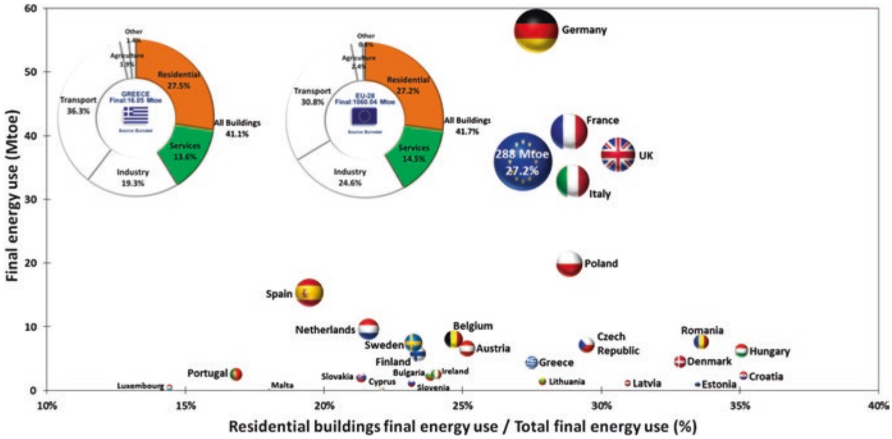

Fig. 13.2 Final energy use (Mtoe) in European residential buildings plotted against the corresponding ratio to the total energy use (%). The bubble size corresponds to the total final energy use in each member state, with the exception for the EU-28 that is purposely not to scale for illustration purposes. The doughnut charts summarise the final energy consumption by sector in Greece (left) and the EU-28 (right). (Data source: updated energy statistical country datasheets for 2017 [1])

France at 40.6 Mtoe, United Kingdom at 37.1 Mtoe and Italy at 32.9 Mtoe. On the other hand, the impact of residential buildings on the total final energy balance ranges from as low as 14.4% in Luxembourg up to 35.1% in Croatia and 35.0% in Hungary. The most important end uses in European dwellings are space heating (64.1%) and domestic hot water (DHW) (14.8%), representing 78.9% of the final energy consumed by households [11]. The most commonly used energy carriers are natural gas (36.0%) and electricity (24.1%).

This work focuses on residential buildings in Greece. It exploits the Hellenic residential building stock model [12] to assess various energy conservation measures in space heating and DHW that constitute the main end uses and evaluate the energy use and savings towards 2030. The following sections outline the main characteristics of the model and the calculation approach. New adaptation factors have been derived and used to obtain more realistic estimates. The results section then compares the model predictions against the officially reported data for 2012–2017 final energy use, demonstrating that the model can realistically capture the actual trends. The building stock model is then used to evaluate the evolution of the energy use and savings resulting from different renovation scenarios towards meeting the 2030 targets.

13.2 Hellenic Residential Buildings

In Greece, residential buildings account for 27.5% of the country's total final energy use or 4.41 Mtoe (Fig. 13.3) in 2017 [1]. During the 2013–2017 period, the final energy use increased by 17.3% following a significant drop during the preceding years that marked the recession period. The exclusive use residential buildings are ~2.99 million or ~79% of the building stock [13], and there are ~6.4 million

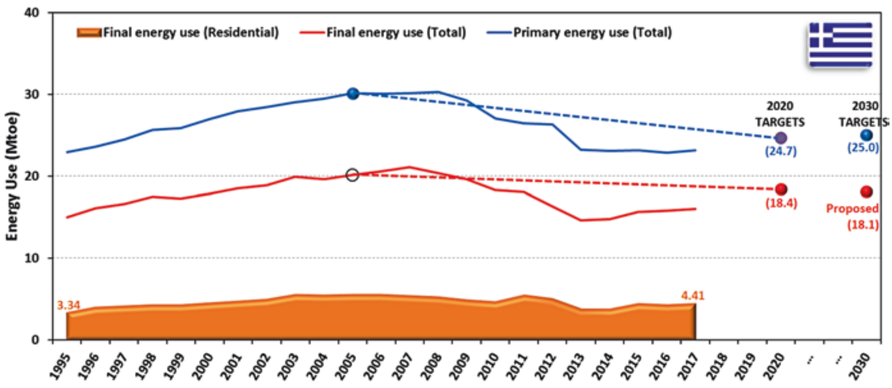

Fig. 13.3 Annual energy use in Greece. The dotted lines represent a linear trajectory between the 2005 actual energy use and the 2020 targets. (Data source: updated energy statistical country datasheets for 2017 [1])

dwellings with a gross floor area of $480 \cdot 10^6$ m^2. The dominant building types are single-family houses (SFH), i.e. low-rise buildings with one or two floors, which represent over 70% of the building stock. The remaining are multifamily houses (MFH), i.e. high-rise apartment buildings with several building units. About 55% of the total dwellings are located in SFH and the rest in apartment buildings (MFH). The detailed characteristics of the Hellenic residential buildings are elaborated in [12].

The majority of the Hellenic buildings are not thermally insulated, since ~60% were built before 1980. This is the first vintage period that marks the year when the first national regulation for building thermal protection (RBTP) was introduced in Greece. This means that the majority of the existing buildings may need, for example, the addition of thermal insulation and the replacement of windows and/or HVAC systems. The requirements for new buildings and major renovations are specified in the national regulation known as KENAK [14], which transposed EPBD in Greece since 2010. Following the national cost optimal assessment, KENAK was revised in 2017 with more stringent requirements (e.g. lower U-values, higher equipment efficiency or performance).

The most important end uses are space heating (56.2%) and DHW (13.5%) [11]. For space heating, the most common fuel is heating oil (47.9%), while for DHW the dominant energy carriers include electricity (45.3%) and renewables with solar thermal collectors (44.6%).

The national 2020 target for the final energy use has been set at 18.4 Mtoe for 2020, which is probably going to be reached (Fig. 13.3), since the final energy use in 2020 is not expected to be more than 17.3 Mtoe [8]. This may very well be part of the aftermath from the recent economic crisis and recession in Greece that has impacted all sectors resulting in reduced activities and energy use. In addition to several other socio-economic impacts, energy poverty has emerged as a major issue in Greece. In 2016, the EU Energy Poverty Observatory ranked Greece in the third place among all European member states, with a staggering ~30% of the population declaring unable to cover the energy costs for keeping comfortable conditions inside their dwelling, compared to the European average of 11% (https://www.energypoverty.eu/indicators-data).

The previous national energy efficiency plans targeted cumulative energy savings of 3.33 Mtoe in the 2014–2020 period, but the target of renovating the building sector was delayed and will be considered following 2020 [8]. For this reason, it is necessary to set more ambitious measures and policies for reaching the 2030 targets [8]. Accordingly, the proposed national energy targets for the 2021–2030 period are set for the final energy at 18.1 Mtoe and/or for the primary energy use at 25 Mtoe (Fig. 13.3). By 2030, the cumulative energy savings are estimated at 7 Mtoe [8]. The key priorities of the proposed NECP include specific actions for the renovation of residential buildings, with a priority on economically vulnerable households for combating energy poverty. The various measures include some that have proven successful in terms of their effectiveness and public acceptance, e.g. installing natural gas boilers in place of oil-fired units, the mandatory installation of solar thermal systems, the exploitation of energy efficiency obligation schemes, energy communities, etc. The plan foresees an increase of the renovation rate to 1% per year [8]. However, the NECP may be insufficiently ambitious and may have to be reconsidered and account for more measures with higher stringency.

13.2.1 Building Stock Model (BSM)

Building stock modelling is used to monitor the current state and project the future evolution of energy use and potential energy savings in the built environment. In the present study, a bottom-up building stock model (BSM) is used following the methodological structure of the European TABULA residential building typologies that have been developed for 20 European countries (http://episcope.eu/building-typology/country). Each typology consists of archetypal buildings that are defined based on the analysis of detailed statistical data from the existing buildings. This is a common approach for handling the heterogeneity and the variations encountered in real buildings. The typologies are then coupled with census and statistical data that exhibit similar characteristics to set up and populate a building stock model. The aggregated energy use is calculated for the selected representative buildings, and the results are extrapolated to the corresponding building stock. During the model development, the results are validated against the officially available data for a particular reference year.

The Hellenic residential building typology consists of 24 building types [15]. The classification is based on three characteristics:

(a) Building size that corresponds to the two categories of residential buildings, namely, SFH and MFH.
(b) Year of building construction that corresponds to the different age bands that mark representative construction practices in compliance with the national regulation in force. In Greece, the pre-1980 period corresponds to “old” buildings that have been built before the introduction of the first national regulation (RBTP) and considered without thermal insulation; the 1981–2010 period corresponds to thermally insulated buildings in compliance with RBTP; finally, the post-2011 period corresponds to buildings that have been constructed according to the requirements of the new national regulation KENAK [14].
(c) Climate zone that relates to the different location of buildings and the distribution of the building stock around the country. In Greece, four national climate zones are defined by the national regulation in KENAK [14]. They range from climate zone A in the south that mainly includes the Hellenic islands and the southern areas of the mainland with mild conditions (heating degree days averaging 858 HDD) to the northern areas of the mainland with cold conditions (averaging 2260 HDD). The different climate zones are also used to account for the availability of different energy carriers and heat supply systems that are available and may be considered during the scenario analysis. For example, in Greece, the central natural gas supply network is only available in the mainland.

Accordingly, replacing oil-fired boilers with natural gas boilers are considered in climate zones B and C. Similarly, district heating is only available in the northern parts of the country and may be considered in climate zone D.

The Hellenic BSM uses "typical" buildings that represent the building stock in each of the 24 classes. The geometry of a "typical" building reflects the characteristics of an existing example building. However, the envelope construction and the technical characteristics of the systems are calculated as weighted averages of their corresponding data derived for the building stock. The BSM includes the 24 building types (i.e. a pre-1980 SFH in Zone C) coupled with different combinations of space heating and DHW generation systems (e.g. a central oil-fired boiler and electric DHW, or local heat pumps and solar collectors for DHW). The BSM then considers different renovations that improve the building envelope characteristics and the system performance. A detailed elaboration of the Hellenic BSM is available in [12].

The BSM is setup using the latest available data from the 2010 Census, complemented with more detailed information derived from the analysis of raw data from a national survey on the characteristics of the building envelopes and systems in Hellenic households [16]. To complete the BSM, eight new building types were defined that correspond to the post-2011 construction period, i.e. new SFH and MFH for the four climate zones. New buildings comply with the requirements of the national regulation up to 2020, and thereafter they are constructed with more stringent standards that resemble the concept and characteristics of the nearly zero energy buildings. A detailed elaboration of the Hellenic residential building typology is available in [http://www.episcope.eu/building-typology/country/gr/].

13.2.2 Calculations

The overall calculation approach includes two main stages [12]. First, the annual energy performance of a typical building is calculated using the official national calculation engine (TEE-KENAK), following the European standards and a quasi-steady-state monthly method for estimating the building's energy demand. The national technical guidelines specify the average weather data that are used as input for the calculations, along with other operational assumptions. For example, the heating system operates on a continuous basis for 18 h per day, throughout the heating season depending on the climate zone, with fixed indoor conditions (e.g. indoor temperature at 20 °C). The calculations are repeated on an annual basis for all building types, towards 2030.

Usually, calculation results deviate from the actual operational energy use, with significant over- or underestimates [17, 18]. This is only to be expected since there are differences in the local climatic conditions, the unique building envelope and system operational characteristics, the prevailing IEQ conditions, the occupant behaviour and the real operational periods, among others, that deviate from the assumptions. Although there are standardized methods that can be used to calibrate simulation results to match actual energy consumption with very high accuracy, this can only be handled on a building basis. Considering the building diversities when dealing with building stocks on a regional and national basis, one needs to consider an alternative and easier process and facilitate the need for closing the gap of calculated and actual energy use.

Accordingly, the second calculation step is to adapt the predicted heating energy consumption from TEE-KENAK using empirical factors in order to make more realistic estimates of the actual energy use, which are then projected to the national building stock [12]. This is accomplished by adapting the calculated values from TEE-KENAK using empirical factors that are derived from the energy performance certificates (EPC) or collected from simple behavioural occupant surveys [19]. In this work, the set of adaptation factors have been updated with the new data presented next.

13.2.2.1 Adaptation Factors from EPCs

As of 2011, energy performance certificates have been issued in Greece in compliance with EPBD. Progressively they provide valuable information about the Hellenic building stock. Among other information, the Hellenic EPCs include the calculated primary and final energy use [14]. As an option, a small percentage of the EPCs (~3.5%) include the actual energy use (e.g. electricity and other fuels) for the operation of the buildings. This information is voluntarily provided by the building owner, processed and entered in the EPC by the building inspector, if available. When this data is available, they offer a unique opportunity to compare the calculated and actual energy use in order to derive empirical adaptation factors, which are defined as the ratio of the specific actual (operational) energy use to the normative calculated (asset) final energy consumption [19]. These factors can then be analysed and grouped for the different building types and used as multiplication factors to adapt the model predictions.

To increase confidence on the available operational data, in this work the analysis is performed using EPCs issued for whole buildings. A total of 1899 cleaned-data EPCs from the Hellenic EPCs repository (buildingcert), which have been issued from January 2011 to the end of 2018, were processed, and the results were then organized in the 24 building types. Currently, the only missing building type from the available EPC database with actual energy use is for whole MFH buildings for the most recent constructions that correspond to the post-2011 period. At this stage, the focus of the analysis is on the energy use for space heating and DHW. The normalized energy use per heated floor area of the buildings, i.e. the energy use intensity (EUI), is illustrated in Fig. 13.4 for 1734 SFH and 165 MFH whole buildings.

As one would expect, there is a notable data scatter with a coefficient of determination of 17.5% for SFH and 36.2% for MFH. This may be due to the building construction and operational characteristics, the location, the occupants' control over the actual operating periods of the heating system and preferred indoor conditions, etc. Altogether, actual operating conditions of the buildings will deviate from

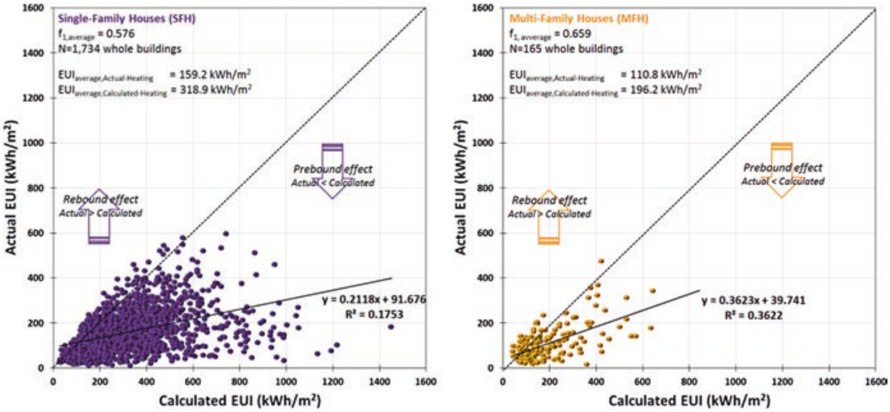

Fig. 13.4 Scatter plots for the calculated and actual space heating and DHW final energy use intensity (kWh/m^2) from 1734 SFH (left) and 165 MFH (right) whole buildings in Greece. The solid lines represent the resulting linear regressions. The 45-degree dashed lines (i.e. $x = y$) identify the (ideal) cases when the calculated and actual energy consumption values are in perfect agreement

the default values used in the calculations. For SFH, the average adaptation factor is 0.576, which means that the actual energy use is 42.4% lower than the calculated value. For MFH, the average adaptation factor is 0.659, i.e. 34.1% lower actual energy use than calculated. The result when the calculated EUIs are higher than the actual energy use is usually referred to as the "prebound" effect. This is usually expected for buildings with a poor energy performance that corresponds to a calculated high EUI, as in the case of old buildings that are not thermally insulated and/or have low efficiency systems. According to the literature, deviations may range from 30% to 47% [20–23]. On the other hand, for high performance buildings that correspond to a calculated low EUI, it is common to observe actual energy use that exceeds the calculated value. This is usually referred to as the "rebound" effect. In this case, the deviations for residential space heating that have been published in the literature range from 36% to 51% [23].

13.2.2.2 Adaptation Factors from Field Surveys

Building occupants can usually alter their behaviour and control how the heating system operates with a direct impact on the actual energy use of buildings [24]. In other words, occupants can influence their dwelling's energy performance towards higher or lower consumption. Their actions may be intentional, for example, adjusting the indoor temperature to secure the desirable indoor comfort conditions, turning on/off the operation of the heating system according to their actual occupancy patterns. They may also involve unintentional actions as a result of other externalities and influencing factors. For example, when energy prices are on the rise, occupants tend to reduce the use of the heating cost in order to reduce utilities and the operational cost of the heating system, even if they have to sacrifice thermal comfort conditions or at the extreme cases as a result of fuel poverty.

As previously discussed, the calculations in the BSM are performed for practically continuous space heating (i.e. 18 h per day) for securing a comfortable indoor environment at 20 °C, covering the entire floor area of a dwelling. However, actual operating conditions may be different. For example, according to the national survey on energy consumption in Hellenic households [16], only 11% of SFH and 8% of MFH operate heating continuously, while the vast majority (i.e. 71% of SFH and 82% of MFH) use heating for less than 8 h per day. The same national survey also reveals that only a very small percentage heat their entire dwelling, only 7% of SFH and 17% of MFH. The impacts from the emerging issue of fuel poverty in Greece as a result of the recent economic crisis and recession is also reflected by a notable trend that has forced 31% of the dwellings to turn off their central heating. Unfortunately, it is not possible to use this valuable data in the BSM since the national survey does not collect the necessary supplementary information to relate the responses and disaggregate the data to the building types.

In an effort to capture similar information, a simple electronic survey of households was initiated a few years ago, focusing on how occupants actually operate the heating systems in their dwelling [19]. The currently available data comes from 278 dwellings (of which 30% SFH and 70% MFH) for practically all 24 building types. Although this campaign does not claim to have reached a statistically representative sample, it provides some initial insight that appears to be in line with the national surveys. The results summarized in Fig. 13.5 point to some notable differentiations of the actual operating hours of heating systems, the heated floor area and the indoor temperature settings, which reveal significant deviations from the assumed operating conditions that are used for the calculations.

The available field data from the simple electronic survey of households are in general agreement with the more detailed national survey, providing confidence in the overall approach and the representative results. Accordingly, the majority of the households use their space heating system for 3–4 h in SFH and 5–6 h in MFH (Fig. 13.5a), while only about 14% in SFH and 9% in MFH use the systems for more than 16 h that resemble the assumed continuous heating used in the calculations. About 16% of SFH and 26% of MFH have turned off their central heating system since some of the residents cannot afford it. The isolation of some areas or turning off the heating systems in spaces when they are not being used is a popular and practical (re)action of occupants for reducing the energy demand. As illustrated in Fig. 13.5b, less than half heat the entire floor area of their dwelling (i.e. 38% of SFH and 44% of MFH), while the majority isolate some spaces. Finally, the average daytime indoor temperature set point that corresponds to the assumed 20 °C in the calculations is practised by only 25% of the occupants in SFH and 19% in MFH (Fig. 13.5c), while 55% in SFH and 64% in MFH maintain a lower set point temperature. The overall negative impact of these actions is reflected on the perceived thermal comfort conditions, with only half reporting that they feel comfortable in their dwellings (i.e. 52% of SFH and 45% of MFH).

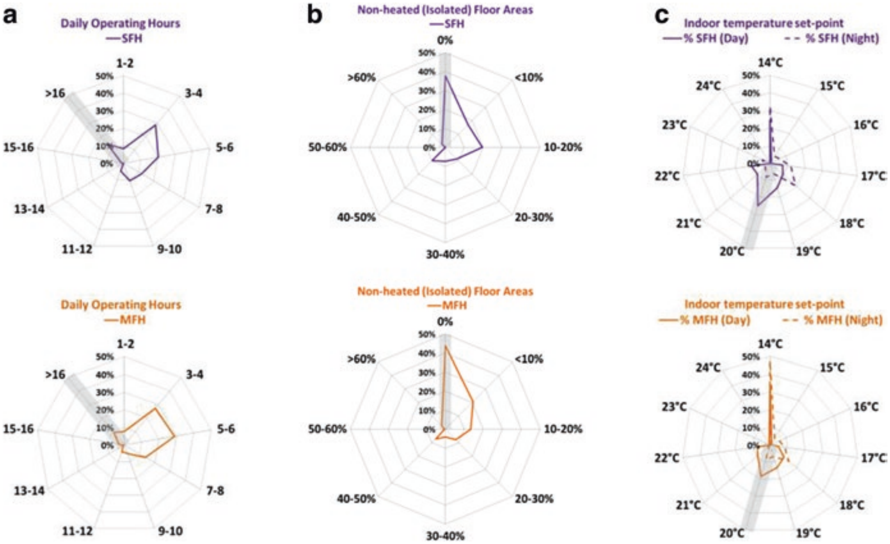

Fig. 13.5 Actual operating characteristics in SFH and MFH buildings from field surveys. The radar graphs illustrate the percentage of (**a**) daily operating hours of space heating systems; (**b**) non-heated (isolated) floor areas of dwellings; (**c**) and indoor day and night set point temperatures. The grey shaded area identifies the assumed values used in the calculations

The derived adaptation factors that address the deviations from the assumed standard conditions used in the calculations for SFH are 0.414 for the heating operating hours, 0.859 for the reduced heated floor areas and 0.885 for the indoor temperature. The corresponding values for MFH are 0.473, 0.884 and 0.845. Similar factors are derived for the different typologies and used as multipliers for correcting the calculated values to obtain more realistic estimates of the actual energy use.

13.3 Modelling the Hellenic Building Stock: A Realistic Outlook

In this work, the Hellenic BSM was used with the two new sets of adaptation factors in an effort to handle the vast diversities of specific real building characteristics and user interactions for dealing with the national building stock. The new factors from the EPCs (f_1) were organized in the 24 building types. The results reflect the general trend of actual energy use. The new factors presented in this work are based on the EPCs that have been issued for whole buildings and do not include building units (i.e. EPCs for apartments in MFH that have been collectively used in previous works [12, 19]). This approach provides better confidence and improves the data quality on the actual energy use. The new factors from the field surveys of homeowners (f_2) provide a conservative estimate of actual energy use in existing dwellings. Since the surveys were conducted over the past few years, they reflect popular behavioural reactions to the recent economic crisis and recession in Greece. The additional data that has been collected and incorporated in the field survey database does not indicate any significant deviations from what was used in previous works [12, 19]. This gives confidence that these simple surveys capture current occupant behavioural trends and uses of heating systems and can be used to monitor future trends and adapt the approach accordingly.

Table 13.1 Average empirical adaptation factors, for different building types (update: Hellenic EPC registry, buildingcert, 2018)

Construction period	Climate zone	Single-family houses (SFH)		Multifamily houses (MFH)	
		f_1 (N)	f_2 (N)	f_1 (N)	f_2 (N)
Pre-1980		0.524 (1074)	0.275 (29)	0.571 (75)	0.277 (65)
	A	0.568 (71)		0.824 (9)	
	B	0.552 (495)		0.514 (36)	
	C	0.520 (363)		0.562 (23)	
	D	0.418 (145)		0.567 (7)	
1981–2010		0.660 (654)	0.334 (55)	0.733 (90)	0.291 (129)
	A	0.750 (92)		0.666 (17)	
	B	0.641 (227)		0.758 (53)	
	C	0.655 (240)		0.737 (17)	
	D	0.633 (95)		0.643 (3)	
Post-2011		0.777 (6)		0.62[a]	
	A	0.754 (3)		0.71[a]	
	B	1.036 (1)		0.61[a]	
	C	0.329 (1)		0.35[a]	
	D	0.79[a]			
All data		0. 576	0.315	0.646	0.299

The corresponding data population (N) is included in parentheses
[a]In the absence of EPCs that include actual energy consumption for whole buildings, the values reported in [19] were adopted. As a result, the f_1 for MFH is different from the value shown in Fig. 13.4.

Table 13.1 summarizes the updated factors for adapting the deviations of actual from calculated final energy use for space heating and DHW, which have been used in the BSM during this study. The number of currently available EPCs for whole buildings that include actual energy use is not yet sufficient for some building types (e.g. recent constructions), and the derived results for (f_1) are indicative. The vision is that as the EPC database is populated with new certificates that include the valuable voluntary information on the actual energy use of the dwellings, it will be possible to easily update the corresponding empirical adaptation factors. This is actually demonstrated in this work, using the enriched EPC database from the past 8 years. On the other hand, the available data from the field surveys have not yet reached a sufficient population to cover all building types in some climate zones (e.g. there is no available data for pre-1980 buildings in zone D). Accordingly, the representative results for (f_2) have been derived and presented for only two tiers, i.e. pre- and post-1980 construction periods. Empty cells in Table 13.1 denote missing information for some specific building types in the available database. In all cases, the population of the available data is also included in order to flag cases that the available number of data may be limited.

The updated Hellenic BSM was used to assess the evolution of the Hellenic residential building stock for the period 2012 to 2030. The first step was to validate the updated BSM for a base year that was set for 2012, which defines the current state of the model that was initially developed for, and compare with the available official data. The year of 2012 was the most recent period with available data for all relevant parameters (e.g. for the existing building stock, officially reported energy use from different sectors) at the time of the initial model development. In this work, the validation process considered the officially reported data for the energy use that has been released since 2013 including the most recently published data for 2017.

13.3.1 Validation

The BSM model uses constant annual rates over the entire period of interest for the building renovation rates, new building construction activity and demolitions. In the absence of officially reported data on annual rates for specific renovation works, the corresponding values were defined considering the most popular measures in the Hellenic market and the occupants' priorities regarding building renovations from the field surveys. Accordingly, the annual renovation rates for building envelope elements (i.e. windows/walls/floors/roofs) are defined and attributed different values for the three building construction periods (i.e. pre-1980, 1981–2010 and post-2011) to represent current and future trends. Specifically, the annual renovation rate for the building envelope is set at 0.56%. Depending on the building type, different rates are used for specific building elements. For example, the popular replacement of windows (using insulated frames with double glazing) is set at an annual rate of 1.0%, since this action is easier to implement and beyond thermal protection it offers additional benefits by improving acoustical comfort, aesthetics, etc. For the technical installations and systems of each building type, the annual renovation rate is also set at 0.56%. The measures include different actions that may keep the same energy carrier, for example, replacing an old boiler with a new more efficient one. In other cases, they may also involve systems that switch to a different energy carrier, e.g. natural gas (replacing an oil-fired boiler with a new gas-fired one) or electricity (replacing the heat generation system with a heat pump). In all cases, the renovations upgrade the building envelope elements and technical systems to higher performance levels that comply with the national regulation (KENAK) requirements for existing buildings. For DHW, an annual renovation rate of 1.0% is considered for installing solar thermal collectors to cover 60% of the hot water demand, in compliance with the national regulation. Finally, the average annual construction rate was set at 0.5%, and the demolition rate was set to 0.17% per year, based on an analysis of the national building construction activity data over the past decade.

Figure 13.6 illustrates the calculated evolution of the final energy consumption for space heating and DHW in the Hellenic residential sector for the period 2012–2020. The model results are illustrated using three sets of adaptation factors, namely, f_1 and f_2 (Table 13.1) and their arithmetic average denoted as ($f_{1,2}$). The predictions corrected with the (f_1) adaptation factors represent the general trend (upper bound) of actual energy use. The results using (f_2) represent a more conservative estimate (lower bound) since these factors reflect the behavioural changes of homeowners and trends of residential energy use in recent years during the recent economic crisis and recession in Greece.

The actual energy use for space heating and DHW was derived from the national energy balance sheets with the latest official EUROSTAT national data for the years

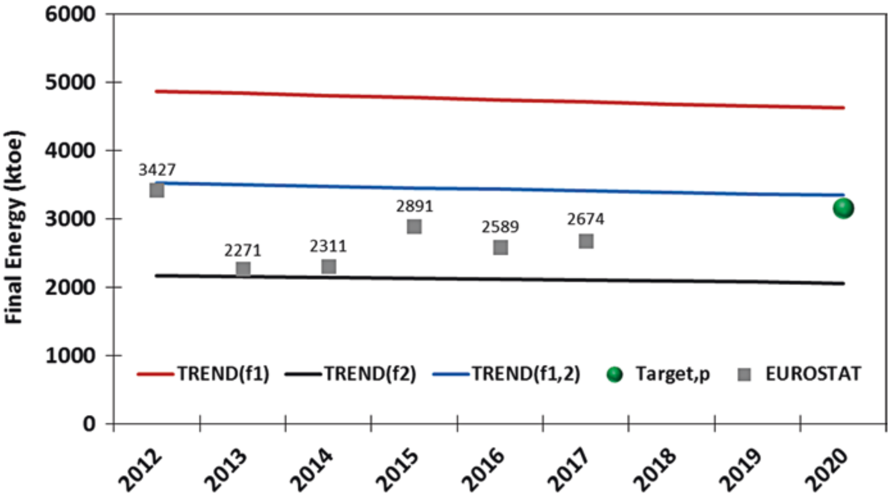

Fig. 13.6 Calculated and actual final energy use for space heating and DHW in the Hellenic residential sector for the period 2012–2020. The rectangles denote the officially reported values extracted from EUROSTAT. The bullet denotes the allocated national target for the year 2020

2012–2017 included in the 2019 edition [1]. As shown in Fig. 13.6, the values range from ~3.4 Mtoe in 2012 to ~2.7 Mtoe in 2017. Despite the significant annual variability of the actual energy use during the 2012–2017 period, the values fall within the band defined by the BSM results. Actually, they are best bracketed by the more conservative estimates shown by the Trend(f_2) and the average Trend($f_{1,2}$). This is anticipated since this historic data is from the economic crisis and recession period that has influenced the energy use in residential buildings. The overall results give confidence to the general approach and that the BSM provides results with reasonable accuracy and manages to capture the actual energy use trends for the period 2012–2017.

13.3.2 Renovation Scenarios Towards 2030

Using the information from the national energy efficiency action plan for the period 2014–2020 [25], the accumulated final energy savings attributed to the residential sector were estimated at 1932 ktoe, with annual savings in 2020 at 523 ktoe. In the draft NECP, the proposed national target for 2030 for all sectors is 18.1 Mtoe or 1.6% lower than the 2020 target [8]. Given that the plan does not allocate a specific target for the residential sector, the same total trend was adopted for deriving the 2030 target. Following this approach, the national proposed targets (Target,p) for space heating and DHW in the residential sector are set at 3.150 Mtoe for 2020 and 3.098 Mtoe for 2030. A more ambitious target (Target,a) set at 2.169 Mtoe is also considered to represent the case that a more aggressive energy action plan is required from Greece in order to collectively reach the Union's 2030 energy efficiency targets [8].

The first scenario considered towards 2030 was the business as usual ("Trend" scenario). The results are illustrated in Fig. 13.7. For this scenario, the envelope and system renovation trends and rates are the same with the ones for the 2012 building stock and the upgrades of existing buildings comply with the KENAK requirements. The Trend scenario will reach an average envelope renovation of ~10% of the total building stock and ~11% for the systems.

Again, the BSM predictions are adapted using the three sets of adaptation factors. It is easily deduced that the targets for 2020 and 2030 will be reached if the living conditions in Greece continue with similar occupant behavioural trends and limited use of the heating systems in their dwellings, accounted for by the conservative f_2 and the average ($f_{1,2}$) factors. However, this will be mainly the result of the homeowners' inability to afford proper indoor conditions in their dwellings in an effort to reduce their energy operating costs.

On the other hand, it is reasonable to expect that eventually the Hellenic economy will recover and Greece will emerge from recession. As a result, it is realistic to foresee a certain rebound in actual energy use in the residential sector. For example, building occupants may strive again to improve the indoor conditions in their dwellings by extending the daily operating hours and use their heating systems for

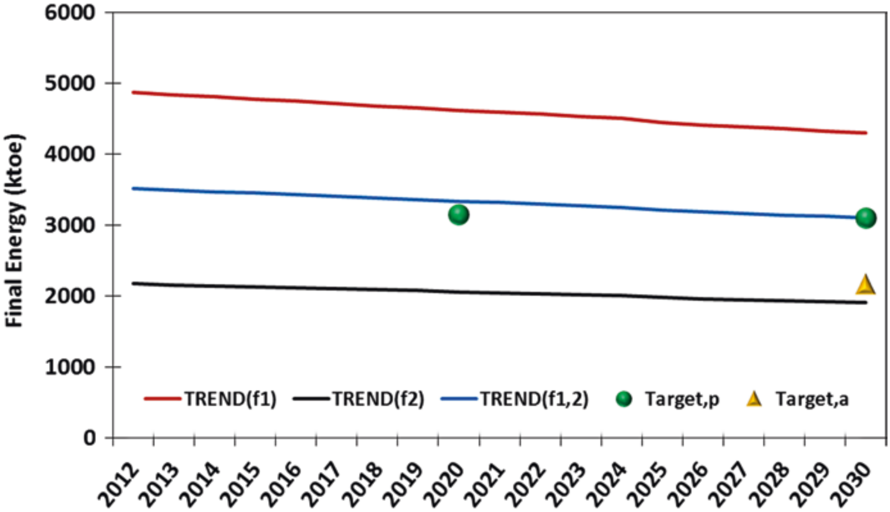

Fig. 13.7 Trend scenario results with the evolution of the calculated energy use for space heating and DHW in the Hellenic residential sector for the period 2012–2030. The bullet denotes the proposed national target (Target,p), derived from [8]; the triangle denotes a more ambitious target (Target,a)

their entire dwelling. In this case, the energy use trends may resemble the BSM results described by the Trend(f_1) line and approach the upper bound. Under these conditions, reaching the proposed 2030 target will mandate more aggressive scenarios and the implementation of a wider variety of possible measures on the envelope and systems and more intensive renovation rates.

The second scenario considered a more aggressive renovation scheme combined with the Trend (combine scenario, CS) for achieving the proposed and ambitious targets set for 2030. The results are illustrated in Fig. 13.8, along with the corresponding results from the previously elaborated Trend scenarios. For this scenario, the envelope is again upgraded to comply with the KENAK requirements, but this time with a high annual rate of 3.6% for the different elements. The renovation rate for the systems is set at 1.13%. Priority is given to measures that the system upgrades not only replace old systems but also switch to different energy carriers, for example, promoting the use of natural gas where it is available (e.g. climate zones B and C) and the use of electricity (e.g. with heat pumps) in zone A. Finally, more emphasis is given on the use of renewables in this scenario by considering a higher penetration of solar thermal systems for DHW and space heating with combi-systems. For DHW, the use of solar collectors is considered at an annual penetration rate of 10%. Solar space heating is considered in all system renovations with an annual penetration rate of 1.13%. For illustration purposes, the implementation of the combined scenario starts in 2021.

Looking into the future under a possible rebound of energy use in the residential sector after 2020, the evolution of the final energy use will be bracketed by the solid

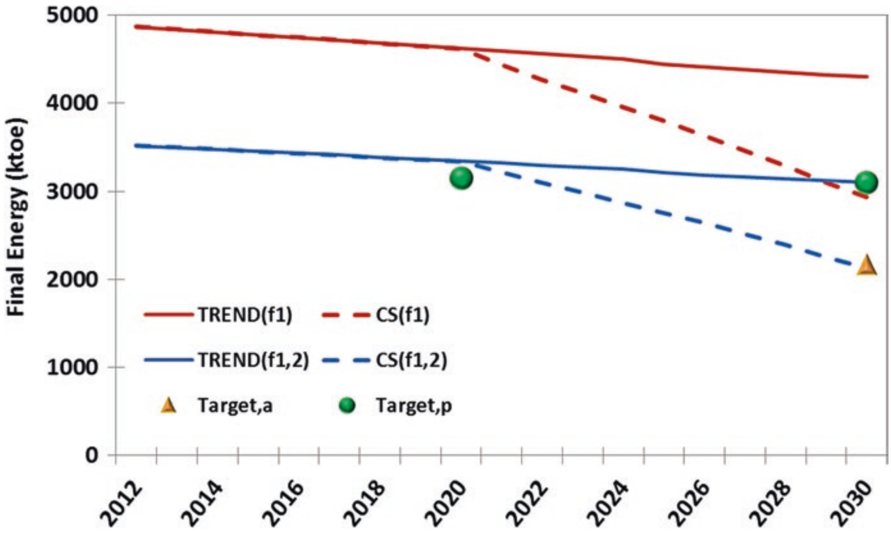

Fig. 13.8 Combined scenario (CS) results with the evolution of the calculated energy use for space heating and DHW in the Hellenic residential sector for the period 2012–2030. The bullet denotes the proposed national targets (Target,p), derived from [8]; the triangle denotes a more ambitious target (Target,a)

lines corresponding to the average ($f_{1,2}$ factors) and the upper bound (f_1 factors) model results. With the implementation of the aggressive scenario after 2020, it is possible to reach the proposed 2030 target (Target,p). In the event that the final energy use under a possible rebound remains close to the average ($f_{1,2}$ factors), the adoption of an aggressive scenario, similar to the one described in this exercise, will make it possible to achieve the more ambitious target.

13.4 Conclusions

Improving the energy performance of existing buildings is instrumental for supporting the EU policies and strategies to meet the 2030 energy efficiency targets. The residential buildings sector represents an important segment of these efforts since it uses about a third of the total final energy and is responsible for one fifth of the total CO_2 emissions. Among the different end uses of residential buildings, the energy for space heating and DHW represents 70–80% of the total final energy use in Greece and the EU-28, respectively.

The work assessed current practices and the feasibility of reducing energy use for space heating and DHW in Greece, using a reproducible and flexible bottom-up model of the Hellenic residential building stock. For the first time since the initial development of the Hellenic BSM for the base year 2012, the overall approach was updated with recently derived adaptation factors that are used to more realistically predict the evolution of the actual energy use towards 2030. The model predictions were compared against officially reported values of the actual final energy use for the period 2012–2017 and confirmed that they bracket the actual annual values. Furthermore, this study reaffirmed that the structure of the model permits easy to implement updates, giving confidence to the overall approach. To maintain or even improve the reliability of the model, one should use, if available, up-to-date input data on the actual renovation trends that are implemented to the various building components.

The updated BSM was used to assess two scenarios, one for a business-as-usual and another more aggressive scenario. Findings show that with the current trends and low energy use as a result of the recent national economic crisis and the poor indoor conditions in Hellenic dwellings, it may be possible to actually meet the 2020 target. However, as the Hellenic economy rebounds, it is anticipated that this will lead to higher energy demand in all sectors, including buildings. Policy-makers should not relax their efforts in developing and implementing a well-organized renovation plan, recognizing that this is a time consuming process, with a high financial burden. Delays in initiating the necessary efforts will require even higher annual renovation rates and deeper retrofits. Reaching the 2030 target while securing proper indoor conditions will need the right policies for encouraging and facilitating some ambitious measures and strong collaboration of the public and private sectors, supported by innovative financing instruments.

The results from the BSM can be used to inform policy-makers and as a benchmark for selecting the most effective energy conservation measures. This is valuable information for setting up realistic building renovation plans in order to meet the national energy targets allocated to the building sector. Current work focuses on extending the BSM to include representative non-residential building types and other end uses (e.g. cooling and lighting). The priority is to include the type of buildings in the service sector for which the necessary statistical data are readily available (e.g. offices and schools) and the ones with high energy use intensities (e.g. hotels, hospitals). For the other end uses, the focus is on cooling and lighting, especially for non-residential buildings. Although the annual energy use for cooling in dwellings currently averages at ~0.3% of the total and ~10% in non-residential buildings, space cooling is the fastest growing end use in buildings to combat the increasing occurrences of heat wave events, satisfying the increased indoor environmental quality requirements, especially in urban environments. Finally, the ongoing work also addresses the embodied energy and carbon emissions for new materials and system components used in common renovations for accessing operational energy savings as part of the total life cycle energy use of buildings.

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References

1. Energy statistical country datasheets, EU Commission, DG Energy, Unit A4, July 2019. https://ec.europa.eu/eurostat/web/energy/data/energy-balances
2. Clean energy for all Europeans package, European Commission. https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans
3. Y. Saheb, S. Shnapp, D. Paci, From nearly-zero energy buildings to net-zero energy districts, Technical report EUR 29734 EN, 113 p., Joint Research Centre, European Commission, 2019. http://publications.jrc.ec.europa.eu/repository/bitstream/JRC115188/kjna29734enn.pdf
4. EU Directive 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency, Official Journal of the European Union L 156, http://data.europa.eu/eli/dir/2018/844/oj
5. N.H. Sandberg, I. Sartori, O. Heidrich, R. Dawson, E. Dascalaki, S. Dimitriou, T. Vimmr, F. Filippidou, G. Stegnar, M.S. Zavrl, H. Brattebo, Dynamic building stock modelling: Application to 11 European countries to support the energy efficiency and retrofit ambitions of the EU. Energy Build **132**, 26–38 (2016). https://doi.org/10.1016/j.enbuild.2016.05.100
6. H. Visscher, E. Dascalaki, I. Sartori, Towards an energy efficient European housing stock: Monitoring, mapping and modelling retrofitting processes. Energy Build **132**, 1–3 (2016). https://doi.org/10.1016/j.enbuild.2016.07.039
7. Analysis of the annual reports 2018 under the Energy Efficiency Directive. JRC 2019. Joint Research Centre, Luxembourg: Publications Office of the European Union, 2019. http://publications.jrc.ec.europa.eu/repository/bitstream/JRC115238/kjna29667enn.pdf
8. National Energy and Climate Plans (NECPs), Energy, European Commission. https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/governance-energy-union/national-energy-climate-plans
9. EC Communication, (2019), 285 United in delivering the Energy Union and Climate Action – Setting the foundations for a successful clean energy transition: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1565713062913&uri=CELEX:52019DC0285
10. L. Gynther, B. Lapillonne, K. Pollier, Energy Efficiency Trends and Policies in the Household and Tertiary Sectors – An Analysis Based on the ODYSSEE and MURE Databases, 97 p., June 2015. http://www.odyssee-mure.eu/publications/br/energy-efficiency-trends-policies-buildings.pdf
11. Energy consumption in households, Eurostat, May 2019. https://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_consumption_in_households
12. E.G. Dascalaki, C.A. Balaras, S. Kontoyiannidis, K.G. Droutsa, Modeling energy refurbishment scenarios for the Hellenic residential building stock towards the 2020 & 2030 targets. Energy Build **132**, 74–90 (2016). https://doi.org/10.1016/j.enbuild.2016.06.003
13. ELSTAT, *Buildings Census 2011* (Hellenic Statistical Authority, Athens, 2015). http://www.statistics.gr/census-buildings-2011
14. E.G. Dascalaki, C.A. Balaras, A.G. Gaglia, K.G. Droutsa, S. Kontoyiannidis, Energy performance of buildings – EPBD in Greece. Energy Policy **45**, 469–477 (2012). https://doi.org/10.1016/j.enpol.2012.02.058

15. E.G. Dascalaki, K.G. Droutsa, C.A. Balaras, S. Kontoyiannidis, Building typologies as a tool for assessing the energy performance of residential buildings – A case study for the Hellenic building stock. Energy Build **43**, 3400–3409 (2011). https://doi.org/10.1016/j.enbuild.2011.09.002
16. ELSTAT, Survey on Energy Consumption in Households 2011–2012, (Hellenic Statistical Authority, Athens, 2013). Available in Greek: http://www.statistics.gr/statistics/-/publication/SFA40/
17. T. Maile, V. Bazjanac, M. Fischer, A method to compare simulated and measured data to assess building energy performance. Build. Environ. **56**, 241–251 (2012). https://doi.org/10.1016/j.buildenv.2012.03.012
18. A.C. Menezes, A. Cripps, D. Bouchlaghem, R. Buswell, Predicted vs. actual energy performance of non-domestic buildings: Using post-occupancy evaluation data to reduce the performance gap. Appl. Energy **97**, 355–364 (2012). https://doi.org/10.1016/j.apenergy.2011.11.075
19. C.A. Balaras, E.G. Dascalaki, K.G. Droutsa, S. Kontoyiannidis, Empirical assessment of calculated and actual heating energy use in Hellenic residential buildings. Appl. Energy **164**, 115–132 (2016). https://doi.org/10.1016/j.apenergy.2015.11.027
20. M. Sunikka-Blank, R. Galvin, Introducing the prebound effect: The gap between performance and actual energy consumption. Build. Res. Inf. **40**, 260–273 (2012). https://doi.org/10.1080/09613218.2012.690952
21. D. Dineen, F. Rogan, B.P.O. Gallachoir, Improved modelling of thermal energy savings potential in the existing residential stock using a newly available data source. Energy **90**(1), 759–767 (2015). https://doi.org/10.1016/j.energy.2015.07.105
22. D. Dineen, B.P.O. Gallachoir, Exploring the range of energy savings likely from energy efficiency retrofit measures in Ireland's residential sector. Energy **121**, 126–134 (2017). https://doi.org/10.1016/j.energy.2016.12.024
23. R. Galvin, M. Sunikka-Blank, Quantification of (p)rebound effects in retrofit policies – Why does it matter? Energy **95**, 415–424 (2016). https://doi.org/10.1016/j.energy.2015.12.034
24. B. Risholt, T. Berker, Success for energy efficient renovation of dwellings – Learning from private homeowners. Energy Policy **61**, 1022–1030 (2013). https://doi.org/10.1016/j.enpol.2013.06.011
25. YPEKA, Long Term Strategy Report mobilizing investments in the renovation of residential and commercial buildings, public and private, of the national building stock, Pursuant to Article 4 of Directive 2012/27/EU, Athens:Hellenic Ministry of Environment, Energy and Climatic Change, December 2014. Available online (in Greek): http://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficiency-directive/national-energy-efficiency-action-plans

Chapter 14
Design Strategies for Green/Energy-Efficient Building Design: An Apartment Building in the Gaziantep Project

Gülser Çelebi, Mine Yazıcıoğlu, and Mehmet Tunçer

14.1 Introduction

One of the most important features of the architectural designs of environmentally friendly buildings is energy use and efficiency. According to the environmentally friendly project, which was supported by the Ministry of Environment and Urbanization (achieved in Gaziantep), the main planning objective was adopted to design buildings that are applicable to the country's conditions and needs. While starting the planning process, topography, the traditional pattern of the build environment, and structural features have been thoroughly evaluated, and the planning decisions were created by transferring elements from traditional to contemporary planning language. Firstly, the adaptability with the topography was considered, and the design decisions were produced with the least intervention. Radically shaping the site is not only expensive, but it also damages the microclimate of the region (Fig. 14.1).

In the planning process, design parameters that are also effective in energy conservation were defined such as the site selection, organization of the streets, orientation of the buildings, intervals, etc. By controlling these parameters, the plan is to design a district that requires the least active systems and thus minimize the use of non-renewable energy resources. This basic approach also shaped the architectural design strategies.

Today, energy efficiency for buildings is achieved by systematically reducing the demand for heating and cooling. Related to this approach, reducing the energy consumption burden with the most appropriate architectural design and optimizing all the energy-consuming systems separately and integrally with the architecture should be used as an inevitable method in the designs. According to [1] Hitchcock's (2003) definition, the objective of indicators that determine the performance of the

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Fig. 14.1 Partial section of the buildings and site

building is the study of revealing in a dynamic and structured format using quantitative definitions. In this context, the building's energy performance indicators are used to determine the building's performance targets more clearly and quantitatively. Documentation of performance data provides "value" throughout the life of the building, from the planning phase of the building to the use and operation of it.

14.2 Energy-Efficient Building Design Decisions

Within the scope of the target mentioned above, energy-efficient building design decisions, transferred to the physical environment, focus on the use of "passive design", "active systems", and "resource conservation and local material use".

14.2.1 Passive Design Principles and Strategies

The most effective way to achieve an environmentally friendly building is to use passive air conditioning. Passive systems are an arrangement created with building elements without using any mechanical and electrical systems. Therefore, in the early design phase, it is inevitable to determine the principles based on climatic data. The purpose of designing buildings based on natural air conditioning is to meet the climatic needs of human beings at the level that requires minimum additional energy with the help of natural conditions.

Solar radiation, air temperature, air humidity, wind or air movement, and existing natural events are the parameters determined by the climatic characteristics in passive systems [2]. In other words, geographical location, altitude (sea level), atmospheric conditions, topography, vegetation, thermal and physical properties of open spaces in the built environment, settlement and location, and geometrical properties such as form and surface materials of the surroundings determine the microclimatic features of the region [3–8]. Within the light of research, the benefit of passive cooling from wind and heating from the sun is preferred as a design decision. Necessary for deciding upon the passive air conditioning of the design and for the simulation of the buildings are firstly, the climatic data of the region, which is obtained from the internet [9]. The region is in the southern part of Turkey, which is located at the transition point of the Mediterranean and continental climate and is influenced by the Mediterranean climate. Generally, the summers are hot and dry, and the winters are cold and rainy. Climatically in passive design, the decision principles of "natural ventilation and wind control", "sun control and natural daylighting", "green roof", and "envelope design and insulation" are considered as the dynamics of design.

14.2.1.1 Natural Ventilation and Wind Control Principles and Strategies

As is known, natural ventilation in buildings is caused by the "pressure difference" through openings. Air flow can provide an appropriate temperature level and remove contaminants from the interiors. In other words, natural ventilation is an environmentally friendly method in which a building can be ventilated without energy. As a design strategy, a convective current such as the "warmed air rises" principle is used for both air circulation, indoor air quality control, and for passive heating and cooling purposes. In summer, simple natural ventilation is possible by allowing the wind to enter through low-level openings (windows, canals, etc.) and releasing heated air from the openings at the upper level openings. Based on this principle, three approaches were adopted to provide summer and winter comfort and strengthen ventilation in design: The first one was the *chimneys*, the second was cross ventilation, and the third was courtyard/*atrium designs.*

According to the *first approach,* specially designed chimneys are used for summer and winter conditions. For summer, it is proposed to cool the interiors by humid air with the help of a propeller by spraying water into the chimney (Fig. 14.2). The chimneys are also designed to be used as a wind catcher.

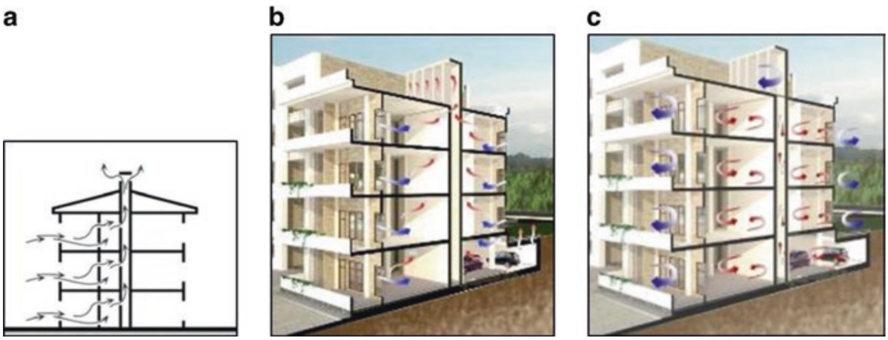

Fig. 14.2 (**a**) Natural ventilation and chimney use for passive energy control in apartment building: (**b**) summer (left), (**c**) winter (right)

In the *second approach*, cross ventilation was effectively used to provide summer and winter comfort and strengthen the ventilation in the buildings (Fig. 14.3a). The stairs were placed in the direction of the prevailing wind, and the openings (windows and doors) were placed facing each other, the aim being to ventilate and cool the apartment buildings in summer (Fig. 14.3b). By closing the openings in winter, the sun directly enters the inside of the buildings.

Since the duration of hot weather is longer than cold weather (approximately 8 months), the principles of the cooling of the buildings were mainly discussed in the Gaziantep project. Also, the height of the apartments was decided as 3.40 m like traditional houses in order to cool and heat the inner spaces by the circulation of heated or cooled air. And additionally, the ceiling was designed with space suitable for the installation equipment of cooling and heating and connected to the chimneys (Fig. 14.4).

Some of the apartment blocks were designed with upper windows, which are called “bird windows”, and are directly related to the traditional houses in Gaziantep (Fig. 14.5a, b).

In addition to the above-mentioned approaches; the *third approach* is based on the courtyard design. In hot-dry climatic zones, the courtyard provides spontaneous air currents between the building and the courtyard through convectional heat transportation [10–13].

In the Gaziantep project, the courtyard effect is directly related to traditional architecture. Water elements were also used in traditional courtyards to ensure the moisture balance of the environment. In other words, ponds provide an effective solution to keep the humidity moist in summer (Fig. 14.6a–c). The area of the courtyard surface, height of the building, the dimensions and position of the courtyard openings, direction of the wind [14], and the total width of the openings are considered as variables affecting the quantitative and qualitative characteristics of the wind in the courtyard [12]. Within the context of research, the design of the courtyard openings is designed according to cross ventilation, which is “perpendicular to

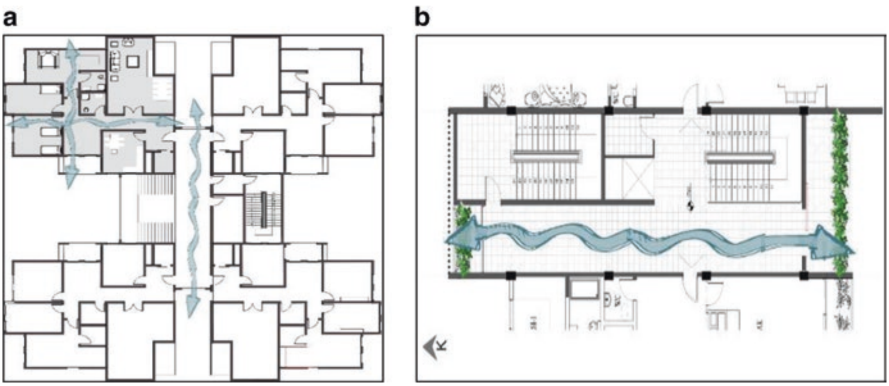

Fig. 14.3 (**a**) Cross ventilation and cooling design strategy for passive climate control. (**b**) Ventilation at stairs for cooling

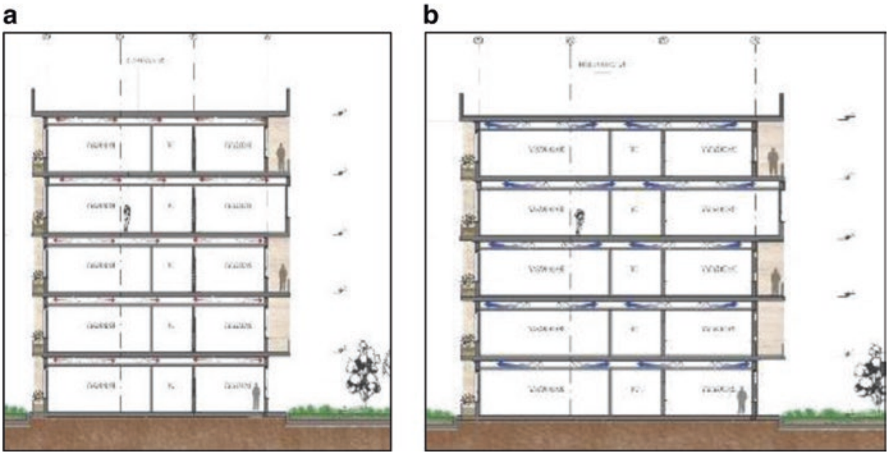

Fig. 14.4 (**a**) Hot air circulation and (**b**) cooling principles at ceiling level

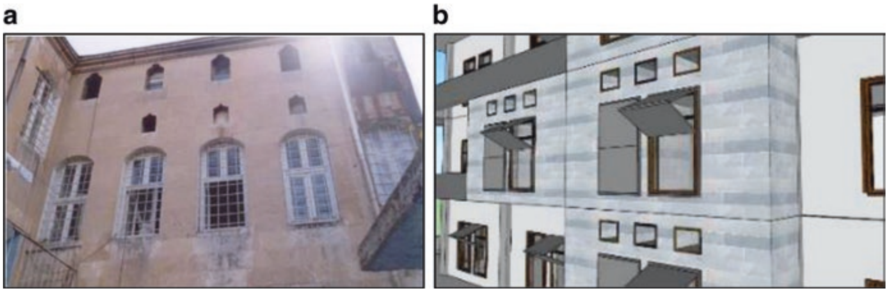

Fig. 14.5 (**a**) "Bird windows" in a traditional Gaziantep house, (**b**) contemporary interpretation of "bird windows" in the design

the wind direction" in apartment buildings. In order to ensure indoor air quality and wind control in the ventilation of indoor spaces, narrow or wide openings were left relative to the prevailing wind, the Venturi event was realized, and the wind speed was controlled in the summer and winter seasons.

14.2.1.2 Sun Control and Natural Daylighting

In the passive solar design, exterior solar control elements (shadings) are effective passive solutions in terms of their ability to capture and control solar radiation [15, 16]. The most significant reason for using a shading device is to prevent the penetration of direct sunlight and solar radiation into the building in the cooling period and to permit the wanted solar gains in the heating period [17, 18]. The primary way of utilizing the sun for passive heating is to open the shading devices and use the windows as solar collectors. According to this approach, passive heating can be realized

Fig. 14.6 (**a**) Courtyard and water element (pool) use between apartment blocks. (**b**) Courtyard design between apartment blocks. (**c**) Apartment view from courtyard

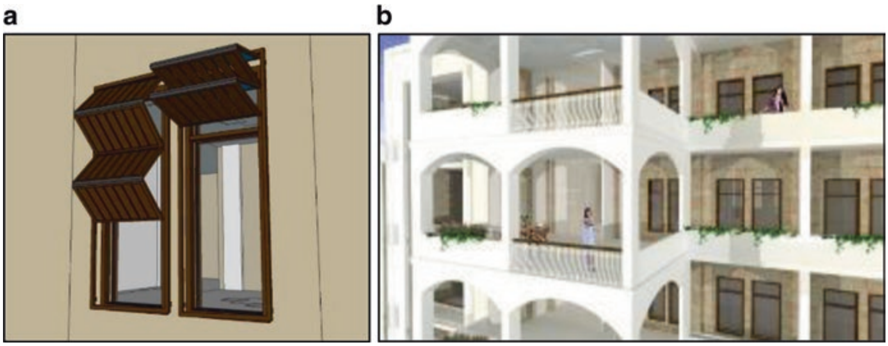

Fig. 14.7 (**a**) Roller shutters for sun, rain, and wind control. (**b**) Balconies used for shading

by using the greenhouse effect based on the reaction of the glass towards thermal radiation [19]. In addition to shutters (roller and insulated shutters), awnings, blinds and curtains, balconies, horizontal eaves, vertical sunshades, and composite elements (combination of horizontal and vertical elements) were decided for the project (Fig. 14.7a, b).

On the other hand, daylighting is the general practice of having vertical windows and openings in a wall exposed to incoming solar radiation to receive natural light inside the room during the daytime. Vertical-shaped windows and "bird windows" allow daylight to enter the interior spaces while controlling the solar radiation

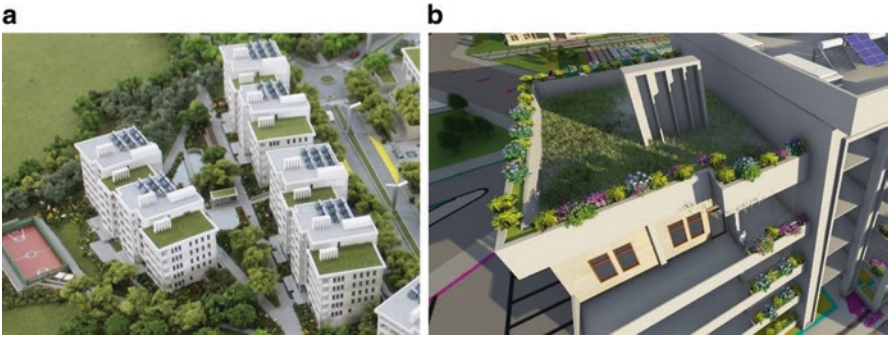

Fig. 14.8 (**a**) A group of apartment blocks designed with green roof. (**b**) Green roof and chimney

(Figs. 14.6 and 14.8). Daylighting is the use of light from the sun and sky to complement or replace electric light. With proper window shapes, size (window to wall ratio), and glazing types, daylight can also significantly reduce the need for artificial lighting.

14.2.1.3 Green Roof

In the design of the buildings, green roofs were used in potential buildings where the heat island effect could occur. Thus, there was an attempt to reduce the heat island effect, and it was thought to decrease the thermal stress by helping to reduce the effect of the temperature changes in the settlement. In addition, green roofs were used to protect the roof from ultraviolet rays and mechanical damage (Fig. 14.8a, b).

14.2.1.4 Envelope Design and Insulation

Regarding energy statistics, the rate of heating energy consumption caused by residential buildings is almost 30% in Turkey. For this reason, residential buildings have an important role in reducing energy needs and greenhouse gas emissions. Depending on the building's energy consumption structure, the thermal performance of the building envelope is the main factor affecting energy consumption [2]; thus, the thermally insulated walls can reduce the energy consumption of either the heating or cooling system [20].

An effective insulation conserves energy and consequently requires less energy for space cooling in the summer and less heat to keep the house warm in the winter. In traditional buildings, materials with high specific heat such as stone, brick, and concrete are included in the structure as thermal mass, and the buildings are kept cool in summer and warm in winter. This feature is often used for heat storage in the passive design.

In terms of controlling the heat transfer in the envelope design of the contemporary buildings, the choice of wall material and coating material, the use of air layers, the choice of thermal insulation material, and the design of glass surfaces (transparent surface ratio) are important factors. As known, heat preservation in the envelope is provided by *thermal insulation*, while the heat storage ability is determined by *thermal mass.* Thermal insulation is used to reduce the heat loss or gain through the building envelope (external walls, windows, roofs, foundation, etc.). Thermal insulation creates a barrier between the warm air inside the house and the cold air outside and vice versa. The better this barrier is, the less energy the building needs for cooling and heating. Therefore, using insulation materials can help to reduce energy consumption and increase thermal comfort. Building materials have the capacity of heat storage in their structure according to their specific heat values and thicknesses. This rule was adopted in the design process. During the material selection, researchers stated that there was no single material that combined both heat preservation and thermal mass.

Therefore, the material selection and arrangement of the envelope layers were determined by taking these two properties into consideration. In other words, the layers were designed according to the thermophysical and hygothermic control rule of the envelope, and material selection was suggested for the wall construction. The materials with the highest thermal resistance were located closest to the cold surface of the envelope, and the materials that were high vapour permeability resistant were located closest to the hot surface of the envelope.

14.2.2 Active Solar Systems

In the design, passive cooling, passive heating, wind pressure ventilation principles, and passive air conditioning had priority. In the periods when the requirements cannot be met by the passive systems, it is considered to integrate strategies with various additional climatic control systems, and an integrated solution was proposed with active systems. Active air conditioning systems are the systems that convert the received solar radiation into electricity and heat energy and enable the efficient use of solar energy in buildings.

Among renewable energy sources, *PVs are* the most effective ways to generate electricity from the sun, which is the easiest to access, abundant, and clean. To receive maximum solar radiation and for the effective use of PV panels, they must be directed towards the sun at an angle corresponding to the local latitude. Turkey is between 36°–42° north latitude and 26°–45° east longitude. Turkey 36°–42° north latitude, 26°–45° is located between east longitude. In the apartment blocks, the PV panel stand is positioned so that it faces the sunlight perpendicularly during the day and at noon during the summer and winter seasons. The latitude angle of Gaziantep is 37°. Thus, the PV stands were positioned at 37° to the south. PV panels are only used for lighting and operating the elevators.

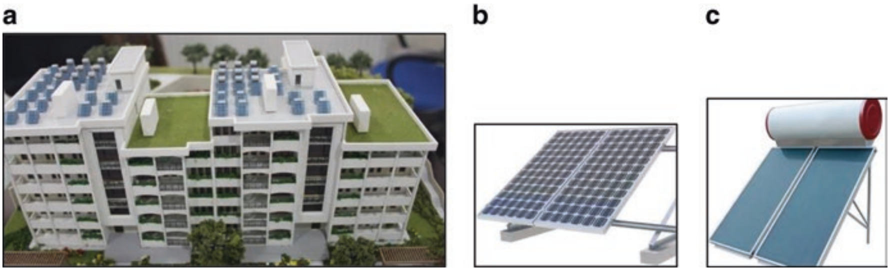

Fig. 14.9 (**a**) Schematic presentation of PVs and solar collectors on flat roof. (**b**) PV panel. (**c**) Vacuum tube solar water heater.

In the studies (conducted by the mechanical engineers in the team) carried out for the project, it was deemed compatible to meet the hot water requirement of the buildings with *solar collectors*. Solar collectors are used in the heating of water. These are systems that operate through the logic of collecting and intensifying the radiation emitted from the sun. Solar collectors were also located near the PV panels, in the same direction and angle on the roof of the apartment blocks (Fig. 14.9a–c).

14.2.3 Resource Conservation and Local Material Use

Buildings consuming huge amounts of energy and natural resources have an impact on climate change by affecting the quality of air and water in cities [21]. On the other hand, construction is an important sector in a country's economy and an important player in a nation's energy consumption, natural resources, greenhouse effect, and carbon emissions. The three strategies for the resource consumption principle are energy conservation, material conservation, and water conservation. Each focuses on a particular resource necessary for building construction and operation [22]. Design decisions on energy efficiency were mentioned above. In this section, the design strategies for resource conservation will be considered.

The quality of the source before entry to a building and after exit is different. Energy transforms into burnt waste/by-products, construction materials into solid wastes, water into grey or sewage water, and consumables into waste or recyclable materials. Within this context, it is possible to classify the methods of conserving resources with two approaches: One is reducing the non-renewable resources that generate input into the building. And the second is reducing environmental pollution through waste management. In the first method, it is essential to reduce the entrance of all non-renewable resources to the building. The second method is to reduce environmental pollution by controlling the amount of waste and by using an efficient waste management approach. Taking these assumptions into consideration, design decisions were made and proposed for other stages of the project.

In the current situation, from the point of the resource conservation, the interaction of the construction materials with the environment is determined by the life cycle assessment method (LCA). LCA is a useful technique for assessing and improving the environmental performance of a product, process, or activity, considering all the steps over its life [23]. The LCA method includes strategies for three phases: pre-production, production, and post-production. Strategies in these phases can lead to design methods to improve the environment-friendly architecture.

In this uncompleted project, a team will continue to work on the proposed building materials and decide on the appropriate materials. Nevertheless, recommendations have been made to reduce transportation energy and focus on local sustainable resources.

Godwin [24], in his research on traditional buildings, presents a number of traditional materials and techniques to meet the emerging standards for sustainability and energy conservation. He describes how these buildings behave in a way that meets sustainable criteria and can be further enhanced to be more sustainable without harming their character. This is an important issue in Anatolia, which has a considerable number of traditional and historic buildings, and as such, there is significant pressure to reduce carbon emissions. The most important factors affecting the building of traditional Gaziantep houses are the climatic adaptation and surrounding resources (such as stone, timber, brick, etc.). It is seen that in the construction of the houses, the most abundant materials were used (Fig. 14.10a, b). Therefore, it has been suggested that these materials with sustainable resources should be used as a priority today. However, with the change of construction techniques and the development of new technologies, it is impossible to maintain these materials with the same technology today. In this context, it is proposed that all the buildings in the project should be constructed with environmentally friendly contemporary construction and materials to be procured from the region.

Water is another source that needs to be protected. Water conservation can be achieved either by reducing the amount of water entering the building, by reducing the amount of waste water, or by means of both methods [26–28]. Waste water from

a b

Fig. 14.10 (**a**) Use of local materials as floor covering and (**b**) stone structure in traditional Gaziantep buildings [25]

Fig. 14.11 Proposed rainwater collection system for apartments

buildings includes grey water and black water. Grey water is waste water from basins, sinks, baths, and showers, and black water is waste from WCs and urinals. Grey water can be cleaned, and this saves 40% of water requirements [28]. Grey water is a valuable resource for gardening and growing plants, especially in arid areas, and contains much less nitrogen than black water. The treatment of black water is more complex. In the project, attempts have been made to develop methods to reduce or eliminate the use of drinking water or other surface or groundwater resources in WCs and landscape irrigation. A grey water conversion mechanism has been proposed for domestic waste water coming from the kitchen, washing machine, and bathroom. And suitable installation spaces have been created in the projects. Rainwater collection systems have been proposed for watering roofs and balcony flowers [29] (Fig. 14.11).

14.3 Conclusion

Not all the studies in the Gaziantep project have been completed yet as was stated above. Nevertheless, energy-efficient design strategies which are considered in architectural design language have been established. All the buildings in the project have been designed considering the local dynamics of the region and scientific studies. In sustainable, eco-friendly, energy-efficient design, the buildings are intended to reflect the spirit of the place, to include the modern city identity, and to be original in a contemporary sense.

References

1. R.J. Hitchcock, "Standardized Building Performance Metrics – Final Report", Ernest Orlando Lawrence Berkeley National Laboratory Report, 3–9, 2003
2. N.K. Bansal, G. Hauser, G. Minke, *Passive Building Design: A Handbook of Natural Climatic Control Amsterdam* (Elsevier Science B.V, New York, 1994)
3. F. Harkouss, F., Fardoun, F., Biwole P. H., Passive design optimization of low energy buildings in different climates, Energy, 165, Part A, 591–613, 2018
4. V. Olgyay, *Design with Climate* (Princeton University Press, Princeton, 1973)
5. S. K. Mandal, K. Sinha, "Achieving Energy Efficiency in Buildings Design through Innovative Planning and Design Solutions" *International Conference on Sustainable Built Environment* (ICSBE-2010), Proceeding Book, Kandy, 13–14 December, 2010
6. N. Lencher, *Heating, Cooling, Lighting* (John Wiley & Sons, New York, 2015). (4.th Edition)
7. C. Ernesto, O.G. Capeluto, Strategic decision-making for intelligent buildings: Comparative impact of passive design strategies and active features in a hot climate. Build. Environ. **43**, 1829–1839 (2008)
8. M. Gercek, Z.D. Arsan, Energy and environmental performance based decision support process for early design stages of residential buildings under climate change. Sustain. Cities Soc. **48**, 101580 (2019)
9. Gaziantep, ˙Iklim: Gaziantep – ˙Iklim grafigi, Sıcaklık grafigi˘, ˙Iklim tablosu Climate-Data.org.in, (2018), https://tr.climate-data.org/location/286/
10. D. Etheridge, *Natural Ventilation of Buildings: Theory, Measurement and Design* (Wiley, Chichester, 2012)
11. Z. Zamani, M. Taleghani, S.B. Hoseini, Courtyards as solutions in green architecture to reduce environmental pollution. Energy Educ. Sci. Technol. Part A: Energy Sci. Res. **30**(1), 385–396 (2012)
12. Z. Zamani, S. Heidari, P. Hanachi, Reviewing the thermal and microclimatic function of courtyards. Renew. Sust. Energ. Rev. **93**, 580–595 (2018)
13. A. Sharma, K.K. Dhote, R. Tiwari, Climatic responsive energy efficient passive techniques in buildings. IE (I) J. AR **84**, 17–26 (2003)
14. S. Sharples, R. Bensalem, Airflow in courtyard and atrium buildings in the urban environment: A wind tunnel study. Sol. Energy **70**(3), 237–244 (2001)
15. S.B. Sadineni, S. Madala, F.R. Boehm, Passive building energy savings: A review of building envelope components. Renew. Sust. Energ. Rev. **15**(8), 3617–3631 (2011)
16. J. Souviron, G. Moeseke, A.Z. Khan, Analysing the environmental impact of windows: A review. Build. Environ. **161**, 106268 (2019)
17. A. Kirimtat, B.K. Koyunbaba, I. Chatzikonstantinou, S. Sariyildiz, Review of simulation modeling for shading devices in buildings. Renew. Sust. Energ. Rev. **53**, 23–49 (2016)
18. A.Y. Freewan, Impact of external shading devices on thermal and daylighting performance of offices in hot climate regions. Sol. Energy **102**, 14–30 (2014)
19. G. Evola, F. Gullob, L. Marletta, The role of shading devices to improve thermal and visual comfort in existing glazed buildings. Energy Procedia **134**, 346–355 (2017)
20. L. Aditya, T.M.I. Mahliaa, B. Rismanchic, H.M. Nge, M.H. Hasane, H.S.C. Metselaare, M. Oki, H.B. Aditiyab, A review on insulation materials for energy conservation in buildings. Renew. Sust. Energ. Rev. **73**, 1352–1365 (2017)
21. S. Vyas, S. Ahmed, A. Parashar, BEE (bureau of energy efficiency) and green buildings. Int. J. Res. **1**, 23–32 (2014)
22. G. Çelebi, Environmental discourse and conceptual framework for sustainable architecture. Gazi University J. Sci. **16**(1), 205–216 (2003)

23. M.M. Khasreen, F.G. Banfill, G.F. Menzies, Life-cycle assessment and the environmental impact of buildings: A review. Sustainability **1**, 674–701 (2009)
24. P.J. Godwin, "Building Conservation and Sustainability in the United Kingdom", The 2nd International Building Control Conference 2011, Procedia Engineering **20**, 12–21, (2011)
25. https://anadoluevleri.com/. Access date 4 Jan 2019
26. I. Şahin, G. Manioglu, Water conservation through rainwater harvesting using different building forms in different climatic regions. Sustain. Cities Soc. **44**, 367–377 (2019)
27. S. Pradhan, G. Sami, R.M. Hamish, Greywater recycling in buildings using living walls and green roofs: A review of the applicability and challenges. Sci. Total Environ. **652**, 330–344 (2018)
28. P. Sassi, *Strategies for Sustainable Architecture* (Taylor & Francis, NewYork, 2006)
29. D.J. Leggett, *Rainwater and Greywater Use in Buildings: Best Practice Guidance* (Construction Industry Research and Information Association, Department of Trade and Industry, CIRIA, London, 2001)

Chapter 15
A Sustainable Approach Towards Energy Savings in the Cities of Romania, Bucharest: A Case Study

Ana-Maria Dabija and Ileana Nicolae

15.1 A Brief History of the Residential Collective Apartments in Bucharest

At the beginning of the twentieth century, Romania was a young kingdom, independent from the Ottoman Empire since 1877 with a capital city that needed to organize itself and host the main institutions in representative buildings (mostly constructed in the last decades of the nineteenth century and the beginning of the twentieth century). According to Andreea Udrea [1], 1906 is the year when the first competition for the systematization occurred. 1906 is the first moment that marks a change in the way the city is defined, all the previous approaches focusing on solving punctual, local problems. It probably is the moment when the great Modernist Boulevard of Bucharest – the Magheru Boulevard – was cut on the map. The work lasted more than 20 years, but the result was a broad urban artery, delimited by genuine modernist style multistorey buildings (Fig. 15.1).

With the constructive system of these high-rise buildings of the 1930s, the reinforced concrete structure was closed with what was called "American masonry". In fact 28-cm-thick walls that were composed by two walls of bull stretcher bricks were connected with header bricks (Fig. 15.2). The system provided a thermal insulation that was superior to the regular brick wall thermal insulation [2].

In the same period, at the borders of the city, new districts of cheap housing were developed: daintily houses that recreated the traditional lifestyle of the inhabitants

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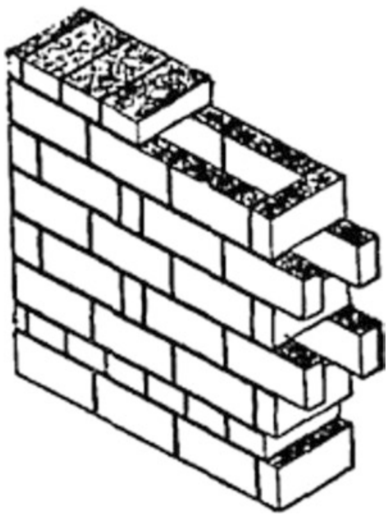
Fig. 15.1 Magheru Boulevard, Bucharest. (Photo: Ana-Maria Dabija)

Fig. 15.2 "American" masonry – system used in the buildings of the 1930s, in Bucharest. (Photo: V. Asquini, Technical Indicator in Buildings, 1946 [2])



or one-storey row houses separated by small gardens were designed by (today) renowned Romanian architects (Fig. 15.3).

After the war, a new style of buildings was imported from the USSR, along with the political regime (Fig. 15.4). The neoclassicist style of the residential apartment buildings, with arched entries that led to inner courtyards where domestic activities were carried out, is spread in several parts of Bucharest.

Fig. 15.3 Vatra Luminoasa, Bucharest, arch Ioan Hanciu, and arch Niculai Aprihăneanu. (Photo: Ana-Maria Dabija)

Fig. 15.4 Soviet-type collective residential buildings. (Photo Ana-Maria Dabija)

As the industrialization process developed, in the 1960s, 1970s, and 1980s, the need to accommodate the workers led to an intensive building activity. New districts were created in the cities, with residential collective buildings developed as did the corresponding administrative and cultural centres. New towns appeared, related to the industrial areas, facilitating the migration and the accommodation of the newly risen labour force.

The thermal agent was supplied to the residential collective buildings form the thermoelectric power stations (CTE), which mainly produced electricity, heat being a by-product that was transported through major channels to the thermal points in the vicinity of the residential buildings. Today, we could consider these power stations as combined heat and power stations (CHP) and very modern as a concept. Unfortunately, the lack of maintenance of the overall system leads to massive loss of thermal energy through the urban ducts that connect the power station to the end user (Fig. 15.5), which led, in recent years, to the use of individual heating systems (a less ecological system, however).

During the twentieth century, the architecture of the residential buildings in Romania changed its style every decade: the Sovietic style was in use for only a decade (in the 1950s), after which the reinterpretation of the modernist style (in the 1960s) took over, as the same architects worked after the Sovietic decade. The 1970s came with a change of technology: reinforced concrete panels proved to be a valid option in a country that built massively collective residential buildings. The prefabricated systems provided a very good response to the major earthquake of 1977 so they were largely used until 1989. However, the buildings constructed with large reinforced prefabricated panels were ugly and therefore were used inside courtyards, at the second front of buildings, while more representative, sometimes

Fig. 15.5 A winter morning in Bucharest, 2019. The heat – hot steam – is lost in the ducts that lead from the thermoelectric power stations to the buildings. (Photo: Ana-Maria Dabija)

Fig. 15.6 Buildings of the 1980s: facing the boulevard and facing the inner courtyard/second line of buildings. (Photo Ana-Maria Dabija)

unique residential buildings, with more expensive finishing systems, were facing the newly cut boulevards (Fig. 15.6).

Research was carried out in the 1980s to produce reinforced concrete panels with no thermal bridges, as the first generation of prefabricated panels had a thermal insulated core but concrete margins. These panels had a good seismic response but a terrible hygrothermal response, as the thermal bridges were the cause of condensation and even water leakage in the period when the indoor temperature in the buildings was low (during the 1980s).

In the mid-1980s, as the postmodern architectural style spread, the Robert Venturi[1] "less is a bore" resonated with the taste for decoration of the political rulers of Romania. The Unirii Boulevard (Fig. 15.7) that leads to the House of the People[2] was an attempt of the architects of the period to create in the postmodernist style.

Immediately after the Revolution of 1989, The Petre Roman Government issued the Decree-Law no. 61 of 1990, which allowed the tenants to purchase the apartments that they were living in and were owned by the state.

In just 3 years, the state gave away about 1.8 million apartments, and, as the local currency dropped, in a few months, the value of the apartments was lost. In order to exemplify, in 1990 the cost of a two-bedroom apartment built 30 years before was 123,000 lei, slightly above the price of a Romanian car, and could be paid with 30 average salaries. The prices established by the law have been preserved in the following years, but inflation was rampant, so the value of apartments has dropped to about ten average salaries in 1991 and then to four in 1992 and only to one salary in

[1] American architect "less is a bore" is stated in opposition to "less is more" promoted by Mies van der Rohe. Mies van der Rohe architecture emphasizes simplicity in lines and means while providing elegance, whereas the postmodern movement in architecture – announced by Robert Venturi's syntagma – uses decorative means that resonate in the local culture and history. The emphasis is given on highly decorated facades.

[2] Romanian Parliament. Currently the world's second largest administrative building.

Fig. 15.7 The Unirii Boulevard. (Photo Ana-Maria Dabija)

1993 which represented less than 100 dollars [3]. Today, 97% of the population of Romania owns a dwelling [4].

After 1990, the process of construction of residential building was substantially diminished, and, although increasing, it never reached the ample activity of the 1980s. According to a World Bank report [5], 31% of the overall stock of residential buildings was constructed before 1961; 19% were built between 1961 and 1971, 23% between 1971 and 1980, and 14% between 1981 and 1989.[3] After 1989, the construction of the residential buildings diminished drastically while being diversified: after decades of living in collective residential buildings, the newly enriched moved from apartments to individual houses and villas, built for them, in the outskirts of Bucharest, on the land recuperated or bought from the state (even at the cost of deforestation). New districts appeared that rose prior to the sewage system of the area. A permanent movement of people from and to the city began to grow, with a pression on the routes to the city and on the ring of Bucharest.

In the city, collective apartment buildings were developed, inserted in the urban tissue. The same report [4] provides the information that 7% of the new residential

[3] A possible explanation for diminishing the building activity in the residential program is the construction of the megalomaniac administrative buildings: The House of the People, The National Museum, The National Library, The House of Science, The Hotel of the Communist Party. Only The National Library kept the original function: The House of the People is the Parliament, The House of Science is the Romanian Academy, The Hotel of the Party is Marriott Hotel. The National Museum is still ruined, torn, and mutilated, uncertain of the function that it will – if ever – provide.

stock of buildings was constructed in the last decade of the twentieth century and about as many in the twenty-first century.

15.2 Energy Efficiency in Buildings

The Regional Operational Programme, financed by the European Regional Development Fund for 2014–2020, is provided with a priority axis no. 3 for energy efficiency in public buildings with 300 million euros allocated to it and with a priority axis no. 4 that supports urban development with a focus on energy efficiency and renewable energy use in public infrastructure, including public buildings and in the housing sector with 852.63 million euros allocated.

When the Energy Performance of the Buildings Directive (EPBD) was adopted, Romania, as a European Country, had to include it in a national law. The law regarding the thermal performance of the buildings was adopted, and it was followed by a methodological norm in 2009. Periodically, the set of regulations concerning the thermal performances is updated, as the performance levels increase, in order to accomplish more energy economies.

As a consequence, the Ministry of Public Works in Romania elaborated a National Programme of Thermal Rehabilitation applicable for the blocks built between 1950 and 1990 that aims to:

- Improve hygiene and thermal comfort conditions.
- Reduce heat loss and energy consumption.
- Reduce maintenance costs for heating and hot water for consumption.
- Reduce pollutant emissions generated by energy production, transport, and consumption.

“Depending on the results of the technical expert’s report and the energy audit done on the building, the following works can be added:

- Repairs to the construction elements which pose potential danger of detachment and / or affect the functionality of the housing block;
- Intervention works on the distribution installation of the thermal agent for heating the common parts of the housing block” [6].

The costs of the interventions are 80% covered by the state and 20% by the owners (or the local authorities, if they have the means). Therefore, in more than a decade, a large number of the collective residential buildings were wrapped in thermal blankets; in most cases the balconies were closed (if the operation had not been already done by the owners). Interventions on the distribution system of heating between the connection point and the floor above the basement were carried out.

In most cases, the ETICS systems were used: thin plasters took the place of thick decorative cement-based plasters, stone, or ceramic veneers. The result is that the personality of some urban spaces or urban arteries is lost forever, the same finishing system being used everywhere, with different colours.

The existence of many owners leads to legal problems that reflect on the architecture of the building: while energy efficiency issues promote the closing of balconies, there are people who want to keep their balconies as they are, as part of their properties, and the state is not allowed to close them against their consent.

Balconies were closed since the late 1970s, without approval, while the apartments belonged to the state: it was a means of energy conservation and ultimately of the survival of people, in dwellings where the inner temperature could drop to 5°C in the last decade of the communist era, when sacrifices were made by the population in the requirement of the state to pay the external debt. As it was a private approach, each family took the measures that were affordable or accessible (Fig. 15.8). The balconies were therefore closed individually, without an architectural coordination. Immediately after 1989, the closing of the balconies was often accompanied with the demolishing of the wall between the room and the balcony, providing an apparent extra living space.

The programme of thermal rehabilitation intervenes on the windows that are not performant according to the calculations, although in some cases the wooden windows are proven to be good and tight.

In what balconies and loggias are concerned, the cheap, light closing, with one glass pane and metal frames, was replaced by thermal insulated units installed in PVC frames (usually).

The thermal blanket, usually 10-cm thick, wraps the building, providing, along with the performant windows, energy savings through the building envelope.

Fig. 15.8 Apartment buildings of the 1980s, before rehabilitation. (Photo Ana-Maria Dabija)

However, according to Jan Rosenow and Ray Galvin [7], "most evaluations of home energy efficiency programmes depend on calculated, rather than measured, levels of energy consumption, failing to take into account the discrepancies that have been observed in practice, between calculated and actual energy consumption both before and after refurbishment". According to the above-mentioned authors, these discrepancies refer to three factors:

- Consumers increase the level of energy services after refurbishment.
- Sunikka-Blank and Galvin [8] found actual consumption to be, on average, 30% below the calculated levels recorded in dwellings' energy certificates. They identified a similar phenomenon in Dutch, French, Belgian, and UK homes.
- A poor technical quality of the refurbishments.

These observations apply to the interventions in the Romanian buildings as well.

We would add some nuances to the factors presented by Rosenow and Galvin: the ageing of the population has an implication on energy use: old persons need a warmer environment (as small children as well) and have a higher need of light, to see. Therefore, more energy is used for artificial light and for heating, as the ageing population today represents a higher percentage of the total population than one generation ago.

On the other hand, the multitude and variation of household devices lead to an increased energy consumption: computers, printers, scanners, telephones, TV sets, air conditioning, numerous kitchen electric devices, washing machines, vacuum cleaners, and powerful and large refrigerators are consumers of energy that did not exist only few decades ago.

In what new residential buildings are concerned, in the past three decades, both individual housing and collective housing buildings were constructed. While in the last decade of the twentieth century the trend was for large individual houses (as a response to the decades of apartment buildings), in the next two decades, high(er)-rise buildings of apartments appeared and flourished. As the banks offered real estate loans with attractive interests, the market prices exploded. Developers build residential parks or independent buildings and put the apartments on the market sometimes before the necessary services of the neighbourhood are finalized. In many cases, although proposals for the urban infrastructure or tertiary sector functions are included in the design – as information – it takes years until the buildings and the facilities are constructed.

The apartments must be interesting and financially affordable for customers so the building materials and finishings are pushed more towards the cheap side. The buyer can change with more expensive interior finishing systems, but the facades are often ETICS with the least expensive finishing layer, a thin plaster.

The energy efficiency of the buildings is usually provided by the thickness of the thermal insulation layer and the type of windows.

In individual housing, however, energy from alternative sources is beginning to be integrated, depending on how rich the owner is and how much he can invest in such systems. Currently, the Romanian government is promoting the use of alternative energy systems.

15.3 Green Energy Trends

An interesting program but unfortunately relatively uncoordinated at the level of the line ministries is the greenhouse program within the Ministry of the Environment.

Benefiting from much lower resources than energy-efficient housing programme, promoted by the Ministry of Regional Development, the greenhouse program (currently upgraded to photovoltaic systems and photovoltaics for isolated households) promotes the use of unconventional energy in buildings.

The areas funded by this program are the following:

- Installation of solar panels
- Installation of heat pumps
- Energy production based on the use of waste (lighters, pellets, etc.)

The most recent development of the PV System Programme of the Administration of the Environmental Fund, launched in 2019, aims to promote the installation of photovoltaic panels, in order to cover the necessities for electricity use and to deliver the surplus in the national network. It targets old and new buildings that are not the subject of a dispute in court, claimed by previous owners or is under an expropriation procedure for public utility.

The following categories of persons can apply [9]:

- Persons who live in Romania.
- The owner of the building on which the photovoltaic system is located or to a person who has the written approval of all the owners to implement the project
- Persons who have no obligations to the state and local budget

The programme finances "the costs of purchasing the photovoltaics panel system with a minimum installed power of 3kWp (system of photovoltaic panels, inverter, connections, electric panel), the installation and commissioning costs of a photovoltaic panel system (15% of costs) electrical equipment and installations) including the VAT related to eligible expenses in a percentage of up to 90% of the total amount of eligible expenses but not more than 20000 lei" (around 4100 euros).

Energy efficiency is not the only requirement that should be fulfilled by a building. It comes along with the idea of comfort and the well-being of the inhabitants, with durability, safety in use, and protection against noise, not to mention mechanical resistance of the building and its components.

Romania being a country with high seismic risk, the first measure that supports the sustainable development should be – not only declarative – the structural safety of the built heritage. Through the national program for the consolidation of buildings with seismic risk, due to a poor financing and an inefficient communication with the owners of the apartments, the achieved performance was to consolidate (by 2013) only 8.4% of the 190 buildings listed as having important seismic hazard, respectively, 16 buildings [10]. Strangely enough, although the specialists emphasize the fact that the next expected major earthquake will probably destroy most of the buildings erected prior to the 1960s, this doesn't seem to scare anybody. The memory of the previous major earthquake, in 1977, that killed more than 1500 people in Bucharest, is growing dim and for many people is nothing more than a story.

Apart from the traditional way of producing energy – the BIPV systems – or saving energy, wrapping the building in a thermal blanket and diminishing the heat loss through windows, we would propose an approach that saves energy while providing well-being and a better quality of air: greening the building envelope.

15.4 Greening the City

Bucharest is the capital city of Romania. With a population of around 2,000,000 persons, it provides about 9% of the total population of Romania and 15% of the total urban population. The built area is over 70%.

Green space per capita is about 23.6 sqm, with important differences between the districts of the city (0.6 sqm in the District 6 compared to 16.38 sqm in District 3), the difference up to the average being offered by the existence of cemeteries.

The World Health Organization (WHO) recommends 50 sqm/capita of green area in the city [11]. According to the European Standard [12], 26 sqm/capita of green area is required.

It is not a new statement that the urban heat island effect can be diminished with the aid of increasing the green areas of the cities.

In some countries, the legislation encourages the use of the green envelope. Switzerland, for instance, promoted the use of green roofs by funding them for a 2-year period in the mid-1990s to stimulate their use in order to save energy; in Munster, Germany, a storm water fee was applied, in 1991, based on the amount of impervious surface on a property. According to Gail Lawlor et al., “green roof reduces the fee by 80 to 90 per cent, based on its water retention capacity” [13].

In Romania, legislation exists both for the use of green roofs and green facades, but the use of these systems is still very shy.

For some decades now, the benefits that the plants bring in the urban environment are emphasized in scientific research throughout the world. As new buildings appeared in the cities, the green areas vanished slowly, leaving way to the concrete, stone, and asphalt surfaces that reflect and re-reflect the heat.

The phenomenon of urban heat island can cause temperature rises of up to 5 °C, compared to the normal temperature, largely due to the growing areas of built structures.

Green systems, where a vegetal component of the building envelope is accomplished, can greatly reduce the excessive heat caused by solar radiation in urban space.

The use of plants protects the building due to the shadow, its quality depending on the density of the plants of the green walls. By extension, not only will the supporting building register a lower temperature but also the surrounding environment in the immediate vicinity and, by extension, the urban environment.

Plants lead to the improvement of air quality by filtering the particles propagated into the atmosphere, through leaves and branches, but also through the absorption of gaseous pollutants through photosynthesis.

The effect of shading and improving the environment generate benefits for the buildings in the sense of reducing the climatic stress on the facades of the buildings, thus extending their life; plants generate a "protective" layer of the walls and create a buffer space that prevents heat exchanges with the outside, ultimately leading to energy savings.

Visual and physical contacts with plants can lead to other categories of direct health benefits: stress reduction. Increasing the recovery rate of patients with various diseases simultaneously generates the increase of people's resistance to diseases [14, 15].

Living envelopes are designed to reduce the overall impact of the built environment on human health and the natural environment.

Hanging plants can reduce the peak temperatures of a building by shading the sunny walls. These can reduce the daily temperature fluctuation by up to 50% in urban climatic zones. The vegetation with semi-persistent leaves also offers protection in the cold, winter season, by maintaining an air buffer between the plants and the wall, reducing the effect of the wind on the wall surface, absorbing polluting gases, and filtering the air.

Some general benefits of the plant systems integrated in the facades are found primarily in the energy performance of the building. The plant facades improve the thermal insulation by adjusting the outside temperature of the building. The level of insulation depends on several factors, among which the most important are climate, type of facade, and density of plant elements. Thermal insulation occurs by preventing the movement of warm air, and this can be accomplished by plants, through shading and evapotranspiration process of plants as well as by creating a buffer space that protects the indoor environment from the actions of the wind in winter.

Another important impact that green building envelope systems have on the interior space and the construction itself is on the interior temperature of the building and its microclimate. Plants function as a solar filter and prevent the absorption of thermal radiation by the building materials, thus saving some of the building energy that would otherwise be used on HVAC devices. The vertical vegetation can conserve the temperature of the facade, keeping it cold during the summer, while in winter the vegetation that retains its leaves can prevent the heat from getting lost through the facade, thus acting as an additional layer of thermal insulation.

As they act as filters against pollutants, plants can contribute to the effort of providing good indoor air quality.

Plants grow on buildings anyhow. But as beneficial as they may be, they can destroy the facades and induce unnecessary humidity in the walls of the building envelope, if they are not correctly managed (Fig. 15.9) and are allowed to climb freely on the building walls.

The old Bucharest has a strange and sad characteristic: in the interwar period, high-rise buildings were constructed, in the proximity of low buildings that were probably expected to be demolished but resisted to this day. Therefore, the numerous

Fig. 15.9 Houses covered/invaded by wild vines. Cotroceni, Bucharest. (Photo: Ileana Nicoale)

Fig. 15.10 Example of metal structure suitable for walls. (Photo Ana-Maria Dabija)

blind walls represent a common urban presence in Bucharest that can act as a supporting wall for climbing plants, if the appropriate structures are designed (Fig. 15.10) and built.

As seen in Fig. 15.11, plants climb and cover large surfaces of walls, in this case damaging the facade due to the way they cling to the wall. The humidity that the plants induce in the wall is also significant and damaging. A system that is attached to the wall that supports a structure that facilitates the climbing of the vegetation creates a "skin" that is very similar to the principle of the ventilated facade that would add value to the building and the environment.

Fig. 15.11 Building in Bucharest covered with vine. (Photo Ana-Maria Dabija)

Fig. 15.12 Victoriei Street, Bucharest, existing vs. proposed. (Photo and simulation: Ileana Nicolae)

Regarding the multitude of existing walls (blind walls), the associated efforts and effects are null. If no measures are taken to increase the area of green space per capita in the urban area, if the dislocated vegetation is not brought back to the city knowingly, the environmental quality indicators will increase.

The following images (Fig. 15.12) are viable proposals of how to manage blind walls in Bucharest while contributing to the energy efficiency of the building and to the well-being of the environment, by diminishing the urban heat island effect. The scale of the intervention spans from a minimum intervention of grid and vines to thermal and hydro-insulation followed by the use of modular panels (a more sophisticated and expensive solution that resembles even more the ventilated facade systems).

The use of vegetation vertically is essential for achieving an ecological balance. Alternatives to using green/live building envelopes can bring direct health benefits, can bring colour to the urban landscape, a note of optimism, and cheerfulness, can create differentiations according to the season, can function as seasonal indicators for buildings and streets, can become landmarks at the city level, and, last but not least, can re-create the lost ecosystems of the cities [16].

15.5 Conclusions

Energy efficiency in residential buildings can be achieved by different means: from the concept of the building that takes into consideration the laws and forces of nature to more simple approaches of producing and/or saving energy by the use of thermal insulated envelope systems, of alternative energies integrated in building products, components, and systems that provide the energy necessities of the dwellers/building; one of the less exploited fields of energy conservation is the use of green envelopes on the existing (blind) walls of the city.

The benefits are not only for the dwellers/owners but also for the city. The reflections and re-reflections of the solar radiation on the built surfaces, mainly composed of mineral products like asphalt, concrete, metal, and glass, can be compensated by the planted masses that introduce a new urban and architectural aesthetic, provided that the use of plants is made according to professional architectural designs and using the appropriate plants, in the appropriate orientation, and by taking into account their environmental requirements. The plants contribute to the purification of the air and provide a balance between the temperature and the relative humidity of the air, creating its own microclimate. The air quality in the urban environment will be improved by the extension of traditional gardens on rooftops and facades. It is no surprise that throughout the world, the decorative rooftop gardens and planted terraces have been replaced by urban farms where vegetables and fruits are produced.

Living envelopes in a city like Bucharest would provide not only some energy saving in the buildings but also a less expensive means of reducing the effects of pollution as well as diminishing the effects of solar and electromagnetic radiation.

References

1. A. Udrea, The Urbanistic Plans of Bucharest. First Half of the XX-th Century. Doctoral Thesis. Tutor Nicolae Lascu Bucharest, UAUIM, 2013
2. V. Asquini, Indicator tehnic în construcții, 1946, “Cartea Românească” Publishing House, p. 267
3. A-M. Dabija, Hell is paved with good intentions! A decade of thermal rehabilitations of mass buildings in Romania in ICBEST Proceedings Interdisciplinary Perspectives for Future Building Envelopes ISBN 978–975561479-3, p. 638
4. ‘Hypostat’ European Mortgage Federation
5. Advisory Services Agreement on Consolidation of the Strategic Planning Capacity of the Ministry of Regional Development and Public Administration for Renovation of the National Building Stock for Energy Efficiency and Seismic Risk in Romania. International Bank for Reconstruction and Development/the World Bank. 2019

6. https://www.mdrap.ro/programul-national-privind-cresterea-performantei-energetice-la-blocurile-de-locuinte
7. J. Rosenow, R. Galvin, Evaluating the evaluations: Evidence from energy efficiency Programmes in Germany and the UK. Energ. Buildings **62**, 450–458 (2013)
8. M. Sunikka-Blank, R. Galvin, Introducing the prebound effect: Relationships between energy performance ratings and actual heating energy consumption in German dwellings, and their policy implications. Build. Res. Inf. **40**(3), 260–273 (2012)
9. https://www.afm.ro/main/programe/sisteme_fotovoltaice/2019/prezentare_program_sisteme_fotovoltaice.pdf
10. A-M. Dabija, Some Considerations on the Relationship between Providing Sustainability in the Anthropic Environment and the Energy Consumption Problem in Romania, in Energy and the Environment in the Contemporary Context, EUIM 2017
11. World Health Organization, Health Indicators of Sustainable Cities in the Context of the Rio+20 UN Conference on Sustainable Development, (WHO, Geneva, 2012)
12. Fundamentum Note – OUG nr. 108/10–10–2007, Official Monitor nr. 698/16–10–2007)
13. G. Lawlor, B.A. Currie, H. Doshi, I. Wieditz, Green Roofs, A Resource Manual for Municipal Policy Makers, 2006, in https://commons.bcit.ca/greenroof/files/2012/01/resource_manual.pdf
14. D. Norfolk, *The Therapeutic Garden* (Bantam Books, 2013), London
15. C.C. Marcus, M. Barnes, *Healing Gardens: Therapeutic Benefits and Design Recommendations* (Wiley Series in Healthcare and Senior Living Design, 1999) John Wiley & Sons, USA
16. I. Nicolae, Doctoral thesis, The Living Envelope of the Buildings, defended in 2018

Chapter 16
The Heat Island as a Result and Cause of Environmental and Social Degradation: Two Different Settlements in the Town of Afragola of the Metropolitan City of Naples

Paola De Joanna and Luca Buoninconti

16.1 Introduction

The Salicelle District is one of the interventions carried out under emergency conditions as part of the extraordinary plan for the earthquake that struck Campania in November 1980, producing nearly 300,000 homeless. Built entirely between 1982 and 1993, the Salicelle District is located in the municipality of Afragola in the north area of Naples, connected to the metropolitan city through the Median Axis that crosses the entire northern periphery in an east-west direction.

The district was built for 7000 inhabitants in apartments of different sizes according to the urban planning standards of the time, but in reality, the accommodations are currently overpopulated, and many rooms located on the street level, originally intended for commercial activities, have been illegally occupied and used as dwellings. Under these conditions, today the total number of inhabitants is unspecified, approximately estimated at around 9000 occupants in fact. The buildings for the houses are of the court and in line type; the urban layout is structured around a central core consisting of three squares, the parish complex, the market, the middle and elementary school, the nursery, the urban park, the post office, the social centre and the market; some of these activities, such as asylum and the market, are not functioning, while the social centre has been replaced by a polyclinic to deal with the serious health shortage of the neighbourhood (Fig. 16.1).

From the construction point of view, the technological solutions were conditioned by the urgency of the realization, and therefore the project group had to adapt the project to the fastest and immediately available construction solutions on the

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Fig. 16.1 "Le Salicelle" residential district in Afragola, Naples Metropolitan City

market, opting for heavy prefabrication (Peikert) and the transverse tunnel for the residential buildings. The Peikert turned out to be extremely rigid and strongly influenced the compositional aspects of the buildings, and even the choice of materials and components for completion was imposed by the consortium which contracted the works with the result of a general impoverishment of the solutions realized.

The study presented here focuses on the quality of urban space in terms of climate; the presence of large impermeable surfaces and the lack of green spaces determine a condition of overheating of the residential islands, moderately attenuated by the geomorphological characteristics of the site which, despite being completely flat, is surrounded by large rural spaces which therefore do not hinder the passage of the winds and breezes.

Also, the use of these spaces is conditioned by the effects of the heat island because they become unattractive and unpleasant due to the excessive temperature, the poverty of the vegetation and the onerous maintenance. The climate condition into the court buildings are analysed and their possibility of improvement; for one block of linear buildings, chosen as sample, the environmental impact coefficient is assessed trough two different methods, and the possibilities of its reduction are valued with the introduction of new technologies.

Figure 16.2 shows the census of the permeable areas within the neighbourhood, distinguishing public spaces from private ones and detecting the size, the type of vegetation and the maintenance conditions; a picture emerges in which the green is not well distributed or usable, the green spaces at the service of the houses are

	AREE A VERDE			
	Ad uso Privato	Dimensione complessiva	Stato manutentivo	Tipo di piantumazione
	Di pertinenza della singola abitazione	Mq. 11.687	Non adeguato	Nessuna - vegetazione spontanea - sterpaglia
	Di pertinenza degli edifici a multipiano	Mq. 14.900	Adeguato	Alberature di media dimensione Essenze di specie diverse
	Di pertinenza degli edifici a corte	Mq. 9.300	Mediamente adeguato	Alberi d'alto fusto (pini) - macchia mediterranea e piante da bordura
	Ad uso Pubblico	Dimensione complessiva	Stato manutentivo	Tipo di piantumazione
	Aree su fronte strada	Mq. 14.200	Mediamente adeguato	Alberi d'alto fusto - macchia mediterranea
	Aree non recintate	Mq. 25.130	Non adeguato	Alberi d'alto fusto - macchia mediterranea
	Aree a verde recintate	Mq. 15.570	Mediamente adeguato	Alberi d'alto fusto - macchia mediterranea
	Orto Urbano Salicelle	Mq. 12.000	————	

Fig. 16.2 Census of permeable areas

	SERVIZI	Dimensione complessiva	Manutenzione	Difformità rilevate	Gestione	Tipo di gestione/ Tipo di utilizzo
	Aree a parcheggio	Mq. 26.600	Mediamente adeguata	Rotture diffuse del manto stradale	Pubblica	Non a pagamento
	Complesso sportivo Salicelle	Mq. 14.200	Adeguata	————	Privata	A pagamento per i campi di calcio
	Area Sportiva in disuso	Mq. 2.100	Non adeguata	Degrado della pavimentazione	Privata	Utilizzo diverso dall'originario
	Area Sportiva	Mq. 2.531	Mediamente adeguata	Parziale degrado della pavimentazione	Privata	
	Centro sportivo "Le Club"	Mq. 11.300	Adeguata	————	Privata	A pagamento
	AREE IMPERMEABILI	Dimensione complessiva	Manutenzione	Difformità rilevate	Gestione	Tipo di gestione/ Tipo di utilizzo
	Area ex Mercato	Mq. 2.300	Non adeguata	Degrado generale della struttura	Pubblica	Utilizzo diverso dall'originario
	Aree libere a servizio del quartiere	Mq. 4.800	Non adeguata	Degrado delle pavimentazioni	Pubblica	Nessuna attrezzatura
	Aree libere a servizio degli edifici multipiano	Mq. 18.500	Non adeguata	Degrado delle pavimentazioni	Privata	Nessuna attrezzatura

Fig. 16.3 Census of impermeable areas

exiguous and not adequately planted, while the larger spaces are residual and abandoned or not accessible.

Figure 16.3 shows the census of impermeable surfaces, with the exception of asphalted roads; the areas are distinguished in relation to the intended use, and for each one the measurement of the surface, the type of management, the state of maintenance and the degradation conditions are recorded. The surfaces considered are partly abandoned or improperly used, and almost all of them are paved with concrete slabs and without equipment.

The relationship between permeable free surfaces (ALP, 102000 sq m) and waterproof free surfaces (-ALI 71000) may seem favourable, but it must be kept in mind that road surfaces that account for almost double the amount (200,000 sq m) are not included in the tables of the calculated waterproof areas.

On this scenario, some investigations have been developed concerning the conditions that affect the consequence of the heat island and the perception of comfort in pedestrian areas. In particular, a residential block of in-line buildings were studied located in the northern area of the neighbourhood and a residential block of court buildings in the southern area. We wanted to examine the climatic quality of public space in relation to different types of buildings that configure different conditions of usability and therefore different needs of users.

16.2 Heat Island in the Batch of Buildings in Line

The heat island is the statistical phenomenon observed in urban areas for which in cities and in heavily populated places the average temperatures observed are higher than in other parts of the territory with a lower density of inhabitants. This increase, which can be evaluated around 0.5–1.0 °C for small agglomerations and from 1 to 2 °C for large ones [1],[1] is due to a set of phenomena that can be briefly described as follows. In a natural environment, the sun's rays in fact come:

– Partly absorbed by vegetation, which uses energy in the photosynthesis process to produce sugars.
– The quantity that does not affect the plants is partially reflected due to the albedo, i.e. the reflection coefficient, towards the celestial vault.
– Only the remaining part is absorbed by the soil.

The fraction of absorbed energy heats the surface, and this transfers the heat by conduction to the air layers immediately in contact; by convection, the heat spreads also to the upper layers. When the sun's rays reach an anthropized place, it happens that:

1. The amount of green surfaces is minimal, if not zero, so the absorption by the vegetation is almost completely negligible.
2. The reflected portion, before reaching the celestial vault, is subject to multiple reflections due to the presence of numerous vertical surfaces (Fig. 16.4a); this labyrinth effect multiplies the absorption of heat.
3. The amount absorbed by the surfaces and subsequently transferred to the air in the form of heat is very high, and its heating effect is amplified by the reduced thermal capacity that characterizes most of the building materials.
4. Buildings obstruct the natural flow of the air which, flowing more slowly (Fig. 16.4b), does not allow adequate heat dispersion, determining that stagnation commonly indicated *heat island.*

The presence of human activities increases the temperatures even more because engines, air conditioning systems and the human presence itself are the source of a further thermal gain. From the foregoing considerations, it is clear that, in general, the phenomenon analysed is originated from:

1. The properties of surfaces radiated by the sun
2. Ventilation of the place
3. The presence of human activities

[1] See UNI 10339:1995, Impianti aeraulici ai fini del benessere. Generalità, classificazione e requisiti, pag. 30.

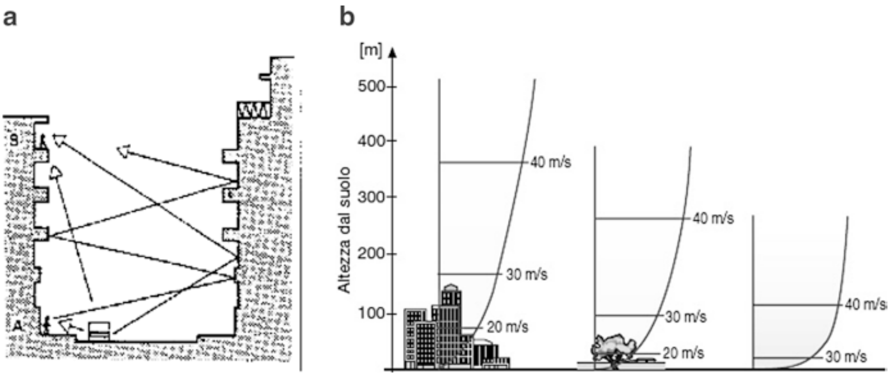

Fig. 16.4 Effect of the presence of constructions (**a**) on reflection and (**b**) on ventilation

Among the environmental quality assessment tools, the indicators developed by the Municipality of Bolzano [4] and the ITACA Protocol [2] are of interest: the RIE index and criterion C.6.8 "island heat effect".

The Building Impact Reduction Procedure, which gives rise to the RIE index, as indicated by the Municipality of Bolzano, arises from the consideration that "…the waterproofed and sealed surfaces cause a heating of the overlying air mass and convective motion leads to recirculation of powders. The heat of the accumulated and irradiated sun has, as a direct consequence, an increase in temperatures in our cities, missing the natural mitigating effect given by the evapotranspiration process of vegetation"[2].

The value assumed by the RIE can be calculated with the help of a spreadsheet applying the algorithm:

$$\mathrm{RIE} = \frac{\sum_{i=1}^{n} S_{\mathrm{V}i} \frac{1}{\Psi_i} + (S_{\mathrm{e}})}{\sum_{i=1}^{n} S_{\mathrm{V}i} + \sum_{j=1}^{m} S_{ij} \Psi_j}$$

S_{vi} are green surfaces, S_{ij} are not green, and those S_e are lined; all are multiplied by *outflow* coefficients. The evaluator will therefore have to catalogue all the surfaces using reference tables which, in addition to cataloguing the areas as green or not, also indicate their respective outflow coefficient (Fig. 16.5).

Using a calculation sheet [6, 9], in which the areas of all the surfaces and the relative outflow coefficient are shown, the value of the RIE index can be quickly calculated. Alternatively, it is possible to use a software available on the municipality's website, which clearly applies the same procedure and reaches the same result. Since the use of this tool is mandatory to obtain the authorizations to carry out interventions on buildings in the municipality, the designer must demonstrate that

[2] www.comune.bolzano.it/urb_context02.jsp%3FID_LINK%3D512%26page%3D10%26area%3D74%26id_ context%3D4663

N.rif.	Categoria di superficie	Sezione indicativa o immagine tipo	Specifiche o varianti	Norme di riferimento, valori limite o indicazioni	Ψ
N1	Superfici a verde su suolo profondo, prati, orti, superfici boscate ed agricole				0,10
N2	Corsi d'acqua in alveo naturale				0,10
N3	Specchi d'acqua, stagni o bacini di accumulo e infiltrazione con fondo naturale				0,10

Fig. 16.5 Part of the table available in the RIE procedure of the Municipality of Bolzano (in Italian)

the index calculated for the project (RIE2) is higher than the minimum value obtained according to the same index referred to the actual situation (RIE1) and to a reference number depending on the area (RIE Z), available on a specific cartography. Generally, it is desirable that in the maintenance and restructuring interventions be verified that RIE2 > RIE1; in those of new construction, where it is built in a natural space (and therefore it can only be that RIE2 < RIE1), it will be necessary to contain the project index within specific limits.

The heat island effect criterion of the ITACA Protocol takes into account the need to "ensure that outdoor spaces have acceptable thermal comfort conditions during the summer"[3], whose performance indicator is the ratio between the area of the surfaces capable of decrease the heat island effect with respect to the overall area of the intervention lot. In formal terms:

$$\text{Index} = 100 S_{\text{reif}} / S_{\text{I}}$$

The procedure in the standard describes how to identify the surfaces to be counted in the S_{reif} quantity, i.e. the surfaces:

- *Green*, including garden roofs
- Which are in the shade at 12:00 PM on June 21
- With an inclination of up to 8.5° having a solar reflection index (SRI) equal to or greater than 78
- With an inclination greater than 8.5° having SRI equal to or greater than 29

In the sheet C.6.8 is attached a list of surface finishes of which the SRI indexes are made known, to allow the determination of the S_{reif} surface. The SI quantity is instead easy to determine because it coincides with the area of intervention.

[3] See UNI/PdR 13.1:2015, *Sostenibilità ambientale nelle costruzioni - Strumenti operativi per la valutazione della sostenibilità. Edifici residenziali*, pag.71.

Descrizione		Coefficienti		
		ρ	$\varepsilon_{(ir)}$	SRI
Scaglie di asfalto granulare ghiaino pigmentate				
	bianco	0,25	0,91	26
	grigio	0,22	0,91	22
	argento	0,2	0,91	19
	sabbia	0,2	0,91	19
	marrone chiaro	0,19	0,91	18
	marrone medio	0,2	0,91	9
	marrone scuro	0,08	0,91	4
	verde chiaro	0,16	0,91	14
	nero (onice)	0,03	0,91	-2
	nero	0,05	0,91	1
Tinteggiature polimeriche bianche e diossido di titanio				
	bianco	0,72	0,91	89
	su compensato elastometrica invecchiata	0,73	0,86	89
	su legno	0,84	0,89	106
	su metallo	0,77	0,91	96
	bianco titanio	0,83	0,91	104

Fig. 16.6 Part of the table available in sheet C.6.8 of the ITACA Protocol (in Italian)

The value obtained is compared to a reference benchmark, which assigns the maximum score to the 100% value (5 points), an average score to 60% (3 points) and the minimum to 0% (0 points) (Fig. 16.6).

Both indices, as can be easily deduced from the calculation procedures, exclusively consider the physical properties of the surfaces of the building [7, 8], without considering either the effect of the wind or that of the human activities present.

16.2.1 Application and Comparison Between the Two Methods

The methods analysed in these pages follow a common guideline, which sees the increase in the quantity of green or high reflective surfaces as the best strategy to combat heat islands. It is therefore interesting to see what results are obtained by applying them to the case study, or rather to a batch of it, because the analysis conducted on the entire neighbourhood would be long and perhaps less significant.

The chosen part (Fig. 16.7a) is composed of ten linear buildings, of variable height (eight of this have six levels and two only three), which overlook almost completely paved areas, with the exception of a central green area. They are oriented along an almost vertical axis (in the NNW-SSW direction), and this makes their shadows at 12:00 PM almost nil, creating a condition of obvious disadvantage (Fig. 16.7b).

The RIE index was then evaluated through a simple table, which can be implemented in a spreadsheet, which is shown below:

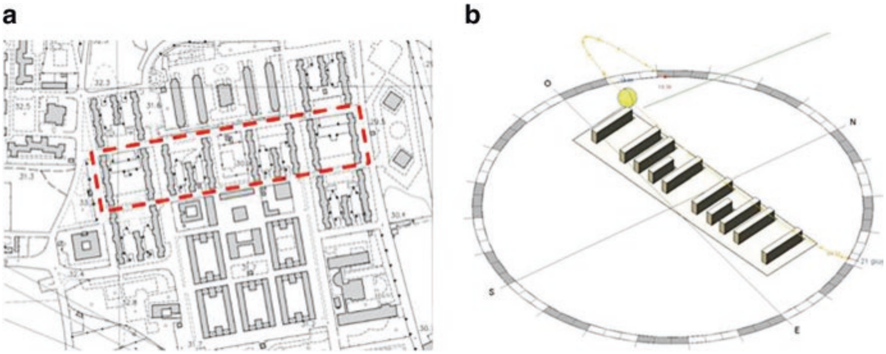

Fig. 16.7 Delimitation of the chosen part (**a**) and sun exposure analysis at 12:00 PM on June 21 (**b**)

Fig. 16.8 Position of the surfaces analysed in the lot

Even if the RIE procedure does not provide absolute values to evaluate the quality of the surfaces constituting the analysed area, certainly an RIE1 = 0.67 is low, therefore indicative of a reduced environmental quality in relation to the analysed phenomenon. Figure 16.8 shows the shape and position of the surfaces shown in Table 16.1.

A similar table can be compiled to determine the value of the ITACA index as shown in sheet C.6.8: here they must also include the (very few) shaded horizontal surfaces at 12:00 PM on the summer solstice and any materials with an adequate index of solar reflection SRI function of inclination (Table 16.2).

Also in this case, the result is extremely low and is close to the 0% reference value, which also corresponds to the lowest attributable value (score = 0). Both the RIE Index and Ithaca provide the same value, because they use similar evaluation strategies based on surface quality.

In particular, the ITACA Protocol suggests to follow a particular procedure: in addition to increasing the green areas, it will be necessary to orient the building in

Table 16.1 Calculation of the RIE index for the chosen lot

Type of surface	Colour	S_{vi} (mq)	Ψ*i*	S_e (mq)	S_{ij} (mq)	Ψ*j*	RIE
Green on deep soil	Green	2353	0.1	620			**0.67**
Continuous roofs	Dark grey				11,458	0.85	
Semi permeable surfaces	Sand				2927	0.70	
Asphalt paving	Light grey				24,308	0.90	

Table 16.2 Calculation of the ITACA index for the heat island effect

Type of surface	Quantity (B) mq	Quantity(A) mq
Shaded surfaces at 12:00 PM of del June 21	252	252
Green surfaces	2353	2353
Surfaces with inclination up to 8.5° and SRI equal to or greater than 78	0	11,458 + 2927 + 24,056
Surfaces with an inclination greater than 8.5° and SRI equal to or greater than 29	0	0
Total B surfaces	2605	
Total A surfaces		41,046
Index	**6.3**	

the East - West direction, in order to increase the shaded surfaces. However, it must be considered that, as mentioned in the first part of this article, the wind can have a mitigating effect even in the harshest heat conditions because it removes the air that gets very hot when it comes into contact with the surfaces. For this reason, it is useful to check which are the prevailing winds, that is, those that blow more frequently in the area. To do this, you can use the anemometric diagrams, available online on the Italian Air Force website,[4] and especially those related to the spring and summer periods, when the effect of the heat island is more unpleasant or harmful to users (Fig. 16.9).

Once the reference meteorological station (Naples Capodichino) has been selected [3], the diagrams show how during the day the winds come mainly from the northern quadrant during the night (surveys at midnight and at 6:00 AM); these prevailing winds continue to blow even during the day in the spring months, with a greater tendency towards NE at 6:00 PM. In summer, instead, there is a clear inversion at 12:00 PM (wind coming from the south) and then rotates towards the western quadrant in the late afternoon (6:00 PM). This summer phenomenon is due to the strong presence of sea breezes which, blowing from the Tyrrhenian to the coast, are one of the characteristics of the mild climate near the sea [5]. It is thus evident that the orientation of the constructions allows the propagation of the winds, making the increase in temperatures less evident: this cannot be deduced only from the analysis carried out, i.e. from the RIE and ITACA indices.

[4] http://clima.meteoam.it/atlanteClimatico.php

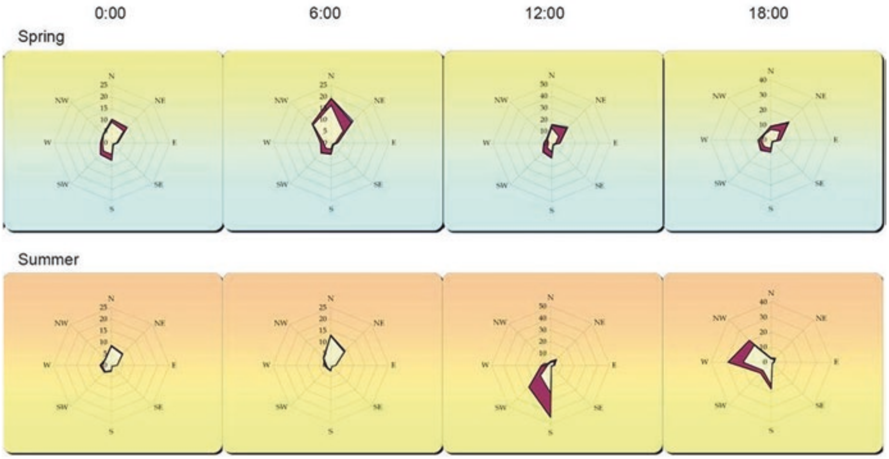

Fig. 16.9 Spring and summer anemometric diagrams published on the Climatic Atlas of Italy

Fig. 16.10 The building with internal court

16.3 Microclimate and Usability of the Garden Courts

The settlement complex to the south of the district consists of buildings in line and in blocks, these arranged in such a way as to configure green spaces concluded within each lot. The internal courtyards are permeable on the shorter sides and bounded on the longer sides by the buildings in line (Fig. 16.10). The interior space is neglected and underutilized by the residents; therefore, it presents deterioration of the paved parts and of the fences as well as the state of abandonment of the greenery and plantings. The floorings are made in concrete with jet, joints between are closed with bricks, and the surface of the jets has not been polished; therefore, it crumbles easily as well as being particularly scratchy and is therefore not suitable for children to play. The boundaries of the flower beds are also in unfinished concrete and widely crumbled in the corners; it also has evident wet areas produced by a bad water flow.

Finally, the concrete paving of the paths is strongly exposed to the sun in the hottest summer hours and therefore determines a general overheating of the completed space (Fig. 16.11). The conditions of physical degradation are added to an inefficient distribution of space and trees in relation to the sunny conditions (Fig. 16.13) and ventilation (Fig. 16.14) of the courts and in relation to the activities that could be performed there. The tall trees allow the visibility of the courtyard space even from the highest floors (Fig. 16.12), but they leave the green areas almost completely bare. They also restore protection from the sun in the summer months, but as they are evergreens, they hinder the passage of the rays solar in the winter months. Among the favourable conditions found, with respect to the layout of the courts, are therefore considered: the presence of tall trees, visibility of the court from the apartments at all levels, presence of shaded walking areas, and protection from cold winter winds thanks to the orientation of the buildings that delimit the interior space.

For a redevelopment hypothesis, the activities that are mainly expected to take place in these spaces, the type of users and the preferred time slots have been defined, in order to establish the control of the best climatic comfort conditions in the desired times and spaces.

Users: Children 4/10 years, adolescents 11/13 years, elderly
Activities: play, rest, walk, crops
Periods of use: first afternoon hours (winter), early afternoon until sunset (spring/autumn), and morning/afternoon to sunset (summer)

In particular, the following topics were considered: redesign of the common areas destined to green areas within the blocks of the courtyard and reduction of impermeable surfaces for the mitigation of microclimatic conditions.

Interventions on internal courts have been designed with a view to giving back space for play or free time in an easily controllable context through small interventions supported by environmental analysis to control passive comfort conditions in

Fig. 16.11 The paths and fences

Fig. 16.12 Tall trees

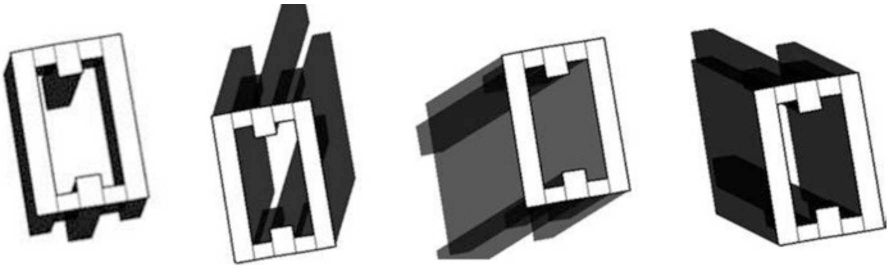

Fig. 16.13 Sunny conditions

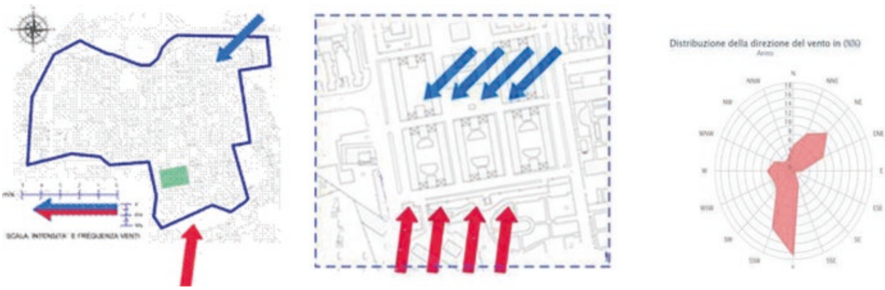

Fig. 16.14 The direction of main winds

order to rationalize space resources available. Redevelopment of the play areas is planned, as well as the creation of vegetable gardens and the use of vegetable screens where necessary.

16.4 Conclusions

The study applied to the residential complexes of the “Le Salicelle” neighbourhood has brought to light shortcomings produced by the need to build the neighbourhood quickly and with scarce economic resources; the scarce availability of materials and the need to adopt imposed construction technologies have limited the design choices. Public space is penalized by an unfavourable relationship between areas with permeable surfaces and areas with impermeable surfaces that determine, during seasonal peaks, prolonged uneasy conditions with respect to the mitigation of the effects of heat and cold, producing a general perception of unsuitable and undesirable space. Compared to the two analysed building block types, we can assume that in the case of in-line buildings, the heat island effect is mainly produced by the presence of extended horizontal paved and impermeable surfaces that act as thermal accumulators and – in the absence of shaded areas – transfer the heat to the overlying air layer; some minimal interventions such as the replacement of the asphalted areas with grassing floors and the realization of temporary shadings realized with textile coverings could significantly affect favourably the outdoor thermo-hygrometric comfort.

In the case of buildings arranged in a court, the space concluded lends itself to host permanent functions and not only for passage; therefore, additional study is required aimed at guaranteeing comfort conditions in certain time slots and seasons. The proposed methodology suggests considering the climatic conditions in the times of greater permanence in order to identify an effective distribution of space and planned activities in relation to seasonal sunshine and ventilation conditions.

Acknowledgement All the work is carried out with a common studies of both the authors, writing of the text is to be attributed at Paola De Joanna for Sects. 16.1 and 16.3 to Luca Buoninconti for Sects. 16.2 and 16.4 is to be attributed at both the authors.

References

1. UNI 10339:1995, *Impianti aeraulici ai fini del benessere. Generalità, classificazione e requisiti*
2. UNI/PdR 13.1:2015, *Sostenibilità ambientale nelle costruzioni – Strumenti operativi per la valutazione della sostenibilità. Edifici residenziali*
3. http://clima.meteoam.it/atlanteClimatico.php
4. www.comune.bolzano.it
5. J.M. Fitch, *La progettazione ambientale* (Muzzio, 1980)
6. D. Francese, *Il benessere negli interventi di recupero edilizio* (CUSL Nuovavita, 2002)

7. C.F. Ambrosino, *Strumenti per la verifica della sostenibilità dei prodotti edilizi con materiali avanzati* (Napoli, 2009)
8. C. Girardi, *Eco-efficienza e innovazione tecnologica nella produzione industriale per l'edilizia. Criteri per la selezione di prodotti per gli interventi di retrofit* (Napoli, 2011)
9. L. Buoninconti, *Benessere e architettura. Un approccio integrale al comfort* (EAI, 2016)

Chapter 17
Settlement Scale Analysis Approach to Reach Nearly Zero Energy Communities

Ece Kalaycioglu Ozdemir and A. Zerrin Yilmaz

17.1 Introduction

Total primary energy consumption throughout the world is continuously increasing [1]. In response to this, each nation should build an energy efficiency policy and set action plans to slow down this increment or even decrease energy consumption. Correspondingly, the European Union (EU) has already set long-term energy efficiency targets, for 2020, 2030 and 2050, and published directives related to several sectors, such as renewable energy, transportation, district energy systems, etc. [2].

Buildings are one of the most energy-consuming sectors. They are responsible for 1/3 of the total energy consumption [3]; thus, providing the energy efficiency in buildings is one of the most important issues. The EU published the first directive on building energy performance (EPBD) in 2002 to mandate the energy certification for buildings [4]. Then in 2010, EPBD was revised, as EPBD Recast [5], to reach the Union's 2020 targets [2]. In EPBD recast, new terms about building energy performance were introduced. "Cost-optimal energy level" was defined as the energy performance level which leads to the lowest costs which include the investment, operating, maintenance and disposal costs during the building's economic life cycle. EPBD Recast sets also a calculation methodology to determine the cost-optimal levels for buildings. Furthermore, it introduced the "nearly zero energy building" term as a building with a very low energy consumption with a significant renewable energy contribution. Relatedly, it sets targets for the construction sector as by 2018, all new public buildings and by 2020 all new buildings should be constructed as nearly zero energy building (NZEB). In this point, EPBD Recast leaves

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the exact definition of NZEBs, as primary energy consumption levels and renewable energy contribution level, to be set by each member states for their local climate conditions and different building types.

Considering the explained issues, in this study, it was intended to investigate the cost-optimal methodology of EPBD Recast and propose a new method to apply it to a group of buildings in settlements. This way, it was aimed to achieve nearly zero energy levels at larger scales than single buildings, to increase the contribution of renewable energy systems by site-level applications and to compensate the high investment cost effects of renewable energy systems for buildings.

17.2 Methodology

As it was explained, the cost-optimal methodology proposed by EPBD was adapted for settlement scale analyses. Basic steps of the cost-optimal methodology which implies to single buildings are, respectively, the definition of reference building, the definition of energy efficiency measures, calculation of the annual primary energy consumptions and global costs of each defined measure and determination of the measures leading to cost-optimal and nearly zero energy levels. These steps were followed by settlement scale analyses as:

- Definition of reference settlements with different energy levels of buildings (with reference, cost-optimal and nearly zero energy buildings)
- Determination of district energy system alternatives, including renewable energy systems
- Calculation of the annual primary energy consumptions and the global cost of each district energy system alternative with each energy level of settlement
- Determination of the most favourable energy level of settlement with district energy systems according to their primary energy consumptions, global costs and investment costs

In this study, the proposed methodology was applied to an example settlement as a case study, and renewable energy contribution levels were examined at building and settlement scale. Thus, the financial and energy efficiency effects of reaching nearly zero energy levels both at building and settlement scale were analysed. Case study settlement is located at the south of Eskişehir, Turkey, and it is assumed to be a newly planned district. Thirty-four residential, seven office and one light industry buildings are assumed to be located in the district. Total floor areas for each function are given in Table 17.1.

Table 17.1 Total floor areas for each type of building in the settlement

	Residential	Office	Light industry
Number of buildings	34	7	1
Single building floor area (m^2)	5,353.83	16,802.71	10,729.13
Total floor area for each function (m^2)	182,030.22	117,618.97	10,729.13

The first step of the cost-optimal methodology is the definition of the reference buildings to represent the buildings with the same function. In the study, the geometry and plan layouts of each building type were determined by analysing Eskişehir's building stock and to represent it best. Reference buildings' internal gains for people, lighting and electrical equipment were determined according to the reference building definition rules of Turkish National Building Energy Certification System [6]. In cases where no data is available, like for light industry building's production area, ASHRAE 90.1-2007 Section G [7] or real building data was used. For mechanical systems definitions, the Turkish Regulation for Energy Efficiency in Buildings [8] has sufficient data for residential buildings to be modelled in a detailed dynamic simulation tool. For other types of buildings, ASHRAE 90.12007 Section G mechanical system definitions were modelled.

As the second step, for each building type in the study, energy efficiency measures on building envelope, lighting systems and mechanical systems were implied. Energy efficiency measures on building envelope include the insulation thickness increment, transparency ratio increment, different glass and frame combinations and several sun control elements manually controlled or automated seasonally by solar gains. Energy efficiency measures on lighting systems include the implementation of energy-efficient fixtures providing the same illumination levels and daylight sensors. Energy efficiency measures on mechanical systems include high-efficiency plants and several different heating and cooling systems. Besides these measures, renewable energy systems as solar panels for hot water production and photovoltaic panels for electricity production were also implied to the buildings. Renewable energy systems used for each building is summarized in Table 17.2. Energy efficiency measures were also combined into packages to reach higher energy performance levels.

Implying each measure or package means the calculation of the annual primary energy consumption and the global cost of the building with each measure. Thus, the improvements in energy performance can be expressed as energy consumption and long-term costs by comparing to the reference cases. EPBD allows the member states to develop their own calculation methodology for annual primary energy calculation, which will be used also for building energy certification. In the study, the detailed dynamic simulation tool EnergyPlus [9] was used for energy performance calculations, as Turkish national calculation tool has limitations to calculate the above-mentioned detailed measures determined for this study. Global cost calculations were made according to the Regulation 244/2012 which sets the general framework of the cost calculations of cost-optimal methodology [10]. Global cost includes basically the investment cost of energy efficiency measures, annual energy

Table 17.2 Renewable energy systems used in each type of building

	Solar collectors	PV panels
Residential buildings	26 panels – 65.5 m^2	26 panels – 7280 Wp
Office buildings	None	250 panels – 70,000 Wp
Industry building	None	950 panels – 266,000 Wp

Table 17.3 District energy system alternatives for the settlement

	Cogeneration	Boiler	Chiller	PVs
A01	+	–	–	–
A02	+	–	+	–
A03	+	+	–	–
A04 (A01 + PV)	+	–	–	+
A05 (A02 + PV)	+	–	+	+
A06 (A03 + PV)	+	+	–	+
A07	+	+	+	–
A08 (A07 + PV)	+	+	+	+

costs during the determined life cycle of the building, maintenance and residual costs related to the measures. Net present value method explained in EN 15459 [11] was used for projected long-term cost calculations. After the calculation of annual primary energy consumptions and global costs of each package for each type of building, all results were compared to each other, and the package with the lowest global cost was chosen as the cost-optimal solution. Similarly, the package with the lowest annual primary energy consumption was chosen as nearly zero energy solution.

As explained before, in the study, cost-optimal methodology of EPBD was proposed to be implied at settlement scale. Thus, after determining the reference, cost-optimal and nearly zero energy levels for each type of buildings, then all the results were compiled together to generate reference settlements. Three reference settlement cases were defined with reference, cost-optimal and nearly zero energy buildings, however, without any district energy system. Some alternatives shown in Table 17.3 were analysed for district energy systems. Similar to the building scale analyses, annual primary energy consumptions and global costs were calculated for each level of settlement with each district energy system alternative. For annual primary energy calculations, building scale results were converted into district energy system demands, and EnergyPro simulation programme [12] was used to simulate district energy systems. Global cost calculations were made similarly using net present value calculation methodology, and the investment, operation, maintenance and residual costs were calculated both for buildings and district energy systems.

17.3 Results

The results were obtained by following the explained methodology. For each building type, reference, cost-optimal and nearly zero energy levels were determined basically by implying cost-optimal calculation methodology of EPBD. Then the methodology was applied to the case study settlement by following the explained steps. In this section, firstly, the energy performance results for each type of building

Table 17.4 Energy performance results of residential building

	Reference		Cost-optimal		Nearly zero energy	
	Electricity [kWh/m^2-y]	Natural gas [kWh/m^2-y]	Electricity [kWh/m^2-y]	Natural gas [kWh/m^2-y]	Electricity [kWh/m^2-y]	Natural gas [kWh/m^2-y]
Primary energy consumption by fuel [5]	47.74	49.10	36.34	25.48	29.26	12.66
Primary energy consumption	96.84		61.82		41.92	
Improvement percentage	–		36.2%		56.7%	

are given, and the reference, cost-optimal and nearly zero energy levels are compared. Then in the following graphs, each energy level for the related building was displayed, and the renewable energy contributions were discussed. In the graphs, reference cases were indicated as "reference", cost-optimal cases were indicated as "COB" and nearly zero energy cases were indicated as "nZEB".

Table 17.4 shows the residential building's reference, cost-optimal and nearly zero energy cases' final and primary energy consumptions. According to the results, the cost-optimal level of residential building has about 36% less annual primary energy consumption compared to the reference case. Nearly zero energy case has even higher energy performance with nearly 57% of annual primary energy reduction. These three energy levels of the residential building were demonstrated in Fig. 17.1, where also the primary energy consumption and global cost results were shown for each energy efficiency improvement measure.

For the residential building, solar collectors and photovoltaic (PV) panels were analysed as renewable energy systems. In Fig. 17.1, especially some measures with and without renewable energy systems were highlighted. Photovoltaic contributions for reference, cost-optimal and nearly zero energy cases are generally similar with approximately 5 kWh/m^2 annual energy production and between 10 and 20 €/m^2 global cost increase. However, solar energy contribution results are dependent on the building heating system and energy performance level. Considering the measure package 29, to reach the cost-optimal level, the boiler of the reference case was changed to a condensing boiler (P35). Then, if we investigate the same capacity solar energy contributions for both P29 and P35 cases, it can be said that the case with the normal boiler had a higher benefit of the solar system. Additionally, looking to the global costs, solar energy system has increased the global cost of the building with condensing boiler (P35), while it decreased the global cost of the building with standard boiler (P29). In the case which is indicated as P37, additional to the condensing boiler, heated floor system was used instead of radiators. Solar energy contribution again increased the global costs while decreasing the primary energy consumptions. Nevertheless, the nearly zero energy case of the residential building uses both solar and photovoltaic systems which carry the primary energy consumption level to the minimum.

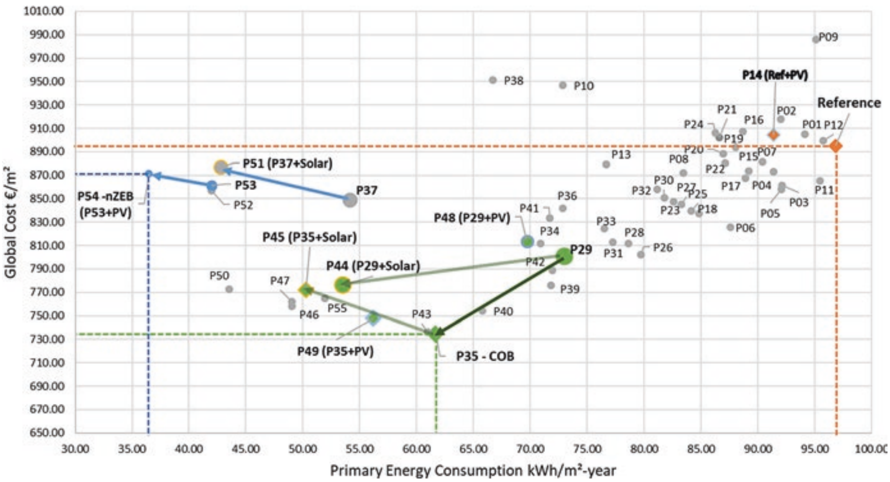

Fig. 17.1 Primary energy consumptions and global costs of each energy efficiency measure for residential building

Table 17.5 Energy performance results of office building

	Reference		Cost-optimal		Nearly zero energy	
	Electricity [kWh/m²-y]	Natural gas [kWh/m²-y]	Electricity [kWh/m²-y]	Natural gas [kWh/m²-y]	Electricity [kWh/m²-y]	Natural gas [kWh/m²-y]
Primary energy consumption by fuel [5]	154.32	20.68	105.61	0.00	88.81	0.00
Primary energy consumption	175.00		105.61		88.81	
Improvement percentage	–		39.65		49.25	

Similarly, office building energy performance results were summarized in Table 17.5. According to the results, the cost-optimal case of the building has about 40% of improvement, and nearly zero energy case has nearly 50% of improvement compared to the reference case. For the office building, the reference, cost-optimal and nearly zero energy cases were also shown in Fig. 17.2 with their global cost levels. For the office building, only the photovoltaic system was used as a renewable energy source, while solar energy system produces low-temperature hot water which was inappropriate to use in office building mechanical systems, like air handling units or fan coils. In the graph, given in Fig. 17.2, the photovoltaic contribution to reference building was shown with energy efficiency measure package 27. Furthermore, nearly zero energy level (P68) of the office building was determined by the photovoltaic system inclusion to the cost-optimal case (P65).

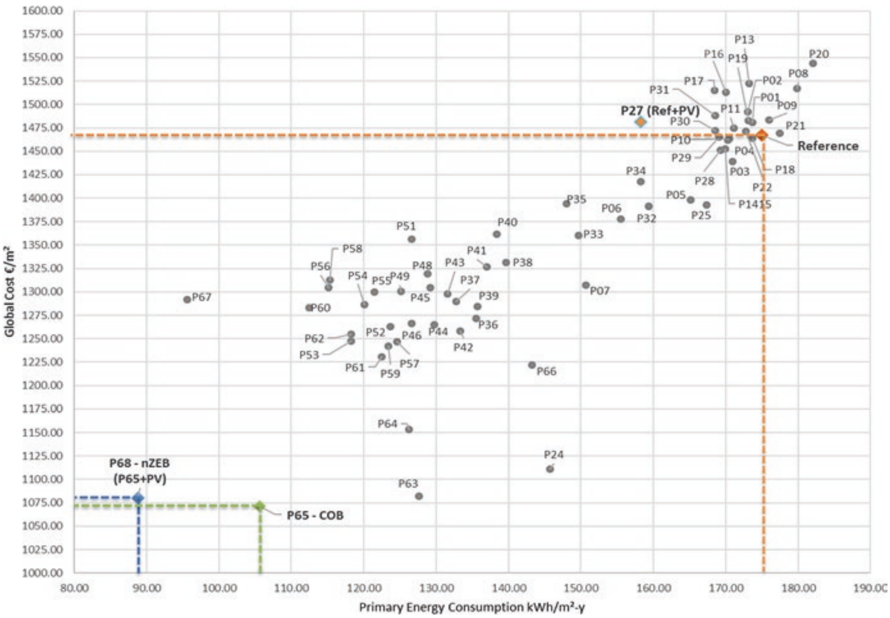

Fig. 17.2 Primary energy consumptions and global costs of each energy efficiency measure for office building

Table 17.6 Energy performance results of light industry building

	Reference		Cost-optimal		Nearly zero energy	
	Electricity [kWh/m^2-y]	Natural gas [kWh/m^2-y]	Electricity [kWh/m^2-y]	Natural gas [kWh/m^2-y]	Electricity [kWh/m^2-y]	Natural gas [kWh/m^2-y]
Primary energy consumption by fuel [5]	317.59	74.75	210.70	20.81	95.91	21.17
Primary energy consumption	392.34		231.51		117.08	
Improvement percentage	–		40.99		70.16	

Lastly, industrial building energy performance results were summarized in Table 17.6. According to the results, the cost-optimal case of the building has about 41% of improvement, and nearly zero energy case has nearly 70% of improvement compared to the reference case. For the industrial building, the reference, cost-optimal and nearly zero energy cases were also shown in Fig. 17.3 with their global cost levels. As the renewable energy source, only the photovoltaic system was used again, similar to the office building. As seen from the graph in Fig. 17.3, the PV system contribution is about 100 kWh/m^2 for each case. However, global cost

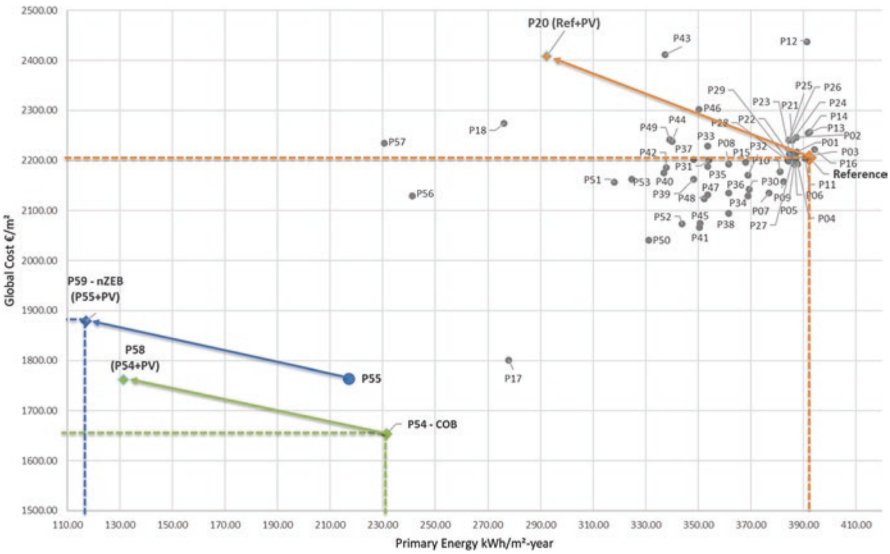

Fig. 17.3 Primary energy consumptions and global costs of each energy efficiency measure for light industry building

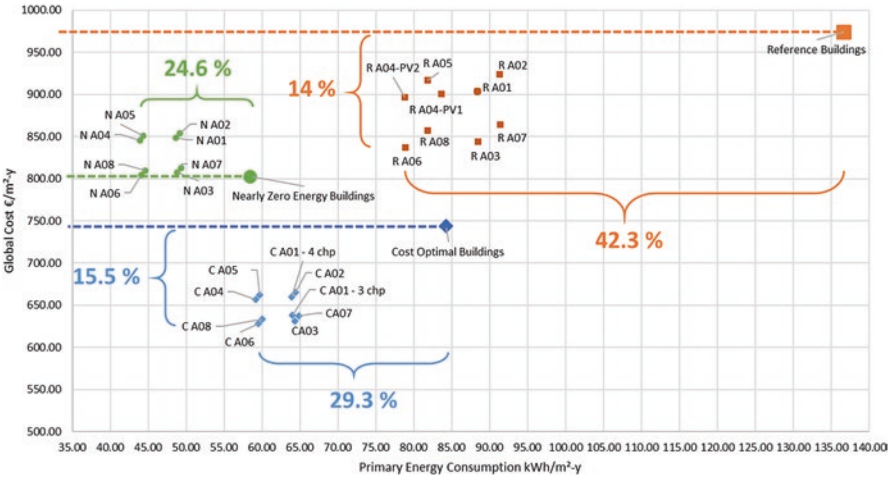

Fig. 17.4 Primary energy consumptions and global costs of each district energy system alternatives for each energy level of buildings

increase caused by PV system changes from about 200 €/m^2 for reference case to about 130 €/m^2 for nearly zero energy case.

Settlement scale annual primary energy consumption and global cost results were given in a graph in Fig. 17.4. Generally, according to the results, the district energy system contribution to the energy efficiency decreases when the building energy efficiency level increases. What's more, global costs of district energy systems are lower with cost-optimal buildings, and they are even higher than the reference case with nearly zero energy buildings. District energy system alternatives with and without PV system were given before in Table 17.2. For each energy level of settlements, renewable energy contribution (PV system) decreases the annual primary energy consumption about 5 kWh/m^2, and the global costs are also slightly lower compared to the same systems without the PV system.

17.4 Conclusions

Renewable energy system usage is inevitable to reach nearly zero energy levels for buildings as it was asserted in the definition of EPBD, and the results of this study also confirm the case. However, renewable energy system investments increase the global costs of buildings depending on the system size, and the system size is dependent on the available roof and/or façade area of the building. For this reason, it was one of the objectives of this study of adapting the cost-optimal methodology for settlement scale analyses to lower the global cost increases caused by high renewable energy system investment costs. By this way, larger renewable energy systems can be used at settlement scale with less global costs.

Consequently, it can be asserted that energy politics and targets set by governmental authorities are fundamental to reach high energy-efficient communities with controlled effects on the economy. The long-term targets should be set in conjunction with scientific researches, and the whole period towards a sustainable environment should be divided into smaller phases with shorter period targets. Turkey has already developed its own building energy performance certification tool by following the European Union Directive; however, for the next phases and targets, more distinct and major steps should be taken.

References

1. International Energy Agency, Key World Energy Statistics, 2017
2. https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union, date retrieved 25.02.2018
3. International Energy Agency, World Energy Outlook, 2018
4. Directive 2002/91/EC of the European parliament and of the council of 16 December 2002 on the energy performance of buildings, Off. Eur. Union. **L 001**, 65–71
5. Directive 2010/31/EU of the European parliament and of council of 19 May 2010 on the energy performance of buildings (recast), Off. J Eur. Union, **L 153**, 13–35
6. Binalarda Enerji Performansı Ulusal Hesaplama Yöntemine Dair Tebliğ (Building Energy Performance National Calculation Method). T.C. Resmi Gazete, 27778, 07.12.2010
7. ASHRAE 90.1 Energy Standard for Buildings Except Low-Rise Residential Buildings. SI Edition, 2007

8. Binalarda Enerji Performansı Yönetmeliği (Building Energy Performance Regulation). *T.C. Resmi Gazete*, 27075, 05.12.2008. Last revision: Turkish Official Gazzette, 30051, 28.04.2017
9. https://energyplus.net/, date retrieved 02.08.2017
10. Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU, Off. J. Eur. Union. **L 81**, 18–36
11. EN 15459 Energy Performance of Buildings – Economic Evaluation procedure for energy systems in buildings, 2007
12. https://www.emd.dk/energypro/, date retrieved 02.08.2017

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https://doi.org/10.1007/978-3-030-40671-4

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