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

F. Vavili (✉)
School of Architecture, Faculty of Engineering, Aristotle University Thessaloniki, Thessaloniki, Greece
e-mail: faniva@arch.auth.gr

A. Kyrkou
Department of Architectural Design and Architectural Technology,
School of Architecture, Faculty of Engineering, Aristotle University of Thessaloniki, Thessaloniki, Greece
e-mail: aikyrkou@arch.auth.gr

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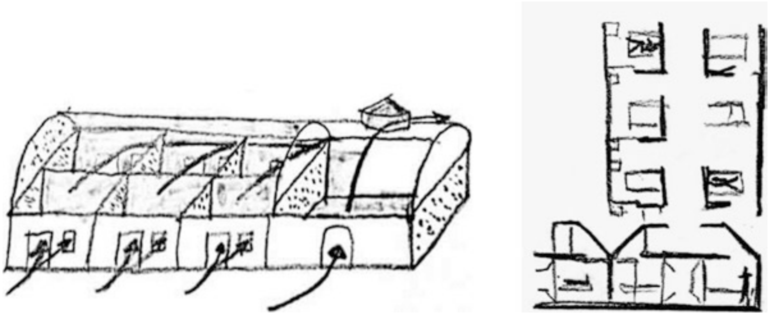

Fig. 10.1 Hand sketches by A. Kyrkou based on Thompson and Goldin (1975, pp.56–57), layout and isometric of Salpetriere pavilion by architect Francois Viel (left) and on the Le Corbusier "Venice Hospital" 1965 (right)

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

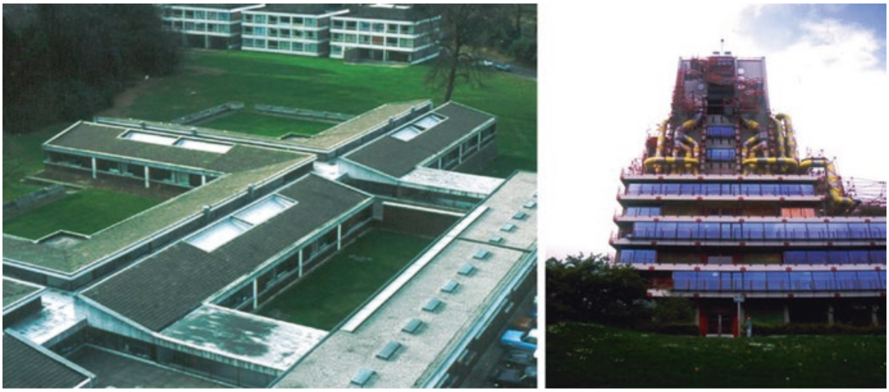

Fig. 10.2 At Wexham Park Hospital by Powell and Moya (1966), the natural landscape and sun played a significant role in the overall design of the hospital. The horizontal layout of the hospital was based on the concept for each patient to have access to natural light, ventilation and interesting views. 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-

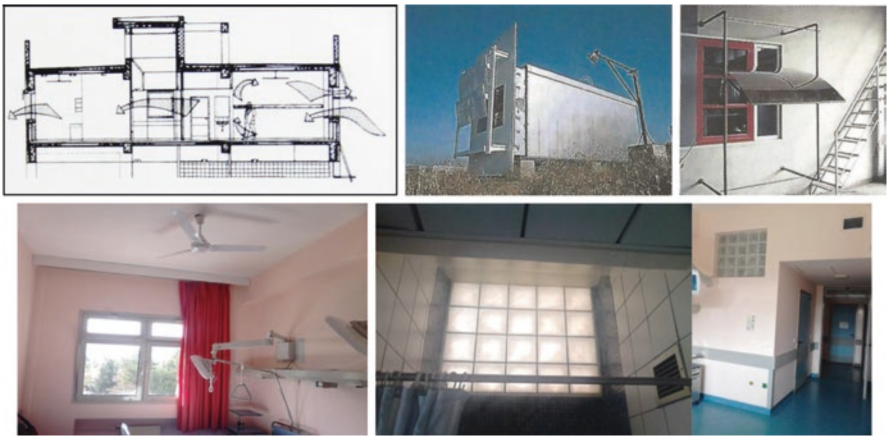

Fig. 10.6 The ventilation and lighting of the hospital were an important parameter in the design process of Papageorgiou General Hospital (1999), Thessaloniki, Greece. (Photos: A. Kyrkou)

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.

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