Collecting and Reviewing Written Resources that Map the Knowledge Triangle for Transferring Research and Innovation on Sustainable Rehabilitation of the Built Environment in Continuing Education

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Abstract. The aim of this study is to map an overview of the education, research and innovation on energy efficiency focused on the rehabilitation of the built environment. The research is organized as follows:

- Introduction and contextualization on energy efficiency.
- The main educational resources are depicted regarding (i) the educational levels on energy efficiency, (ii) the professional attributions, (iii) the role of energy manager and (iv) various examples of existing studies.
- The main research and innovation challenges are presented considering (i) the role of Energy Service Providers (ESPs); (ii) Energy Conservation Measures (ECMs); climate adaption and adaptive comfort; (iv) heating, ventilation and air conditioning systems: adaptive setpoints; (v) mixed mode potential; (vi) Net Zero Energy buildings (NZEB); (vii) climate change and (viii) fuel poverty.
- Conclusions of the educational, research and innovation challenges.
- References including the citations in which the main text is supported.

Keywords: Energy efficiency · Built environment · Sustainable rehabilitation

1 Introduction

As a result of the oil crisis of the 1970s, concerns about the effects of climate change on the planet have exponentially increased. Currently, global warming and the depletion of non-renewable resources are the main concerns in society. Based on these problems, a greater demand on the improvement of the energy performance has been reflected in several sectors, including building sector. This is due to the bad energy behaviour presented by most of the existing building stock [1–4]. In quantified data, the building sector is responsible for approximately 30% of the energy consumption at a global level [5], generating 40% of pollutant gas emissions in the atmosphere [6, 7]. Given

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this circumstance, the European Union has set up the steps required to reach a low carbon economy by 2050 [8]. To achieve this goal, the building sector needs to reduce pollutant gas emissions by 90%, among others. Recently, the Directive 2018/844 [9] has established that European countries need to devise strategies of energy renovation of the existing building stock, with the aim of having efficient buildings before 2050.

In this context, education is a crucial agent for sustainable development. Nowadays, the rapid rise in international students and the commitment of the universities are key points towards a low carbon environment [10]. There has been considerable progress in the incorporation of sustainable development and energy efficiency into the curricula of higher education institutions. However, particularly on competences for sustainable development and on pedagogical approaches, there has been limited research on the connection between how courses are delivered and how they may affect sustainability competences [11]. A combination of pedagogical approaches must be considered to cover all the competences in energy efficiency education.

Regarding the specific case existing buildings refurbishment, the use of alternative or low-energy consumption air-conditioning systems is also a very interesting option; in this case, research is being done to explain how the installation of these systems can affect the building's consumption. [14]; under certain climatic conditions, a free-cooling system can provide comfort with an energy consumption close to zero. Another investigation by Christian, Carsten and Mads [15] explores the possibility of having a zero energy consumption building in Denmark, starting from an existing building and installing different air-conditioning options, all of which are 100% renewable.

The organizations competitiveness needs the improvement of the efficiency and energy savings, as well as, a decrement of greenhouse gas emissions that produce the climate change. On the other hand, the increase in efficiency and energy savings decreases energy dependence.

Europe's future growth depends on greater efficiency in the use of resources and, to a large extent, greater energy efficiency. The Energy efficiency directive can be a valuable part of the basis for growth and job creation in the coming years and would limit European imports of expensive fossil fuels.

2 Education on Energy Efficiency

2.1 Educational Levels on Energy Efficiency

The application of the educational levels on energy efficiency could be classified in:

(a) Professional training. It is in charge of the training of the technicians in energy efficiency (TEE). In Spain there is a specialty of energy efficiency in the upper modules of professional training.
(b) University training.

- Bachelor's programs. All students of technical degrees have professional attributions for the practice of energy efficiency. However, the degree programs do not incorporate enough energy skills for professional practice, so the currently training offered is incomplete. In recent years there are many students who choose this topic for their final undergraduate project.

- Degree in energy management. In Spain there is no specialized degree in energy management.
- Postgraduate/Master's degree. Nowadays it is the main training implemented. This training is used for the speciality of all technical qualifications. Non-technical graduates (graduated in law, physics, chemistry, environmental sciences, geography, etc.) who studies these masters are enabled as auditor and/or energy manager. On the other hand, in recent years there are many students who choose this theme for their master's degree final project.
- Doctorate program. In recent years there are many students who choose this topic for doctoral thesis PhD.

2.2 Professional Attributions

In Spain the professional attributions in energy efficiency are classified into three lines:

Technicians in Energy Efficiency (TEE). It is the technician in charge of the execution, control and maintenance of the energy efficiency measures. Currently it is usually a refrigeration or electrician specializing in energy, but the attributions are not regulated by law.

Energy Auditor (EA). It is in charge of the evaluation of the facilities in the actual state, as well as its diagnosis and proposals for improvement.

Energy Manager (EM). It is in charge of the evaluation, audit, planning, execution control and maintenance of the energy conditions of the buildings, as well as of its proposals for improvement. According to the Royal Decree 56/2016, the minimum requirements will be "to be in possession of any degree or master with knowledge of energy."

2.3 The Role of Energy Manager

An energy manager (EM) is a professional who studies, from an integral approach, the use of energy of a building or production process. The competences included are:

- Audit.
- Study and implementation of Energy Conservation Measures (ECMs).
- Control of execution and monitoring.
- Maintenance and control of ECMs.

The academic requirements for the obtaining of the Certificated of specialized and advanced studies on EM are Degree or graduate with knowledge of energy.

Aims of the studies on Energy Manager:

- Provide the technical personnel of the curricular/educational training or knowledge necessary to enable them as Energy Managers EM.

- Possibility of inclusion in degree programs of the different engineering.

Competences developed at advanced form:

- **G01.** Capacity of search, analysis and selection of the information.
- **G02.** Know and be able to apply to the projects the kinds of elements that show initiative, commitment, enthusiasm and capacity of motivation.
- **G03.** Problem-solving Skills.
- **G04.** Be able to communicate their conclusions with the knowledge and reasons that sustain them, to specialized and not specialized public, in a clear way and with no ambiguities.
- **G05.** Obtain skills in the learning, which allow them to continue studying in an autonomous and self-guided way.

Targets or specific Competences:

Main reason: Labor market access. Job offers.

1. Curricular/educational training.
2. To promote the energetic management.
3. Basic principles.
4. Basic knowledge.
5. Resolution of practical cases.
6. Economic, legal and administrative aspects.
7. To propitiate the international homologation:
   - CEM (The Certified Energy Manager® (CEM®)).
   - ISO (International Standardization Organization).
8. Interdisciplinary relationship between the different engineering, especially industrial and building engineering.
9. To encourage an interuniversity and international framework:
   - Share courses/information.
   - Share knowledge and experiences.
   - A common academic commission.

2.4 Example of Existing Studies

At present, there is no specific degree of energy management or sustainability. The few studies that there are at the graduate level. In the University of Seville, there is one course of continuous training, and two master:

1. Energy adviser (Continuous training). Type of teaching: Continuous training. No access requirements, 6,00 ECTS, quarterly, non-presential.
   Content: Theory. Project practices. Seminars of companies. Practices in companies.
   Module: Theoretical and practical aspects of energy assessment.

2. Energy manager (Master). Type of teaching: Lifelong training (postgraduate), 60 ECTS, annual, non-presential.
   Content: Theory. Project practices. Laboratory Practices and Practical Work Exhibitions. Seminars of companies. Practices in companies. Travels to companies.
   Module: Energy Management. Market. Tools and tools for energy management. Energy saving measures. Solutions and methodologies. Maintenance. Audit Control. Professional activity. Fine work of the master. Internship in a company/institution.
3. Eco-efficient rehabilitation of buildings and neighborhoods (Master). Type of teaching: Lifelong training (postgraduate), 60 ECTS, annual, non-presential.
   Content: Theory. Project practices.
   Module: Introduction to Sustainability, Eco-efficiency, Economics and Politics Environmental. Environmental Planning and Eco-efficient. Eco-efficient Construction Materials and Products. Building and Environment. Passive Systems. Use and Integration of Renewable Energies in Buildings. Eco-efficient Rehabilitation. Final Master's Project.

3 Energy Efficiency Research and Innovation Challenges

3.1 The Role of Energy Service Providers (ESPs)

The directive 2012/27/UE and the Royal Decree 56/2016 set certain definitions that affect the Energy Service Providers (ESPs), establishing a wide variety of tasks and actions, which allows the provision by the ESPs of multi energy services with different scopes.

It is necessary to develop the energy services market in order to ensure the availability of both the demand and the supply of energy services. Transparency can contribute to this, through lists of ESPs, as set out in the Directive and the Royal Decree, for which it is advisable to classify them, in coherence with the legal provisions and with existing practice and experience. The classification of the ESPs establishes clarity and confidence in the market about the different typology of existing ESPs, based on their actions. The classification also recognizes the existing singularity with respect to the groups of companies, when providing energy services.

The ESP classification aims at the specialization of the different energy service providers, encouraging them to engage different administrations and companies, with the consequent improvement of the energy efficiency, the energy saving promotion and the reduction of greenhouse gas emissions.

3.2 Energy Conservation Measures (ECMs)

The adoption of energy conservation measures (ECMs) constitutes one of the most significant performances considering energy efficiency. From the different elements of buildings, those elements from the envelope mostly contribute to the inefficient energy performance of the existing building stock, due to heat losses or gains occurring through them [12–15].

Thus, adopting efficient ECMs by means of the energy analysis of buildings is fundamental to fulfil the objectives of reducing pollutant gases by 2050. However, the efficiency of adopting ECMs in building envelope is currently a study gap, particularly in warm climatic regions. Most studies has focused on the analysis of the building envelope improvement in cold or mild climatic regions. Some of these studies are as follows: (i) Aksoy and Inalli [16] analysed the influence of passive design parameters, such as the shape factor and the orientation position, in a building located in a cold region of Turkey; (ii) Invidiata et al. [17] analysed the influence of six design strategies of a residential building located in the north of Italy in future scenarios of climate change. These authors studied these strategies from the perspectives of adaptive thermal comfort, evaluation of the life cycle, cost analysis of the life cycle, and the multicriteria decision making, with the aim of selecting the best option for the sustainability improvement of the building; and (iii) Bhikhoo et al. [18] carried out a sensibility analysis in different design aspects of a typical dwelling in Thailand, which is located in the wet-dry tropical climate region (Aw class according to Köppen-Geiger climate classification [19]). Results showed a great influence on the placing of insulating material at the ceiling or the inclusion of balconies in the design.

Moreover, most of these studies focused on public buildings, such as offices or shops: (i) Spyropoulos and Balaras [20] analysed the energy performance of 39 office buildings in Greece, determining the most important aspects; (ii) Rubio-Bellido et al. [21] studied the influence of office buildings on the energy demand in future scenarios, determining that the relationship of the shape and the relationship window-wall can significantly influence the decrease of the energy demand during the design phase of these buildings; (iii) Ge et al. [22] analysed different optimization strategies of energy efficiency, such as the envelope improvement or solar protection, in a research building located in the city of Hangzhóu, in the Cfa climate zone.

3.3 Climate Adaption and Adaptive Comfort

Until now, the integration of the climatic adaptability of the users and the low energy consumption has been raised through the adaptive comfort models. These models are set in the international standards EN 15251:2007 [23] and ASHRAE 55-2017 [24], which consider that users can interact with the environment. These models present limitations in warm climates, if the trend to global warming is considered [25, 26].

Their advantage, when compared to models of static comfort, [27] relies on the fact that occupants of naturally ventilated buildings may have a wider comfort range [28] than those who are accustomed to centralized HVAC systems. In addition, current adaptive standards, which are derived from studies carried out by the RP-884 and SCATs projects, prove that indoor temperatures in naturally ventilated spaces are closely related to the external temperatures. In particular, a variety of studies have established the relation between vernacular architecture and its surrounding environment in a way that adaptive comfort plays a crucial role [29]; besides, locally available construction materials are also important [30] and, considering adaptive comfort, even standards for zero energy buildings can be achieved [31].

3.4 Heating, Ventilation and Air Conditioning Systems: Adaptive Setpoints

Another aspect to highlight from the existing scientific literature are the setpoint temperatures used in the modellings analysed. The modification of setpoint temperature values has a significant influence on the energy consumption [32]. In this sense, some studies highlighting this aspect are as follows: (i) Spyropoulos and Balaras [33] established setpoint temperatures of 20 °C for heating and 26 °C for cooling in bank branches, according to the national legislation for public buildings in Greece. The results obtained a decrease of the energy consumption for HVAC by 45%; (ii) Hoyt et al. [34] used setpoint temperatures of 18.3 and 27.87 °C for heating and cooling, respectively, in an office building located in 7 different climate zones. By using these setpoint temperatures, a saving between 32 and 73% was achieved; and (iii) Wan et al. [35] studied the impact of climate change on office buildings in subtropical climates and the influence of the setpoint temperatures used. By using setpoint temperatures for cooling higher than 25.5 °C, reductions of the energy demand in different future scenarios were obtained.

Thus, variations of these setpoint temperatures can lead to a variation in amortization periods of the ECMs to be carried out, since the energy consumption varies. However, in most of the studies mentioned above, setpoint temperatures were based on the index Predicted Mean Vote (PMV). In recent years, several research studies have highlighted the importance of using adaptive setpoint temperatures, which can be defined as setpoint temperatures with the aim of keeping the internal operative temperature within the adaptive comfort limits. These research works focus on the application of adaptive comfort models from ASHRAE 55 [36] and EN 15251 [37] in setpoint temperatures, analysing the advantages and limitations presented with respect to the models based on the PMV. Some of these research studies are as follows: (i) Sánchez-García et al. [38] studied the use of adaptive setpoint temperatures in future climate scenarios with the objective of reducing the energy demand in office buildings; (ii) Holmes and Hacker [39] analysed the application of the adaptive thermal comfort approach in different office buildings in United Kingdom, both in current and future scenarios; and (iii) Kramer et al. [40] assigned the lower limit of the comfort area of the model developed by van der Linden et al. [41] for Holland. This model was established in the standard ISSO 74 [42] to the heating setpoint temperature of a museum, which obtained a reduction of the energy consumption by 74%. However, there is a lack of research studies on this field in Spain: (iv) Sánchez-Guevara Sánchez et al. [43] applied the adaptive comfort model from ASHRAE 55-2013 by means of setpoint temperatures that monthly varied, and reductions by 20% in the heating energy demand as well as of 80% in the cooling energy demand were obtained; (v) Barbadilla-Martín et al. [44] compared energy demands of a building with mixed mode by using usual setpoint temperatures as well as setpoint temperatures based on the neutral temperature of a thermal comfort model previously developed in the city of Seville [45]. Usual average setpoint temperatures were 23.5 °C and 22.3 °C for cooling and heating, respectively, whereas the average neutral temperatures were 24 °C and 21 °C for cooling and heating. The results showed reductions by 27.5% and 11.4% in cooling and heating, respectively.

3.5 Mixed Mode Potential

Mixed mode buildings have already been widely studied in terms of energy savings [46–48]. However, in terms of thermal comfort, there is still no consensus regarding how mixed mode buildings should be assessed considering natural ventilation and air conditioning separately. There is a similar lack of consensus about whether the adaptive comfort approach is suitable for both modes of operation. Several field studies in mixed mode buildings have been made, although there has been disagreement when some found a unique model for both modes of operation [49, 50] and others did not [51]. Other authors considered that mixed mode buildings should be studied separately for both modes of operation, so developed comfort models for air conditioning and natural ventilation [52–54]. The results were consistent with this, with occupants' actual thermal sensation and acceptance varying when operation modes changed from air conditioning to natural ventilation, or vice versa. But, in general, the adaptive model was more suitable for mixed mode buildings [55]. Furthermore, it is necessary to consider that people might be used to using natural ventilation or air conditioning. In this way, people who tried to adapt their thermal sensation using adaptive comfort strategies more than others were found to switch on the air conditioning less frequently [56]. Since adaptive models might be more suitable for mixed mode buildings, there must be adaptive opportunities. Otherwise, perceptions of overheating could be intensified [57].

3.6 Net Zero Energy Buildings

From 2020 new buildings will be NZEB and it will be promoted deep renovations in existing buildings in order to reduce to the maximum their energy consumption [58]. It has been widely worked on the concept of NZEB hitherto and [59] and an international and national standard framework has been generated [60].

In this context, the European Union has established annual thresholds for the use of primary energy consumption and minimum energy production from renewable sources in situ according to climatic zones. Therefore, it is necessary to tack the methodology proposed for the implementation of NZEB taking into account other influential parameters such as the preferences of the users, the indoor environmental quality, the variation of the external conditions in the context of the climate change and socio-economic and cultural factors [61].

3.7 Climate Change

Climate change has been profoundly analyzed because of its influence on the construction industry. For this reason, it has become a matter of attention for both governments and research institutions over the last few years. Starting with the foundation of the Intergovernmental Panel on Climate Change (IPCC) in 1988, which has recently published its Fifth assessment report (AR5) [62], there have been numerous studies that focus on climate change, the increase of gas emissions and the scarcity of natural resources. Along this line, sundry prediction models have been generated for various climate scenarios [63]. Most of these models have been developed in the United Kingdom [64], although they have increasingly extended throughout the international framework

[65, 66]. Currently, the IPCC, supported by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO), which is the most widely accepted organization in this matter, envisages multiple emission scenarios for the near future [67]. According to several research projects [68–70], patterns for energy demand and consumption may be altered by climate change; therefore, they should be taken into account when devising schemes for energy supply and should also be carefully considered in order to prevent energy poverty.

3.8 Fuel Poverty

Energy poverty, commonly linked with lack of access to energy sources and/or a deficient coverage of energy needs may be quantified in different ways, mainly considering high prices of fuel or energy, low building performance and low level of income. (Thomson and Snell [92]).

The origin, evolution and discussion about the definition of energy poverty can be found in some key publications in this field [71]. For the sake of clarity in the discourse, the definition given by B. Boardman, which is considered a key text in the fuel poverty debate, is adopted in this manuscript [72]. Boardman states that "fuel poverty" can be defined as "the inability to afford adequate warmth because of the inefficiency of the home"; the threshold for affordability is established at 10%, twice the median household expenditure on fuel in 1991 [73]. Since then, despite the 10% threshold being broadly used as a general criteria to evaluate fuel poverty [74–77], many authors have raised their concerns about the real significance of this figure. Methods for measuring energy poverty can be classified into three groups: gathering the impressions about energy services in homes, analysing expenditure and the direct measure of certain energy services.

Several studies have come to light in recent years analysing fuel poverty and their implications in a variety of national contexts, such as Greece [78], Italy [79], Ireland [80, 81], India [82], Japan [83] and the UK [84, 85]. Others have placed focus on their implications for health [86] risks for adults [87] and the death rate [88]. From a perspective of geography [89], these have focused on rural areas [84, 90], the vulnerability of homes [75, 91], and even from a social justice point of view [92].

In recent years, several studies, which are more focused on the development of new indexes to measure fuel poverty, have come to light in order to clarify some issues pertaining to this term, as well as their implications for public policies:

The Building Fuel Poverty Index (B_{FP}) [79], which establishes a relationship between building energy performance and the risk of fuel poverty in the Italian context, in order to quantify the number of existing buildings that need economic subsidies.

The Progress out of Poverty Index (PPI) [93] based on a Rwandan case-study, which consists of 10 weighted questions regarding the characteristics of households, whose primary sources can be observed and scored with respect to a poverty line.

The Sustainable Energy Development Index (SEDI) [94], a composite index focused on establishing the sustainability level of both intra- and inter-generational needs and correlated to both the Human Development Index (HDI) and the Energy Development Index (EDI).

The Energy poverty comprehensive evaluation index [95], focused on identifying the characteristics of China's energy poverty both at the national and regional levels, as well as the policy implications of energy poverty alleviation.

Those studies provide a solid scientific base which proves that fuel poverty is present nowadays and can have detrimental effects on occupants and be a burden on the finances of lower-income households [96].

4 Conclusions

This study was focused on a comprehensive understanding of the education, research and innovation on energy efficiency with the particular approach of the rehabilitation of the built environment.

Considering the educational resources, various initiatives are now focused on the rehabilitation on the built environment in different educational levels, professional attributions and the appearance of the energy manager as key factor in the future development of education. In this sense, the examples shown an effort but a large room for improvement at educational level.

Regarding the research and innovation challenges, a holistic approach was considered. To accomplish an affordable and sustainable rehabilitation of the built environment, the role of Energy Service Providers (ESPs) es crucial to properly applied Energy Conservation Measures (ECMs). In this sense, there are various important factors in a climate change and fuel poverty context that must be considered in a low energy consumption approach.

This study paves the way for specific educational and research initiatives which contribute to a sustainable and energy efficiency approach for the rehabilitation of the built environment.

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