Buildings' Energy Efficiency and Building Energy Codes: a Literature Review

Dr. Siba A. Awawdeh[1,*], Prof. Chris Tweed[2]

[1] *Hashemite University, Zarqa, Jordan*
[2] *Welsh School of Architecture, Cardiff, UK*
** Corresponding author. Tel: +962-5390333, Ext.4612, Fax: +9625- 3826348, Email: Siba@hu.edu.jo.*

Abstract: International concerns in relation to energy conservation began to emerge during the oil crisis in 1973. At this time attention focused on how to conserve this non-renewable energy source. Since then the buildings has been considered as high potential of saving energy, thus improving the energy efficiency of buildings became an important aspect of conservation. It attracted interest from the relevant bodies in the developed countries where, as a result, building energy codes were developed. During the late 1980s and 1990s, the economic imperative for energy conservation began to diminish due to the dropping of oil prices to pre-1970s levels. Gradually the environmental concerns replaced the economic ones. This was enforced by the call to reduce the green house gases emission to protect the environment from the potential danger of climate change. The environmental aspect has driven the recent development of the building energy codes aiming to reduce CO2 emissions.
The distinctive features of each community determine the detailed aspects of the building energy codes; the codes should therefore reflect the cultural and political context of the targeted community. Learning from others experiences represent the first step towards creating successful building energy codes,

Keywords: *Energy Efficiency, Building's Energy Codes, Climate Changes*

1. Background

1.1. Buildings' energy consumption

Buildings consume almost 40 percent of the primary energy in most countries and are one of five main users of energy [1]. Energy is consumed in buildings for heating and cooling, mechanical ventilation, lighting, water heating and for other services [2]. The Buildings consumption of energy can be reduced by improving their efficiency [3]. Many previous technical studies had demonstrated the potential of the built environment in saving energy [4].
The oil crisis in the 1970s was the main motive for developed countries to reduce the consumption of energy, they started in two ways: reducing the use of energy (demand side) and trying to find another source of renewable energy (supply side). Creating Building Energy Codes (BECs) was one of the policy instruments used by the developed countries to reduce the consumption of energy in the building sector [5]; [6]; [7]; [8]. Nadel's research in (1997) showed that the use of energy efficiency standards was increasing continuously and being updated periodically [9].
Climate change has promoted further concerns regarding buildings' impact on the environment, accordingly the BECs formed the basis of energy and environmental policy in the 1990s, since improving buildings' efficiency attempts to control the growth of green house gases (GHG) emissions by reducing their consumption of energy [3].

1.2. Problems resulting from the high usage of energy in buildings

The increased usage of energy in the building sector with the continuous increase of new buildings contributes to the potential for climate change. The environmental impact of building is widely acknowledged and in the past three decades progress has been made in developing ways to reduce this [10].
The majority of the energy used in buildings is from non-renewable sources that are diminishing rapidly. By operating at optimum efficiency, these resources can be retained for

further generations. At the same time buildings must be capable of providing occupants with the reasonable comfort levels in the absence of energy.
Additionally the economy drives our life and is strongly dependent on the price of oil. Saving energy is beneficial for both the end users and the economy of each country. Improving the energy efficiency of buildings would results in savings on energy bills for the occupants, and reduce electricity peak load, thus reducing the country's need for new power stations.

2. Buildings' Energy Efficiency

Improving the buildings' energy efficiency does not mean a decrease in the standards of indoor comfort; it is a call for an efficient use of the energy. In short "efficiency involves reduced energy consumption for acceptable levels of comfort, air quality and other occupancy requirements, including the energy used in manufacturing building materials and in construction" [16,p.7].
There is no specific definition of the Energy Efficient Building; this term has been used to describe a variety of buildings worldwide [12]. According to Meier et al. (2002) an energy efficient building must be above the average of the following aspects: firstly the equipment used must be efficient and the materials suitable for the climate conditions, secondly, the amenities and services provided must fulfill the building use, and finally the consumed energy of the building must be lower than similar buildings. The embodied energy in both construction and demolition of the buildings is the fourth important aspects to be considered in the future [11].
There is no standard scale to measure the buildings energy efficiency; it is a terminology with a variable scale that depends on the type of building, climate and the common practice of the local construction industry.

2.1. Assessing buildings energy efficiency

Evaluating the energy efficiency of the buildings is not a straightforward task, as the buildings consumption of energy is the result of a complex interaction between the building, climate and user [10]. The energy performance of the buildings is the main indicator of their energy efficiency. The literature recognises two means for evaluating the energy performance:
1.The building's performance compared to other standard building;
2.The use of simple performance indicators such as the annual energy consumption of the buildings per floor area and comparing it to a target value which represents the maximum energy budget of the building.
The methods used to assess a building's thermal performance must be monitored carefully to ensure they reflect the actual thermal performance of the buildings [13]. A building energy budget represents the maximum accepted value for the building's consumption of energy. According to Casals (2006) the proper indicator used to evaluate the energy performance of the buildings should be able to: a) quantify the need of energy of the buildings, expressed for example in terms of kWh/m^2 per year; b) consider the primary energy consumed by the building; c) analyze the energy life cycle; d) limit the energy supply of the building (renewable and non renewable); and e) encourage the use of renewable energy [14]. The indicators in use worldwide for both the regulations and the certification exclude the embodied energy and the life cycle, while both are significant in assessing the energy performance of the building. The analysis of life cycle is believed to consider the effect of buildings on both the environment and energy [15].
The simulation programs are recognised as a valuable tool for the development of the BECs and the evaluation of the buildings' energy performance [16]. The simulation programs are used to find the building's consumption of energy, because the simple analyzing tools is not capable to gauge the actual energy performance of the buildings which have a complicated

energy system, where the different building systems interact together, along with the external environment and the user interaction [14]. This difficulty is more highlighted when considering a bioclimatic approach to the design of building, where the simulation tools, are capable of handling the complexity of the building's thermal interaction [17]; [18].

2.2. Policy mechanism to adopt energy efficiency measures in buildings

There are two main approaches to conserve energy in buildings: the technical and the political. The technical approach guides the designers of the buildings towards the more efficient and effective energy-using designs and techniques. While the political approach, enforces the use of specific measures that is considered effective to reduce the buildings consumption of energy. Different policy mechanisms have been implemented worldwide to improve the energy efficiency in buildings. The literature identified the following mechanisms used [19]; [6]; [8]:

•Mechanisms that control and regulate the energy efficiency in buildings. These mechanisms are subdivided into normative and informative regulatory mechanisms. The BECs are an example of the normative type. While the informative mechanisms provide the end-user with information which he is not forced to consider, such as labeling programmes.

•Mechanisms that consider the economic and market methods, these had voluntary elements.

•Mechanisms that employ fiscal and incentive tools to conserve energy in buildings. This mechanism is applicable for different sectors and technologies.

•Mechanisms that provide information and support to increase the public awareness and enhance voluntary work.

The policy considered by the governmental bodies can significantly influence the building's consumption of energy; hence affect its environmental impact. Thus the nature of the different policy instruments must be understood by the policymakers, so they can choose the most suitable mechanism to achieve efficient policy package. Moreover, the local conditions have a significant impact on the building design and activities, thus these local factors will influence governmental policies. In order to transfer the market towards better energy efficiency it is recommended to combine different policy instruments [20].

Harmelink et al.'s study (2008) has identified the following four main points that contribute to the success of the policy instrument used [21]:

•The policy instrument should have definite objectives, and the implementing organization should be authorized;

•The instrument should be competent of balancing and combining the elasticity and stability;

•The stakeholders should be involved in the selection of the instrument; and

•The instrument should be capable of adapting and incorporating new policies.

There are two main ways to implementing energy efficiency measures in buildings, mandatory or voluntary. The mandatory codes are a straightforward way of restricting the behaviour of people and organisations to achieve objectives; this tool has been used to control the energy use in building since the mid-70s. They are the most widely adopted and used in over 30 countries and regions. Some developing countries started to use them in the 1990s [3]. The voluntary programmes are used to tackle energy or environmental problems which cannot be solved easily by regulations. These instruments include codes and eco-labeling schemes in which organizations commit to making their products or production processes more environmentally friendly [22]. Since 1990 the use of voluntary approaches has increased to deal with environmental problems which include GHG emissions [23].

3. Building Energy Codes

The BECs or regulations are a form of regulatory instruments, they are defined as the documents used by local state or national government bodies to control building practices

through a set of statements of acceptable minimum requirements. As these requirements are based on socio-political and community consideration, they differ from country to country or from locality to locality [24]. The BECs are used by the government bodies to improve the building's energy efficiency, hence achieving a positive change to the social, economic and environment in society. BECs are found to be the most effective and cost-effective regulatory instrument that lead to improving the energy efficiency of buildings thus reducing the emission of GHG [25]. The building standards are a set of technical documents that standardize in terms of quality or performance and sometimes in terms of size or procedure some activity in relation to building construction [24].

3.1. Building energy codes and energy efficiency

The majority of developed countries considered the use of BECs an effective policy towards saving energy. The survey of Janda and Busch in 1994 showed that there is an increased international concern over energy standards as part of their energy efficiency agenda [8]. Levine et al. (1995) found that countries on almost every continent were now in various stages of developing, improving, and expanding their BECs [26].

The BECs played a significant role in the improvement of energy efficiency of new buildings in most of the OECD countries [19]. Moreover Schipper's et al. study (1986) found that most studied countries had shown a decline in their energy demand from 1973 to 1984. This decline is believed to be related to the BECs which have been enforced since 1973 [27].

The BECs has seen a significant development along with the rapid growth of other instruments [5]; [6]; [7], since 1970s around 30 developed countries had established and implemented their own regulations [8]; [5]. The improvement in the calculation methods, computer modeling, and building research over the past two decades provide the necessary tools for developed countries to revise their original standards.

Moreover, the increasing awareness of the impact of climate change on our environment has boosted further development of the BECs. Consequently, third and fourth generations of BECs are under revision in a number of European Countries, USA, and Canada [5]; [28]. The BECs were found to be one of the most effective and cost effective in reducing GHG emission [7]; [28]. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standards (90 series) are the most widely adopted model nowadays, the methods proposed in the current and previous versions of the standards was the basis for the codes in a number of developing countries [8]; [26].

3.2. Types of building energy codes

There are two main forms of codes and regulations, prescriptive and performance [29]. Under those two categories the World Energy Council identified the following types of the building codes: a) envelope component, b) overall envelope, c) limiting heating and cooling demand, and d) energy performance. Limiting the heating and cooling needs and the energy performance are the two approaches recently preferred; both approaches are of the performance type.

3.2.1. Prescriptive codes

The prescriptive approach is based on providing a detailed description of the building's technical requirements. In this approach the regulations specify the minimum requirements for different building components, which the buildings have to comply with to satisfy the code. The requirements are chosen based on their suitability for the climate and capability to save energy. The regulations might differ in the building component they target and in the stringency level of their requirements [7].

The main advantages of the prescriptive codes are that they are simple to use, they are straightforward for builders or designers to follow, easy for third parties to check and relatively easy for building regulations to enforce [29]. While their disadvantage is that they tend to limit development of new technology and techniques, this might serve as a barrier for innovation and make the regulations very restrictive, as they do not encourage innovative design solutions. This would limit exploitation of the different passive cooling or heating techniques, because prescriptive codes are not able to consider the interaction between the building system and the measures that would optimize performance.

3.2.2. Performance-based Codes

The performance-based approach is based on describing the required performance of the building without specifying how to achieve it. This approach has been used by a number of developed countries in their building energy codes [30]; [31], and others are in a process of developing this approach in their building codes.

The performance-based code fulfils the need for a more flexible approach [32]. The main advantages of using such an approach are believed to be:

•offers greater flexibility and encourages creative solutions and innovation of new materials [33]; [34]; [35], also it allows for design flexibility and can consider innovative features [33];

•reduces the cost as it promotes creative new solutions to; and

•concentrates on quality rather than price only [34].

The use of performance based approaches for establishing the building code was recommended in Deal and Fournier's study (2001) because it will "raise the overall standard for code development….encourage more regionally based design and construction solutions…..promote better quality solutions….and…..less confusing"[36].

On the other hand, managing and acquisitioning the technical, environmental and administrative knowledge is believed to be one of the disadvantages of this approach, along with the administrative cost [34]. Moreover, the buildings' performance over time represents one of the technical problems related to the performance approach, because the performance of innovative solutions over time is not known. The performance of the traditional prescriptive solutions has been well investigated and confirmed [35]. Additionally, it is easier for the architects to follow prescriptive codes especially for typical low cost projects.

Using the performance approach in the building energy codes requires setting an energy budget for the targeted buildings, the buildings' annual energy consumption (heating, lighting, cooling, etc.) is generally the value used in this context. The performance-based code cannot be directly transferred from developed countries to developing countries; the implementation process for such codes in developing countries requires detailed guidance for construction techniques and materials selection, where a number of local issues must be considered before implementing it. The advancement of the local codes must consider the: contents, approval process, compliance procedures, verification methods and certificates and professional involvement. All these will have an impact on the implemented codes and their mixture of prescriptive and performance-based approaches [35]. Performance-based regulations require a high degree of skills in both the administrative bodies and the designers, the simulation programs are considered an essential tool in this approach as a means to show compliance with the codes [37]. Accordingly, the use of such approach in developing countries obliges establishing the required skills and institutions beforehand [33].

3.2.3. Overall Thermal Transfer Value (OTTV)

This approach is considered a partial performance method, which is based on describing the required performance of the building envelope. This approach is used to control the design of the building envelope to reduce the external heat gain through it, which will lead to a

reduction in the electricity required for cooling the buildings. It acts as an index to compare the thermal performance of buildings. This method is more suitable for application to buildings in hot climates, because it accounts for solar heat gain through the envelope [38]. It measures the average heat gain through the three major components of the building envelope: the conduction through opaque walls, the conduction through window glass, and solar radiation through window glass. This method was first proposed by ASHRAE based on the main significant factors that affect the thermal gain of the buildings.
The related authorities set the required OTTV value which the buildings must not exceed in order to satisfy the code. Whilst ASHRSE stopped the use of the formula in the 1980s, the Association of Southeast Asian Nations (ASEAN) countries continued to use and develop it as a measure in their energy code. This development was carried out under the ASEAN-USAID building energy conservation Project [39].

3.3. Importance of Building Energy Code

The literature emphasized the impact of improving the energy efficiency to control the growth of CO_2 emission. The BECs are one of the most effective regulatory instruments, which are capable of improving building's energy efficiency, thus reducing the building's emission of GHG [7]. BECs promote designing and operating energy efficient buildings. Furthermore, it pushes the different parties involved in the construction industry to develop building products and services that save energy [8]; [33].
BECs would increase the public awareness regarding conserving energy in buildings. In addition, the BECs would help to form the basis for building performance assessment and energy efficiency program development [8]; [33].
Finally, successful BECs would be capable of overcoming the majority of the barriers that hinder delivering the energy efficiency techniques in the building sector [7]. The regulation is the measure that will force the construction industry to adopt energy conservation techniques [40].

4. Conclusion

There has been world concern regarding improving the energy efficiency of buildings since the oil crisis in 1973, with buildings being identified as one of the five main energy consumers worldwide. The building's energy performance is the main indicator of buildings' energy efficiency. Thus, the indicator used to evaluate the energy performance of buildings is considered a significant element for building regulations. Simulation programs were recognised as a valuable tool in the buildings evaluation process, they are used to find the building's consumption of energy. In addition to their use in the development process of the BECs worldwide.
Different policy mechanisms have been implemented worldwide to improve the energy efficiency in buildings. The BECs are found to be the most effective and cost-effective regulatory instrument that lead to improving the energy efficiency of buildings. The requirements of the BECs are based on socio-political and community consideration, thus they differ from country to country. The literature showed increased international concern over energy standards as part of their energy efficiency agenda; it was found that countries on almost every continent were now in various stages of developing, improving, or expanding their BECs.
There are two main forms of codes and regulations, prescriptive and performance. The performance-based approach has been used by a number of developed countries in their BECs, and others are in a process of developing this approach in their building codes. OTTV is considered a partial performance method; it is more suitable in hot climates, because it accounts for solar heat gain through the envelope.

References

[1] World Business Council for Sustainable Development, *Energy Efficiency in Buildings Business realities and opportunities*, 2010

[2] Roaf, S., Fuentes, M. & Thomas, S., *Ecohouse: a design guide,* Architectural Press, 2007, pp. 15.

[3] Lee, W.L. & Yik, F.W.H., Regulatory and voluntary approaches for enhancing building energy efficiency, Progress in Energy and Combustion Science 30, 5, 2004, p. 477-499.

[4] Kasabov, G. *Buildings, the key to energy conservation: issues and case studies,* RIBA Energy Group, London, 1979.

[5] Deringer, J.J., Iyer, M. & Huang, Y.J., Transferred Just on Paper? Why Doesn't the Reality of Transferring/Adapting Energy Efficiency Codes and Standards Come Close to the Potential? Proceedings *ACEEE Summer Study on Energy Efficiency in Buildings*, 2004.

[6] IEA, *Evaluating Energy Efficiency Policy Measures & DSM Programmes Volume I*, International Energy Agency, 2005

[7] Koeppel, S. & Ürge-Vorsatz, D., Assessment of policy instruments for reducing greenhouse gas emissions from buildings, UNEP–Sustainable Buildings and Construction Initiative, September, Budapest, 2007

[8] Janda, K.B. & Busch, J.F., Worldwide status of energy standards for buildings, Energy 19, 1, pp. 27-44, 1994.

[9] Nadel, S., The future of standards, Energy and Buildings 26, 1, pp. 119-128, 1997.

[10] Roaf, S., *Closing the loop: benchmarks for sustainable buildings*, Riba, London, 2004.

[11] Meier, A., Olofsson, T. & Lamberts, R., What is an Energy-Efficient Building, Proceedings *ENTAC 2002-IX Meeting of Technology in the Built Environment*, 2002.

[12] Lowe, R. & Bell, M., Building regulation and sustainable housing. Part 2: technical issues, Structural Survey 18, 2, pp. 77-88, 2000.

[13] Casals, X.G., Analysis of building energy regulation and certification in Europe: Their role, limitations and differences, Energy and Buildings38, 5, pp. 381-392, 2006.

[14] Chwieduk, D., Towards sustainable-energy buildings, Applied Energy. 76, 1-3, pp. 211-217, 2003.

[15] Carlo, J., Ghisi, E. & Lamberts, R., The Use of Computer Simulation to Establish Energy Efficiency Parameters for a building Code of a City in Brazil, *Eighth International IBPSA Conference*, pp. 131, 2003

[16] Beausoleil-Morrison, I., Calla, R., Mottilo, M., Purdy, J., Wyndham-Wheeler, P., Lopez, P., Dubrous, F. & lubun, M., Using Building Simulation to support an Energy-Efficient Incentive Programme, *Seventh International IBPSA Conference,* pp. 823, 2001.

[17] Chen, C., Pan, Y., Huang, Z. & Wu, G., "Energy Consumption Analysis and Energy Conservation Evaluation of a Commercial Building in Shanghai", *ICEBO2006, Control Systems for Energy Efficiency and Comfort*, 2006.

[18] Chirarattananon, S. & Taweekun, J., "A technical review of energy conservation programs for commercial and government buildings in Thailand", *Energy Conversion and Management,* vol. 44, no. 5, pp. 743-762, 2003.

[19] OECD Working Party on National Environmental Policy, *Case Studies on Policy Instruments for Environmentally Sustainable Buildings*, OECD, France, 2002.

[20] Wiel, S. & McMahon, J.E. 2003, "Governments should implement energy-efficiency standards and labels—cautiously", *Energy Policy,* vol. 31, no. 13, pp. 1403-1415.

[21] Harmelink, M., Nilsson, L. & Harmsen, R. 2008, "Theory-based policy evaluation of 20 energy efficiency instruments", *Energy Efficiency*, vol. 1, no. 2, pp. 131-148.

[22] Barde, J.P. 1995, "Environmental policy and policy instruments", Principles of Environmental and Resource Economics: a Guide for Students and Decision-Makers, , pp. 201.

[23] Organisation for Economic Co-operation and Development 1999, *Voluntary approaches for environmental policy: an assessment*, OECD, Paris.

[24] Walker, G.R. 1997, "Internationalization of housing standards. Proc. 1997 International Building Construction Standards Conference/Workshop.", department of industry science and tourism, pp. 102-108.

[25] UNEP 2007, Assessment of policy instruments for reducing greenhouse gas emissions from buildings. Summary and Recommendations, September, Budapest.

[26] Levine, M.D., Koomey, J.G., Price, L., Geller, H. & Nadel, S. 1995, "Electricity end-use efficiency: Experience with technologies, markets, and policies throughout the world", *Energy*, vol. 20, no. 1, pp. 37-61.

[27] Schipper, L., Meyers, S. & Ketoff, A.N. 1986, "Energy use in the service sector: An international perspective", *Energy Policy*, vol. 14, no. 3, pp. 201-218.

[28] World Energy Council 2004, Energy Efficiency: A Worldwide Review Indicators, Policies, Evaluation A Report of the World Energy Council in Collaboration with ADEME, WEC.

[29] Hitchin, R. 2008, Can building codes deliver energy efficiency? Defining a best practice approach, RICS, London, UK.

[30] International Code Council 2006, *International energy conservation code, 2006*, International Code Council, Country Club Hills, IL.

[31] ASHRAE, S. 2007, ANSI/ASHRAE/IESNA Standard 90.1-2007 Energy Standards for Buildings except Low-Rise Residential Buildings (I-P Edition), American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE), Atlanta, GA

[32] Meacham, B., Bowen, R., Traw, J. & Moore, A. 2005, "Performance-based building regulation: current situation and future needs", *Building Research & Information*, vol. 33, no. 2, pp. 91-106.

[33] Hui, S.C.M. 2002, "Using performance-based approach in building energy standards and codes", *Proc.of the Chonqing-Hong Kong Joint Symposium 2002*, pp. 8-10.

[34] Brochner, J., Ang, G.K.I. & Fredriksson, G. 1999, "Sustainability and the performance concept: encouraging innovative environmental technology in construction", *Building Research & Information*, vol. 27, no. 6, pp. 367-372.

[35] Marshall, H.E. & Petersen, S.R. 1979, "Economics and the selection and development of energy standards for buildings", *Energy and Buildings*, vol. 2, no. 2, pp. 89-99.

[36] Deal, B.M. & Fournier, D.F. 2001, "Building Codes, Energy, and the Environment How Model Building Codes Affect Sustainability".

[37] Hui, S.C.M. 2003a, "Effective Use Of Building Energy Simulation For Enhancing Building Energy Codes", *Building Simulation 2003- Eighth International IBPSA Conference*, pp. 523.

[38] Hui, S.C.M. 1997, "Overall thermal transfer value (OTTV): how to improve its control in Hong Kong", pp. pp. A52-61.

[39] Chirarattananon, S., Rugkwamsuk, P., Hien, V.D., Taveekun, J. & Mettanant, V. 2004, "Development of a building energy code for new buildings in Thailand", *Proceedings of Joint International Conference on Sustainable Energy and Environment, Hua Hin, Thailand*, , pp. 1–3.

[40] Guy, S., Shove, E. & Guy, S. 2001, A Sociology of Energy, Buildings and the Environment: Constructing Knowledge, Designing Practice, Routledge.