The Concept of Zero Energy Intelligent Buildings (ZEIB): A Review of Sustainable Development for Future Cities

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Authors’ contributions
This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

ABSTRACT

It is noticed that intelligent buildings are aimed to consider social, environmental and economic values beside a substantial focus to the automated technological attributes. Due to many promising green building initiatives, the accelerated level of interests towards the applications of information technology and advanced control techniques in architecture design has been observed. With a viewpoint to the sustainable development of future cities, attributing the eventual impacts of climate change, various interrelated green building design approaches have been implemented. This study aims to elucidate the significant advancements of intelligent building design as a key constituent of eco-city development for creating greener and effective built environments. Current effort in this study is also geared toward considerable and practical implementations that were carried out in order to create buildings with zero energy consumption. Emphasis is placed upon reviewing the recent theories, attempts, implementations, and challenges towards the development of zero energy intelligent buildings (ZEIB). The findings inferred from the theoretical analysis confirm that the significant contribution of ZEIB concept will end up for the sustainable development of future eco-cities.
Keywords: Zero energy buildings (ZEB); intelligent buildings (IB); zero energy intelligent buildings (ZEIB); sustainable development; building energy performances; renewable energy; climate change.

1. INTRODUCTION

It has been internationally promoted to develop innovative approaches for mitigation of carbon dioxide (CO$_2$) emissions due to energy consumption associated with building construction and operation. The energy performance of green buildings has an immense effect on the sustainable development of the built environment. Versatile attempts are observed for creating low energy buildings based on the sustainable energy performances and more recently, the concept of zero energy buildings (ZEB) has become a reality with confirmed effectiveness [1,2,3,4,5,6,7]. On the other hand, intelligent buildings could also be considered as the key constituent for reduction of energy usage. It is therefore essential for experts in the field of architecture, civil, construction and environmental engineering to understand the essence of intelligent buildings and zero energy buildings for operative and successful applications.

This study provides new insights for development of Zero Energy Intelligent Buildings (ZEIB) based on theoretical inferences. It is denoted that the development of key indicators for ZEIB concept could become a part of national/international standards for building industry; however, it is identified that there are still challenges for the respective standardization. First and foremost, despite the predominant similarities in the definition of ZEB and IB, there must be a standard definitive context for both ZEB and IB. Likewise; the circumstance of the computation of energy balance and performance in such ZEIBs must be clarified in support of detailed intelligent operation. In Addition, the economic challenges associated with these advanced technological applications could be considered as another significant factor in creating ZEIBs particularly in those developing countries [8].

2. CHRONOLOGY OF SUSTAINABLE DEVELOPMENTS

Sustainable development has been widely recognized for over thirty years. There is no simple and widely acceptable definition that can define it clearly [9]. In this regard, throughout the initial stages during 1970’s, maintenance and conservation of natural resources has been broadly discussed as the key features of sustainable development [10]. Subsequently, in the 1980s, researchers further evolved the interpretations highlighting quality of life [11] and conservation of crucial environmental progressions [12].

Throughout the 1990s, sustainable development has been a key section of political dialogue centered around the well-being of future generations with respective implementations [13]. On the other hand, cultural divergence and variations are emphasized as a main principle for sustainable development definitions which remain controversial [9,14]. Nevertheless, some contemporary insight placed more emphasis on integrative balance among social, cultural and economical regimes as the core characterization of sustainability trends [15].

With the current consensus, sustainable development is considered as the methodology to satisfy contemporary requirements without compromising future generations to satisfy their needs [15]. These methodologies are specified within various fields such as architectural advancements in line with urbanization and landscaping as a whole. Discussing the context of socio-cultural, environmental and economic sustainability with a strong emphasis in
energy consumption, Kaygusuz [16] develops the linkage to show the significance among these interrelationships to assure the smooth connectivity (Fig. 1).

First of all, it is essential to highlight the increasing rate of the overall worldwide energy demand according to Table 1. The summary explicitly indicates that the increasing rate is progressively continued making the energy consumption worldwide in 2020 become approximately 14,756 million tonnes of oil equivalent [16]. This study therefore analyzes the essence of ZEIB in order to scrutinize their role for creating new urban environmental policies, as well as design and technological guidelines for enhancement of living comfort, mitigation of carbon emissions and reduction of the level of energy consumption via a holistic approach.

Fig. 1. Interrelations between socio-cultural, environmental and economic values with view to the energy [16]
Table 1. Global energy demands [16]

| Energy source         | 1980  | 2000  | 2008  | 2020  |
|-----------------------|-------|-------|-------|-------|
| Coal                  | 1792  | 2292  | 3285  | 4124  |
| Oil                   | 3107  | 3655  | 4320  | 4654  |
| Gas                   | 1234  | 2085  | 2586  | 3046  |
| Nuclear               | 186   | 676   | 723   | 920   |
| Hydropower            | 148   | 225   | 276   | 389   |
| Biomass and waste     | 749   | 1031  | 1194  | 1436  |
| Other renewables      | 12    | 55    | 82    | 196   |
| Total world           | 7228  | 10,018| 12,467| 14,765|

Mtoe, million tons of oil equivalent.

2.1 Sustainability in Urbanization and Landscaping

Urban outdoor spaces are largely regarded to have prominent ecological significance respecting their contribution towards diminution of versatile contaminative factors thus resulting in route for enhancement of microclimatic circumstances. Furthermore, proper development of landscaping and urbanization specifically in terms of preparing urban open spaces results in development of positive effects towards human wellbeing leading to the advancement of human thermal comfort in outdoor spaces [17]. In addition, alongside aesthetic, psychological and healthcare benefits, application of natural features in urbanization expansions may result in diverse social and communal benefits [18]. These key components towards sustainable developments are expected to be localized in order to maximize their effectiveness. According to Kothari et al. [19], sustainable development is highly intertwined with the deliberation of energy. Thus, on one hand, renewable energy sources including solar, winds, and waves, etc. play a significant role for sustainable developments; on the other hand, sustainable energy sources including the waste-to-energy sources are highly influential in the enhancement of sustainability [19].

2.2 Vernacular Sustainability

Design and construction-based techniques involving local resources are largely addressed as vernacular architectural features. Vernacular architecture is developed over an excessive period of time to reflect ecological, cultural and chronological milieu of the respective time period. Indeed, it is denoted that many vernacular built environments are derived from the essence of sustainable design [20,21,22]. In general, vernacular architecture is mostly practiced during development of residential design and construction [23].

Quantitative analysis has revealed that vernacular architecture is climate responsive. Accordingly, the solar passive characteristics used in traditional buildings can be utilized within the modern context. In addition, vernacular constructions could achieve thermally comfortable sensations through utilization of the respectively highlighted solar passive systems. Nevertheless, quantitative analysis has represented the effectiveness of vernacular architecture to achieve climatic sensitivity within various contexts with versatile characteristics [22].
Recent research has discovered the essential role of bioclimatism within vernacular building development that enables further achievement of sustainability while disregarding the utilization of temperature control tools [24]. Such consideration promotes the crucial role of building design for reduction of indoor thermal comfort achievement obstacles [25]. It is concluded that the main theories and doctrines utilized within the context of traditional and vernacular buildings to achieve sustainability can be adopted and used in contemporary modern design and construction implementations; hence properly adopting the mentioned principles result in development of future less energy consuming and sustainable buildings [24,26]. Recent studies by GhaffarianHoseini et al. [27,28] propose the efficient incorporation of the significant attributes embodied in vernacular and intelligent buildings for creating green culturally/environmentally responsive built environments. Overall, accomplishment of low energy consuming and even zero energy buildings results in mitigating the recent critical obstructions caused as a result of high carbon emissions.

2.3 Low Carbon Architecture

Sustainable architectural development is mainly bound to low carbon architecture responding to low carbon economical progressions. It positively affects the society, economy, ecological trends, and architecture [29]. Recently, environmental circumstances are becoming intensely severe. Consequently, researchers and politicians seek to prepare low carbon economy to promote low carbon life style. Accordingly, carbon intensity is expected to be reduced through minimization of carbon emissions due to newly proposed low carbon life style [29]. As one of the major results, green building systems have been promoted.

2.4 Green Building Systems

Contemporarily, the world is confronting with two main challenges of climate changes and energy conservations; hence, collective approaches can be considered as potential solutions [30]. Correspondingly, Malaysia has played a significant role towards reduction of carbon emission whereby the Prime Minister announced during the 15 Copenhagen Climate Change Summit, December 2009, the nation’s attempt headed for 40% reduction of carbon emission per capita from 2005 to 2020 [30].

The terminology of “green architecture” is defined as architectural practices with considerable attitude towards ecological systems highlighting the environmental sustainability [31]. In this regard, with focus on the limitations of this research, the study by GhaffarianHoseini [32] reviews the application of ecologically sustainable design for development of greener intelligent buildings. Ecologically sustainable design is deemed to be a substantial constituent of green building system design for development of low energy, ultra-low energy and zero energy buildings. Meanwhile, recent studies have broadly stated the negative impacts of fossil fuel power generations in terms of pollution while supporting the urge to prepare clean energy generation. Therefore, it is recommended to uphold employment of sustainable and green energy in order to triumph over the restricted characteristic of fossil fuels [33]. As a solution, the idea of on-site renewable energy generation is discussed for attaining energy from renewable supplies within the neighborhood of the respective populated area where the energy is necessitated [34]. Consequently, an innovatively organized particular system [i.e., a novel omni-direction-guide-vane (ODGV) that surrounds a vertical axis wind turbine (VAWT)] is developed to
actualize green design and renewable energy consumption as an integrated methodology to unify wind, solar and rainwater harvesting as represented in Fig. 2 [35].

![Fig. 2. General arrangement of the wind–solar hybrid energy system with rainwater collection feature [33]](image)

The system consists of incorporation towards various green technologies such as rainwater collector, solar array and urban wind turbines [34,35]. This system can be utilized as a means of sustainable renewable energy while highlighting carbon emission reduction and diminishing fossil fuel consumptions through installation on skyscrapers and future urban landscapes. It is highlighted that majority of water preservation and energy conservation approaches, particularly for residential and commercial units, require a higher preliminary investment compared to the conventional ones however, the additional advantages of the aforementioned green building approaches compensate the discussed high preliminary investment by the end of the unit's lifespan [36]. Consequently, Chang et al. [36] develops a stochastic linear programming model to represent how the synergistic design of water preservation and energy conservations caused by green roof systems influence the characteristics of a green home design under uncertainty conditions.

2.5 The Proposed Conceptual Framework for Sustainability

Based on the theoretical inferences of this study with view to the understanding of the essence of sustainability, a conceptual framework is proposed in order to consider the entire interrelated parameters associated with the essence of sustainability (Fig. 3). The development of this framework is obtained from the findings of literature review while considering that despite the broad essence of architecture as a multidisciplinary field with subjective and objective parameters, its main role is to successfully respond to the demands of human and environment. The developed conceptual framework for sustainability is represented according to the following diagram.
The study denotes that sustainability is principally comprised of three main constituents as environmental, social and economic values. Reviewing various sustainable indices, the main aspects of the environmental, social and economic concerns are identified. From the environmental perspective, sustainability is highly bound up with interrelated issues regarding energy conservation, resource protections and ecosystems. With view to the social value of sustainability, the role of comfort, health, cultural and social demands are vitally expressed. With regards to the economic concerns, the cost efficiency and long-term outputs are significantly highlighted. This study argues that it is necessary to consider efficient incorporation of all the aforesaid parameters for sustainable development of eco-cities. With focus on buildings, as a setting with immense effect on life of users, and the local environment; the circumstances towards the development of zero energy, culturally responsive and low cost buildings could be considered as a fundamental objective based on the developed conceptual framework. Meanwhile, according to the evolutionary progress of building design and development, scholarly researches from the past and present situation of built environment could provide promising solutions as innovative approaches towards achieving high level of sustainability in built environments. In this regard, analyzing the essence of vernacular built environments as a cultural/environmental/economic phenomenon from past could delineate innovative solutions based on the traditional attributes while the analysis of intelligent buildings from present situation of built environments could represent current inventions and barriers towards the sustainable development of eco-cities. The proposed conceptual framework also represents the necessity of achieving a congruity between the consideration of the environmental, social and economic attributes of sustainability in the design process and construction process of buildings from the stage of initialization, idea generation and conceptualization until the finalization of the projects. According to this framework, this consistency in design and construction with a viewpoint to the identified solutions, challenges and barriers derived from the analysis of sustainable developments in past and present could be considered as a
promising theoretical proposal for creating greener and smarter cities for the future communities.

3. INTELLIGENT BUILDING DESIGN

“Over the past 20 years, many different buildings have been labeled as ‘intelligent’. However, the application of intelligence in buildings has yet to deliver its true potential [37].”

According to studies on the significance of intelligent buildings, there are many interpretations of intelligent design in relation to the smart houses [38]. The main interpretations mostly consider the crucial role of technology within intelligent building design, without sufficient consideration of social, cultural and user interactions [38]. Other similar studies define intelligent buildings as automated buildings with flexibility, cost-efficiency and integrated technical performances [27,28,39]. However, a few studies criticize previous interpretations while arguing that intelligent buildings must be fully responsive to the user’s actual needs [40].

Other similar studies suggest an inherent relation between the building and well-being of users [41,42]. It is believed that the functional spaces of buildings have a fundamental impact on the well-being of users and the satisfaction of users is highly in accordance with the building environment [43]. The study by Wong et al. [43] expresses that:

“Intelligent building accentuates a multidisciplinary effort to integrate and optimize the building structures, systems, services and management in order to create a productive, cost effective and environmentally approved environment for the building occupants.”

Despite the previous interpretations of intelligent building design, recent studies proclaim that an intelligent building must create a successful combination of intelligent design, environment and the occupants [44]. Thus, they believe that an intelligent building must be able to adjust itself to the environment and the occupants. Interpretations of intelligent buildings vary from region to region. For instance, it has been declared that the significance of intelligent building lies mostly in technology in the United States, while in the United Kingdom, definitions are more focused on users’ actual needs [43].

Looking retrospectively, it can be inferred that an appropriate interpretation of intelligent building design is required in order to consider all the issues that are influential in the enhancement of contemporary houses. Other studies therefore propose a systematic double-level strategy to achieve an appropriate definition of intelligent building based on defined quality modules (M1–M10) that encompass all the issues [45]. The first level expresses the main constituents of quality modules M1–M10 (Table 2), and the second level represents three main areas for the modules: technology, functional spaces and functional requirements [43,45].

According to Table 2, the quality modules are categorized in a way to ensure economic, environmental and socio-cultural concerns. As a result, it can be observed that ‘Environmental Friendliness and Energy Conservation’ (M1) and ‘Culture’ (M7), as two of the fundamental quality modules, are selected as a basis for all intelligent building designs. This fact strongly supports the discussion of this research while overstressing the environmental and socio-cultural values. The new interpretation highlights two main issues, ‘technology’ and ‘user’s actual needs’ [46]. The studies therefore suggest that consideration of this new
definition based on its corresponding modules will enable designers to create environmentally and socio-culturally responsive intelligent building design [46].

**Table 2. Quality Modules for Intelligent Buildings [43]**

- M1: ENVIRONMENTAL FRIENDLINESS; HEALTH AND ENERGY CONSERVATION;
- M2: SPACE UTILIZATION AND FLEXIBILITY;
- M3: COST EFFECTIVENESS; OPERATION AND MAINTENANCE WITH EMPHASIS ON EFFECTIVENESS;
- M4: HUMAN COMFORT;
- M5: WORKING EFFICIENCY;
- M6: SAFETY AND SECURITY MEASURES; FIRE, EARTHQUAKE, DISASTER AND STRUCTURAL DAMAGES, ETC.
- M7: CULTURE;
- M8: IMAGE OF HIGH TECHNOLOGY;
- M9: CONSTRUCTION PROCESS AND STRUCTURE; AND
- M10: HEALTH AND SANITATION.

Similar to the discussed quality modules for intelligent buildings, Clements-Croome [47] presents five interrelated modules as the basis of intelligent building design development:

*Module 1: Concept, strategy and management;*
*Module 2: Building systems, architecture and people;*
*Module 3: Information technology and communication systems;*
*Module 4: Designing intelligence into buildings;*
*Module 5: Financial analysis and investment appraisal.*

Analyzing these modules, it is clear that the developed framework by Clements-Croome [47] is inherently relevant and interrelated to the identified quality modules by Wong et al. [43]. The first module concentrates on a conceptual basis as a multi-attribute approach, with emphasis on environmental systems, management approaches and a linkage to people. The second module, as the target of this study, elucidates the role of congruity between people and architecture (intelligent buildings), and the third and fourth modules cover the impacts of technology applications and focus on the intelligent technological values. The fifth module, as the final issue, highlights the role of economic concerns during intelligent building design developments. It is eventually deduced that the developed framework by Clements-Croome [47] is comprehensively covering the entire interrelated parameters for ensuring successful intelligent building design developments. Likewise, particularly focusing on the second identified Module known as ‘building systems, architecture and people’, the main objective of this research as creating congruency between the house design and people demands their socio-cultural and environmental values being reflected.

Likewise, a recent study by Alwaer and Clements-Croome [44] was carried out to determine the key constituents of sustainable intelligent building design. A systematic analysis based on the responses of architects, building designers, engineers and sustainability evaluators suggests four key performance indicators grouped as: environmental, economic, socio-cultural and technological indicators [44]. This result supports the theory of this study by representing ‘culture’, ‘cultural heritage integration’ and ‘compatibility with local heritage values’ within the socio-cultural indicator group while emphasizing on the issues of environment and energy in the environmental indicator group as shown in Table 3. However, this study argues that irrespective of the aforementioned concerns, there is still no deep consideration on the socio-cultural values of users and environmental values of local region within the intelligent building design developments and particularly smart house design [44].
Table 3. Key constituents of sustainable intelligent building design [44]

Moving towards the concept of zero energy intelligent buildings, with a point of view to the manifestation of advanced Information technology (IT) technologies, building energy management (BEM) should be consistently incorporated in the design of buildings. BEMs are utilized to decrease the level of energy usage while ensuring acceptable indoor comfort [48]. In particular, Doukas et al. [48] introduces an intelligent decision support model with represented approach in Fig. 4 for the energy efficiency of intelligent buildings.

4. ZERO ENERGY BUILDINGS (ZEB)

Various scholarly studies have been conducted regarding the enhancement of the energy performance of buildings for the sake of future green implementations. It is observed that this growing interest has led to the creation of low energy buildings and more recently, the zero energy buildings as a future goal for building industry. With reference to versatile studies with focus on the concept of low energy and zero energy buildings [1,2,3,4,5,7,49] the study indicates that a zero energy building is substantially intertwined with energy efficient designs and advanced integrated technologies in order to cut the energy demand and consumption in view of heating, cooling, electricity, etc; through the application of on-site renewable energy sources.

Indeed, zero energy buildings are defined to have zero energy consumption or even negative energy consumption within a year [50,51]. This fact elucidates the significance of renewable energy supply for zero energy buildings, which could directly be integrated to the building or could be a part of neighborhood community renewable energy system. The study done by Omer [52] defines the demand and supply perspectives for the energy managements in sustainable developments according to the Fig. 5 in which pumping and heating consume fair amount of energy in building. With focus on the energy efficiency of buildings and the indoor comfort, overstressing the substantial impacts of the aforesaid parameters for sustainable development of future buildings, particular approaches are proposed by Kolokotsa et al. [51] which are as follows (Table 4).
Fig. 4. Represented approach of the intelligent decision support model [48]
In reality, buildings consume approximately 30 to 40 percent of overall energy consumption in developed countries [53]. This fact overstresses the substantial necessity to move forward for the development of zero energy buildings as standardized basis for national and international building policies. Zero energy consumption and zero carbon emission is an ideal target for the development of future green buildings. Back to the history of zero energy buildings, it is reflected that the primary attempts towards this concept were actually more concerned of zero heating and accordingly, one of the best samples of that era could be the solar house in 1939 [54]. In the 1970s, the zero energy buildings were mostly concerned of zero heating and the integration of advanced insulation envelopes. Salient examples include the Vagn Korsgaard Zero Energy Home in Denmark and the Saskatchewan Conservation House that clearly confirm the aforementioned foci [55,56]. These attempts have been highly influential for current research that focuses on zero energy buildings and in fact, the current progress is derived from the development of these attempts. Likewise, it is reflected that it is essential to simultaneously consider the application of passive and active techniques while being concerned about the indoor comfort [57].

With the aid of intelligent buildings, according to the main key constituents as discussed previously, it is reflected that real zero energy buildings must be derived from the
incorporation of intelligent environments, automated interacted features, and innovative technologies. The research by Kolokotsa et al. [51] highlights the main constituents of zero energy buildings. Towards this direction, in view of the development of net zero energy buildings (NZEB), six key constituents are identified to be fully intertwined with the conceptual design of buildings. Despite the importance of incorporating the conceptual design stage of buildings with the respective main factors including metric, level of comfort, passive techniques, energy efficiency, renewable energy sources and creative advanced integrated approaches as shown in Table 5, it is implied that the consideration of the aforementioned factors could be very multifaceted and intricate to achieve. With view to these challenges, it is also necessary to analyze the environmental performance of buildings prior to the construction process; hence, the application of building performance simulation (BPS) is highly recommended [57]. Building performance simulation (BPS) is the current approach towards analyzing and moving towards the development of zero energy buildings.

The case of ÉcoTerra house case model is presented and analyzed in view of the development of zero energy houses for future energy schemes according to Noguchi et al. [58] while highlighting the application of advanced renewable energy systems as shown in Fig. 6. Furthermore, according to Fong and lee [59], with view to the application of net zero energy design in low-rise housing in Hong Kong, the circumstances of linking the renewable energy supplies for addressing the needs for lighting and air conditioning as well as all electric equipments and water heating are represented (Fig. 7).

Table 5. Main key design parameters for net zero energy buildings [57]

| Parameter | Description |
|-----------|-------------|
| 1. Metric | There are several definitions for NZEBs that are based on energy, environmental or economic balance. Therefore, a NZEB simulation tool must allow the variation of the balance metric. Consequently, designing NZEBs depends on the thermal comfort level. Different comfort models, e.g. static model and the adaptive model, can influence the ‘net zero’ objective. |
| 2. Comfort level and climate | Passive strategies are very fundamental in the design of NZEB including daylighting, natural ventilation, thermal mass and shading. |
| 3. Passive strategies | By definition, a NZEB must be a very efficient building. This implies complying with energy efficiency codes and standards and considering the building envelope performance, low infiltration rates, and reduce artificial lighting and plug loads. |
| 4. Energy efficiency | RES are an integral part of NZEB that needs to be addressed early on in relation to building from addressing the panels’ area, mounting position, row spacing and inclination. |
| 5. Renewable energy systems (RES) | The aggressive nature of 'net zero' objective requires always implementing innovative and new solutions and technologies. |

In regards to the building performance simulation tools, it is negatively criticized that there are significant barriers during the utilization of the majority of these tools. With reference to Attia et al. [57], according to United States Department of Energy (US DOE) database as of 2011, there are 392 tools to evaluate the building performances based on simulation strategies. These tools are criticized to be mainly concerned about the geometry and envelope of buildings. Thus, despite the development of BPS tools in the last ten years as shown in Fig. 8, limited software are designed specifically for the architects as the main target group. According to Donn [60], the study concentrates on the preferences of architects as the target group of BPS tools and indeed, important factors are prioritized to be implemented during the design of future simulation tools. According to Fig. 9, surprisingly, instead of accuracy, the architects mainly prefer the intelligence of simulation tools as their prioritized key concern followed by usability, interoperability and accuracy.
Fig. 6. Application of advanced renewable energy systems [58, 76]

Fig. 7. Net zero energy design and renewable energy supplies [59]
According to Brahme et al. [61], it is explicitly reflected that the currently available technologies encompass adequate potentials for the development of zero energy buildings. Yet, the majority of energy consumption within a building could be reduced by the application of energy efficient designs and technologies while the remaining part (approximately 30% as stated by Brahme et al. [61]) is addressed through the utilization of on-site and off-site renewable energy supplies. The study done by Marszal et al. [62] further rises up a question regarding the comparison of on-site and off-site renewable energy supplies for the development of zero energy buildings. To ensure the zero energy concept, the mostly utilized on-site renewable systems as the most common types are the photovoltaic (PV) and solar thermal panels [8,63]. In order to create net zero energy buildings in Denmark, instructions are only focused on on-site renewable energy systems. Nevertheless, with view to the possible limitations and constraints of buildings, particularly in high density urban...
areas, being concerned about the limited area of roofs and facades, the application of off-site renewable energy systems could also be logically proposed as elaborated by Marszal et al. [62]. The study by Elkinton et al. [64] proposes the application of wind power and solar thermal systems as the renewable energy supplies for the development of zero energy housing in US. The findings indicate the effectiveness of such systems once there is a health market for renewable energy systems. It has been continuously attempted to develop innovative approaches to reduce the greenhouse gas emissions. In this regard, the study by Kaygusuz [16] clarifies the circumstances of decreasing greenhouse gas emissions based upon the technological perspectives as represented in Fig. 10.

![Fig. 10. Decreasing greenhouse gas emissions based upon the technological perspectives [16]](image)

Moving towards the proliferation of zero energy buildings is principally contributive to the reduction of CO₂ emissions with a significant impact on the environment. Despite versatile proposed approaches for reducing the CO₂ emissions, with strong concern regarding the cost efficiency of selected approaches, the study done by Li [29] introduces the most effective solutions as shown in Table 6.

| Mitigation measures                          | CO₂ mitigation with net economic benefits | Cost (US$/t CO₂) |
|---------------------------------------------|-----------------------------------------|-----------------|
| Thermal insulation                          | Yes                                     | Zero even negative  |
| Fuel switch from coal to gas in boiler in district heating | No                                      | 35*             |
| Coal to gas                                 | No                                      | 550-600         |
| Nuclear                                     | Yes                                     | Zero or negative |
| Fossil fuel generation efficiency           | No                                      | 50-100          |
| CCS                                         | Yes                                     | Zero or negative |
| Hydropower                                  | No                                      | 25-50           |
| Biomass                                     |                                        |                 |
| Other renewables                            |                                        |                 |

Table 6. The effective solutions reducing the CO₂ emissions [29,65,66,67]

This study denotes that energy efficiency, energy conservation and energy generation such
as solar powers could lead to the development of low energy, ultra low energy and nearly zero energy and zero energy buildings. To develop such buildings, it is vital to be aware of the comparison rate between the consumption and generation of energy. Focusing on a single case model in Germany, the study by Heinze and Voss [6] represents the interrelations between the energy consumption (including electricity and heat consumption) and the electricity generations (Fig. 11). Referring to the represented monthly balance graph, it is obvious that the respective interrelations between consumption and generation rates vary accordingly.

**Fig. 11. Interrelations between heat consumption, electricity consumption and electricity generation [6]**

Highlighting on the high rate of energy consumption in hot and humid climates, specifically for cooling purposes, the proliferation of low energy buildings and ultimately, zero energy buildings is an important agenda. Recently, ZEBO is introduced by Attia et al. [57] as a simulation tool for the analysis of building energy performances with more attention to the preferences of architects. It is inferred that there are still limitations and barriers for the user of such tool and the respective interfaces; however, it is considered as a great point of departure for further enhancement of simulation tools. According to Fig. 12, the study indicates the circumstances of analyzing building parameters while considering the energy consumption levels. It is clearly seen that versatile forms applied to the buildings, orientations, types of walls, roofs and many other factors could be customized according to the preferences of architects as the interface strengths.

The study by Zhu et al. [7] expresses the significant importance of using thermal mass as insulated concrete walls structures in order to be utilized for zero energy houses. This application is highly effective for decreasing the energy consumption rate derived from the heating and cooling. The respective details for the application of a thermal mass wall compared to a conventional type are represented according to Figs. 13 and 14.
Fig. 12. ZEBO: Circumstances of analyzing building parameters with view to the energy consumption levels [57]

Fig. 13. Thermal mass and base-line walls [7]
According to Apte et al. [68], the use of energy efficient windows could significantly contribute to the development of zero energy buildings, thus based upon the proposed construction proposals derived from Mitchell [69] for the development of high energy windows, the following categorization is represented (Table 7).

**Table 7. The Construction proposal [68,69]**

| Scheme                        | Characteristics                                                                 |
|-------------------------------|---------------------------------------------------------------------------------|
| Typical                       | Insulation and building systems:                                                |
|                               | • 1993 Model Energy Code levels of insulation (described in text)               |
|                               | • Gas Furnace AFUE = 0.78; AC SEER = 10.0                                       |
|                               | **Shading**                                                                     |
|                               | • Interior shades (seasonal SHGC multiplier, summer value = 0.80, winter value = 0.90) |
|                               | • 1 ft (0.3 m) overhang                                                        |
|                               | • A 67% transmitting same height obstruction 20 ft (6 m) away, intended to represent adjacent buildings |
|                               | • To account for other sources of solar heat gain reduction (insect screens, trees, dirt, building and window self-shading), SHGC multiplier further reduced by 0.1, resulting in a final winter SHGC multiplier of 0.8 and a final summer SHGC multiplier of 0.7 |
| Typical + Overhangs           | Same as above, but with 2-ft (0.6 m) overhangs instead of 1-ft (0.3 m) overhangs |
| Typical + Overhangs + Trees   | Insulation and building systems:                                                |
|                               | • Same as “Typical”                                                            |
|                               | **Shading**                                                                     |
|                               | • Interior shades (seasonal SHGC multiplier, summer value = 0.80, winter value = 0.90) |
|                               | • 2 ft (0.6 m) overhang                                                        |
|                               | • A 10 ft (3 m) diameter obstruction 4 ft (1.2 m) above ground level, located 8 ft (2.4 m) away from the house; zero-percent solar transmittance, March 15-Oct 15; 60% solar transmittance, Oct 15-March 15 |
|                               | • To account for other sources of solar heat gain reduction (insect screens, trees, dirt, building and window self-shading), SHGC multiplier further reduced by 0.1, resulting in a final winter SHGC multiplier of 0.8 and a final summer SHGC multiplier of 0.7 |
| Double Insulation             | Insulation and Building Systems                                                |
|                               | • Insulation levels approximately double those of 1993 Model Energy Code standards, locally specific |
|                               | **Shading**                                                                     |
|                               | • Same as “Typical”                                                            |
| Double Insulation with Efficient HVAC | Insulation and Shading:                                                        |
|                               | • Same as “Double Insulation”                                                   |
|                               | **Building Systems**                                                            |
|                               | • Simulated ultra efficient systems furnace AFUE = 0.95; AC SEER = 16.0         |

* The annual energy consumption for AFUE = 0.95 for a furnace was calculated from the energy consumption for the simulated AFUE = 0.78 by multiplying this value by the ratio of the two furnace efficiencies (0.82).

† Estimates of energy savings from high-efficiency air-conditioning systems were conservative. SEER measurements are misleading in that air conditioners with a higher rated SEER do not necessarily increase efficiency proportionally to the increase in SEER; thus, efficiency improvements for a 16 SEER unit over a 10 SEER unit would be less than 60% (Kavanaugh 2002). The annual energy consumption of a 16 SEER AC unit was calculated by reducing the annual energy consumption of the simulated 10 SEER AC unit by 20%. Peak energy demand for the 16 SEER unit was calculated by multiplying the demand of the simulated 10 SEER unit by 0.943 based on a 6% increase in peak EER found by Kavanaugh (2002).
According to the given windows types as shown in Table 8 and explained by Apte et al. [68], with views in regard to the utilization of low-energy windows, the total saving in energy usage of houses are compared and represented based on versatile selected city regions (Fig. 15). From another perspective, it is theorized to utilize wireless communication technologies as an inherent integrated part of zero energy buildings. The application of wireless systems could have considerable impacts on overall quality of ZEB. These benefits are comprehensively shown by the study of Kolokotsa et al. [51] while the main outcomes are represented in Table 9.

Table 8. Categorization of windows [68]

| Window            | U-Factor (W/m²·K) | SHGC |
|-------------------|-------------------|------|
| 1 Double Clear (static) | 0.49 / (2.75)     | 0.56 |
| 2 Low-e, high solar (static) | 0.36 / (2.05)     | 0.53 |
| 3 Low-e, low solar (static) | 0.34 / (1.95)     | 0.30 |
| 4 Super, high solar (static) | 0.18 / (0.02)     | 0.40 |
| 5 Super, low solar (static) | 0.18 / (0.02)     | 0.20 |
| 6 Dynamic         | 0.18 / (0.02)     | 0.26 or 0.40 |
| 7 Ultra, high solar (static) | 0.10 / (0.07)     | 0.35 |
| 8 Ultra, low solar (static) | 0.10 / (0.07)     | 0.10 |
| 9 Dynamic + Ultra | 0.10 / (0.07)     | 0.10 or 0.35 |

Glazing systems 2-5 have 90 percent argon gas fill. For all windows, U-factor and SHGC are whole-window values for a 60 x 150 cm generic wood-vinyl frame.

Fig. 15. Total saving in energy usage of houses based on versatile selected city regions [68]
Table 9. Utilization of wireless communication systems in ZEBs, Adopted from Kolokotsa [51]

| Benefits of the Utilization of Wireless Communication Technologies in Zero Energy Buildings |
|---|
| Simplicity of Installation |
| Decreasing the Labor Costs |
| Mobility and Portability |
| Minimum Interface with Users |

In the study conducted by Kolokotsa et al. [51], the consumption and generation of energy in two building case models is calculated and represented. The generation curve is mainly derived from the renewable energy systems with the effect of climate while the consumption curve is the energy usage of building according to the climate and user activities (Fig. 16). This approach represents the interrelations between the generated and consumed energy for further clarification regarding the energy performance of green buildings.

![Fig. 16. Consumption and generation of energy [51]](image_url)

Versatile characteristics of zero energy buildings, design approaches, renewable energy supplies and the recent scholarly studies as well as current attempts towards the development of NZEB/ZEB are represented. The findings conclude that the development of zero energy buildings is feasible, effective and operative while it is essentially recommended to consider the reviewed attempts and features for the future studies with a strong viewpoint to the circumstances of the mitigation of potential challenges.
5. FINAL REMARKS: THE CONCEPT OF ZERO ENERGY INTELLIGENT BUILDINGS (ZEIB)

Currently, the idea of Zero Energy Buildings (ZEB) has been transformed to a sensible and practical resolution to alleviate the CO$_2$ emissions and diminish the building sector energy consumption with arising attention provided to this subject recently [8,70]. Significant focus has been shifted towards development of ZEBs [71] however; the main challenges of ambiguous definition and energy equilibrium computation still affect this progress [8,70]. Researchers believe that the definition of ZEB can be authorized by the scheme objectives; the patron's target; CO$_2$ emissions and the energy charge rates [72]. In addition; it is supported to assess the energy balance quantitatively as well as qualitative evaluations in order to clearly ascertain its respective effect on the environment. Kilkis [73] expresses ZEB as ‘a building, which has a total annual sum of zero exergy transfer across the building-district boundary in a district energy system, during all electric and any other transfer that is taking place in a certain period of time’ [73]. Nevertheless, similar researches highlight the exclusive consideration of energy and emission while evaluating the zero energy calculations [74,75].

ZEBs are significantly considerable in promotion of sustainable development due to their essence of energy use reduction and escalating the overall share of renewable energies. In general, the most considerable concerns regarding ZEBs are regarded as; the metric; the period and energy typologies within the energy balance; renewable energy application; energy efficiency; association with the energy infrastructure and the indoor climatic circumstances [8,70]. The following Table 10 represents various available approaches regarding ZEB's energy balance computation.

We propose the incorporation of the main constituents of intelligent buildings and the on-site and off-site renewable energy supplies for creating zero energy intelligent buildings (ZEIB) as a creative approach towards the sustainable development of future cities. The urbanization growth has its own strengths and weakness for the energy conservation, consumption and demands as analyzed by Omer [52] according to Table 11; hence, sustainable development of future urban areas based on the concept of ZEIB could lead to the proliferation of greener and smarter cities.

Recently, building standards are being progressed towards promotion of ZEBs. Hernandez and Kenny [54] developed a definition where ZEBs are defined as buildings where the primary energy consumption plus the respective material’s embedded energy throughout the building lifecycle is either equal or less than overall summation of the produced energy through the renewable energy systems of the corresponding building. The respective calculations of Annualized embodied energy (AEE) articulated in primary energy units per year of service life and annual energy use (AEU) articulated in primary energy units per year can clearly signify the effectiveness of building materials and components plus the required energy to run the building as represented at the following equation;

\[
\text{ALCE} = \text{AEU} + \text{AEE} \quad [54]
\]
Table 10. The study of various approaches for computing net ZEB balance [8]

| Method | (1) Metric of the balance | (2) Period of balance | (3) Type of energy use | (4) Type of balance | (5) Renewable supply options | (6) Fossil & CO₂ factors | (7) Unique features |
|--------|---------------------------|-----------------------|------------------------|---------------------|----------------------------|-------------------------|----------------------|
| Meth. 1 | ✓                         | ✓                     | ✓                      | ✓                   | ✓                          | ✓                       |_EN 15603:2008_ Energy use embraces also the effort for on-site energy generation |
| Meth. 2 | ✓                         | ✓                     | ✓                      | ✓                   | ✓                          | ✓                       |_EN 15603:2008_ Energy use embraces also the effort for on-site energy generation |
| Meth. 3 | ✓                         | ✓                     | ✓                      | ✓                   | ✓                          | ✓                       |_EN 15603:2008_ Local Energy use includes also energy for servers located on the building site not within the footprint and the energy use for treating domestic hot water for on-site energy generation. Net ZEB is only achievable in very special cases. No monthly surplus generation can be credited. |
| Meth. 4 | ✓                         | ✓                     | ✓                      | ✓                   | ✓                          | ✓                       |Local Indirect evaluation of the indoor climate - peak electricity for cooling of indoor temp. above 26°C |
| Meth. 5 | ✓                         | ✓                     | ✓                      | ✓                   | ✓                          | ✓                       |EN 15603:2008 Local Application of rating based on the reference building |
| Meth. 6 | ✓                         | ✓                     | ✓                      | ✓                   | ✓                          | ✓                       |Not valid Fully neglected the renewable supply potential. |
| Meth. 7 | ✓                         | ✓                     | ✓                      | ✓                   | ✓                          | ✓                       |EN 15603:2008 Local Special calculation method of embodied energy |
| Meth. 8 | ✓                         | ✓                     | ✓                      | ✓                   | ✓                          | ✓                       |Local Life cycle approach (simplified method) with main focus on embodied energy |
| Meth. 9 | ✓                         | ✓                     | ✓                      | ✓                   | ✓                          | ✓                       |Not valid |
| Meth. 10| ✓                         | ✓                     | ✓                      | ✓                   | ✓                          | ✓                       |Local |
| Meth. 11| ✓                         | ✓                     | ✓                      | ✓                   | ✓                          | ✓                       |Local |
| Meth. 12| ✓                         | ✓                     | ✓                      | ✓                   | ✓                          | ✓                       |EN 15603:2008 and Local |

* Embodied energy.
Eventually, calculation of ZEBs effectiveness was stated to be widely discussed in various researches highlighting versatile aspects while promoting the major sharing focus points on considering the issues regarding energy balance and gas emissions. Consequently, supporting the net-zero buildings and ZEBs is believed to play a significant role toward provision on insights for future sustainable developments and encouragement of renewable energy utilization. Conversely, utilization of ZEBs are widely discussed and considered to be currently limited to be most effective within the context of residential developments.

6. CONCLUSIONS

The growing interest in innovating new solutions for sustainable development of future cities is promising. In this regard, these studies reviewed the recent attempts, scholarly researches and implementations towards design, evaluation and creation of low energy, ultra-low energy and ultimately zero energy buildings. At the same time, the study analyzed the significance of intelligent buildings and its current potentials for being incorporated with zero energy perspectives. Zero energy buildings are defined to have zero energy consumption or even negative energy consumption within a year. Recent studies conclude that there are six main constituents for development of ZEBs including metric, level of comfort, passive techniques, energy efficiency, renewable energy sources and creative advanced integrated approaches. Intelligent buildings are designed as automated buildings with flexibility, cost-efficiency, energy efficiency and integrated technical performances while being responsive to the environment and user's actual needs. Referring to the concept of zero energy intelligent

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Table 11. Positive and negative impacts of urbanization versus energy [52]

| Positive effects | Negative effects |
|------------------|------------------|
| **Transport**    | **Transport**    |
| Promote public transport and reduce the need for, and length of, trips by private cars | Congestion in urban areas reduces fuel efficiency of vehicles |
| **Infrastructure** | **Vertical transportation** |
| Reduce street length needed to accommodate a given number of inhabitants | High-rise buildings involve lifts, thus, increasing the need for electricity for the vertical transportation |
| Shorten the length of infrastructure facilities such as water supply and sewage lines, reducing the energy needed for pumping | |
| **Thermal performance** | **Urban heat island** |
| Multi-story, multunit buildings could reduce the overall area of the building's envelope and heat loss from the buildings | Heat released and trapped in the urban areas may increase the need for air conditioning |
| Shading among buildings could reduce solar exposure of buildings during the summer period | The potential for natural lighting is generally reduced in high-density areas, increasing the need for electric lighting and the load on air conditioning to remove the heat resulting from the electric lighting |
| **Energy systems** | **Use of solar energy** |
| District cooling and heating system, which is usually more energy efficiency, is more feasible as density is higher | Roof and exposed areas for collection of solar energy are limited |
| **Ventilation** | **Ventilation** |
| A desirable flow pattern around buildings may be obtained by proper arrangement of high-rise building blocks | A concentration of high rise and large buildings may impede the urban ventilation conditions |
buildings, with an attention to the manifestation of advanced IT technologies, building energy management (BEM) is proposed to be consistently incorporated in the design of buildings. The findings also conclude that NZEBs, ZEBs and the so-called ZEIBs are essentially required to be proliferated in urban areas as a future agenda both in developed and developing countries. Meanwhile, the potential strengths and constraints towards this objective are discussed and elaborated for further research and investigations. This theory could be fundamentally influential for mitigation of CO$_2$ emissions, reduction of energy consumption and the enhancement of indoor comfort and living standards. Nevertheless, future studies are necessary to be conducted with view to the innovation of new technological perspectives and rectification of economic barriers towards zero energy implementations besides the standardization of ZEB, NZEB, and ZEIB concepts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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