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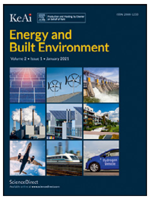

A review on zero energy buildings – Pros and cons

Tabbi Wilberforce[a,*], A.G. Olabi[a,b,**], Enas Taha Sayed[c,d], Khaled Elsaid[e], Hussein M. Maghrabie[f], Mohammad Ali Abdelkareem[b,c,d]

[a] *Mechanical Engineering and Design, Aston University, School of Engineering and Applied Science, Aston Triangle, Birmingham B4 7ET, UK*
[b] *Department of Sustainable and Renewable Energy Engineering, University of Sharjah, P.O. Box 27272, Sharjah, United Arab Emirates*
[c] *Center for Advanced Materials Research, University of Sharjah, PO Box 27272, Sharjah, United Arab Emirates*
[d] *Chemical Engineering Department, Minia University, Elminia, Egypt*
[e] *Chemical Engineering Department, Texas A&M University, TX 77843-3122, College Station, TX, USA*
[f] *Department of Mechanical Engineering, Faculty of Engineering, South Valley University, Qena 83521, Egypt*

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ABSTRACT

Enhancing the energy efficiency of structures has been a staple of energy policies. The key goal is to slash electricity usage in order to minimize the footprint of houses. This goal is sought by putting restrictions on the design specifications with respect to the properties of the raw materials and components as well as the exploitation of sustainable sources of energy. These facts for the basis for zero-energy building (ZEB) being established. This novel technology has faced several obstacles impeding its commercialization and future advancement. This investigation therefore holistically explored and evaluated the state of zero energy building and factors impeding their commercialization. The review further proposed some suggestion in terms of technology that can be considered by the sector to augment existing technologies. Similarly, the investigation touched on the effect of occupant's character in zero energy structures. Policies in terms of government subsidies and tax rebates were recommended to encourage more investors into the sector. Finally, the perception of zero energy building being more expensive compared to the traditional structures can equally be curbed via efficient and effective public sensitization.

1. Introduction

Due to technological advancement coupled with population growth, the demand for energy keeps increasing yearly. This is mainly because energy is the driving force for most global economy. One remarkable event that happened in 2018 based on report presented by the International Energy Agency (IEA) was appreciable increase in the power consumption nearly 2 times that of 2010. The high demand of energy in 2018 had a direct relation to the carbon dioxide emissions which saw a significant from 1.7 to 33.1 Gt [1]. Majority of people across the globe usually spend most of their time indoors hence it is important we consider how buildings can save energy [2–4]. The built environment globally accounts for 1/3 of primary energy as well as 40% of energy resources globally [5–7]. Today, talks about climate change usually highlights the fact that past human activities are a leading factor in the sudden depletion of the ozone layer [8–11]. Due to these critical concerns, different strategies have been considered to minimize the environmental impacts of the fossil fuel through increasing the efficiency of the conventional energy conversion methods [12–16], developing efficient energy conversion devices with low environmental impacts [17–20], and usage of the renewable energy sources that are sustainable and has no or low environmental impacts [21–24]. There has been several discussions regarding how energy is being utilized in buildings [25–27]. A clear investigation into the impact of occupant's attitude in buildings until recently was not the primary focus for investigations into the built environment. Despite the valid argument that the daily route of occupants in a building has a direct relation to the heating, cooling, ventilation as well as the lightning couple with thermal characteristics of the building, a thorough research that seeks to investigate the correlation between human activities and buildings has not been critically evaluated in the last decade. In Europe, several attempts are being made to evaluate and analyze energy used in structures. For in instance, several programes have been rolled out towards nearly zero energy building mainly to mitigate climate change as well as environmental pollution. Furthermore, it has become very important and critical that new buildings are constructed considering the energy needed in the running of such buildings and this is now being buttressed with the need to harness energy from renewable sources. Similarly, the integration of smarts to nearly zero energy houses will significantly limit the energy requirement of the houses [28]. Fig. 1 presents the energy consumption by various sectors.

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[*] Corresponding author.
[**] Corresponding author at: Department of Sustainable and Renewable Energy Engineering, University of Sharjah, P.O. Box 27272, Sharjah, United Arab Emirates.
E-mail addresses: t.awotwe@aston.ac.uk (T. Wilberforce), aolabi@sharjah.ac.ae (A.G. Olabi).

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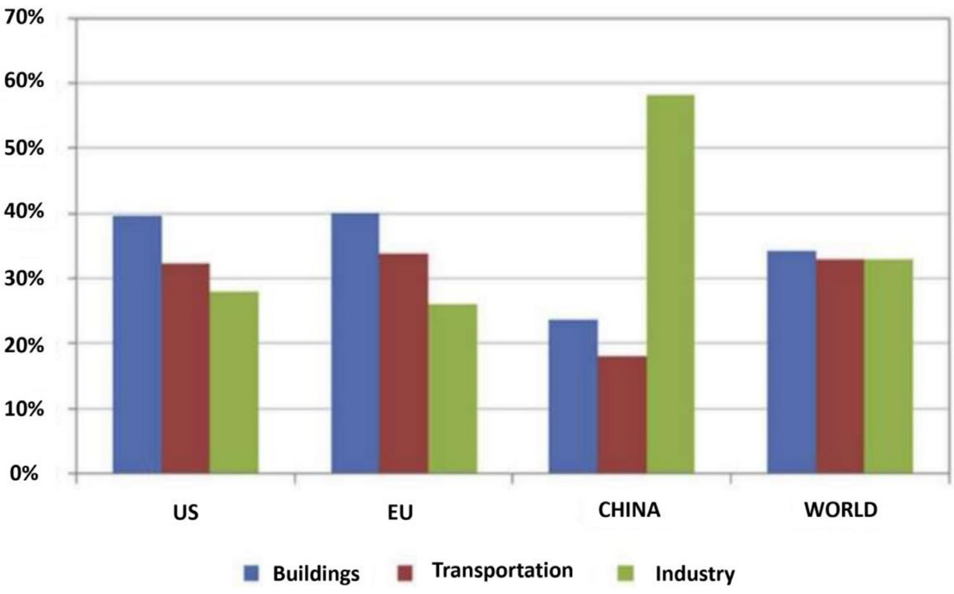

Fig. 1.. Global energy utilized by sector in 2015 with permission from [28].

One continent that is striving to ensure it reduces its energy in building is Asia. It has become very necessary for the continent to evaluate their energy demand due to the high toxic emissions recorded from the continent annually. For instance, the energy demand for China as a country in Asia presently exceeds that of the United States of America. The energy consumed in 2018 in China was pegged at 3.86×10^7 GWh and this was 22% of the energy consumed worldwide. It was however 1.42 more than the energy consumed in the United States of America [1]. It is captured in literature that energy demand in the building industry has exceed that of the automotive industry. 39% of the total energy used globally is mainly for the construction industry [29,30] (see Fig. 2). The energy demand for most Asian countries are tied down to the urbanization coupled with technological advancement [30]. With a gradual appreciable increase in energy demand to sustain the day to day activities in a building, it is becoming an alarming issue in China as the energy generation medium is struggling augment to meet the high demand. This is affecting the quality of life people intend to live in China for instance [31]. All these phenomenon attest to the need for a forensic investigation into energy utilization in buildings. One pragmatic approach reported to save energy of a house is via increasing energy efficiency of the building [32]. It has also been reported that in China where energy demand is very high, only 10–15% of new structures erected annually are in conformity to the energy standards and regulations laid out by the Chinese government. Most buildings are therefore considered as high energy consumption buildings [33]. Zero energy structures are projected to be the future of global economy in the quest of reducing energy demand to be in tandem to energy being harnessed from various sources.

From statistics, the energy demand keeps increasing annually but in China, in 2014, carbon emissions into the atmosphere significantly reduced in spite of an increase in energy. This phenomenon was attributed to the utilization of low – quality coal. This is implying that replacing energy harnessed from coal to an efficient and environmentally friendly medium of energy generation will have a direct impact on carbon emissions [33]. China is the leading producer of toxic emissions into the atmosphere with their construction industry accounting for 42% of global emissions [35] hence reducing these emission with reduce the global emissions significantly. All these key facts highlight the need for a forensic investigation into nearly zero energy buildings. There are factors that has stalled investigations into nearly zero energy buildings. Some of these factors include cost, technological innovations and availability of raw materials suitable to champion the course. Policies formulated to serve as guide for the building industry tend to vary from one country to the other and in some cases even vary from one specific location to the other within the same country [36].

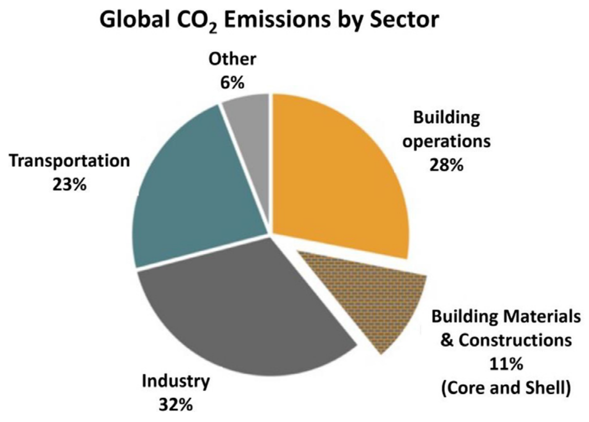

Fig. 2.. Global CO$_2$ Emissions by sector [34] “open access”.

2. Nearly zero energy building

Investigations into nearly zero energy building started around the 2000 [37]. Presently, many analytical and numerical investigations are being championed mainly to ascertain the prospects of nearly zero energy building [38,39]. Key challenge that must be critically evaluated is an in-depth investigation into recent buildings from their energy consumption to economic perspective in tandem to their impact on the environment [40,41]. This investigation with the aid of science direct and Scopus thoroughly searched the latest trends in zero energy buildings and zero energy buildings between 2000 and 2020. The investigation from the over 2000 articles gathered focused on the impact of zero energy buildings as well as climate change, holistic assessments of buildings and technical evaluation of buildings considering their energy requirements. The scope of search was however narrowed than to 215 articles after series of screening. The factors considered during the screening process were the characteristics of the buildings, its sources of energy generation as well as the location. It is important to have a fair idea of a global interpretations to zero energy buildings. Principle of zero energy structures was first presented in 1976. Zero energy buildings was first developed at the Technical University of Denmark by Esbensen and Korsgaard during an investigation into the utilization of solar energy for domestic purposes during the cold season [42]. Several definitions for zero – energy buildings have been presented in many articles since 1977 [43]. A detailed explanation to the various definitions for zero energy buildings was captured in literature but it failed to show consistency in the definition of zero energy buildings by various authors [44]. Not only does the absence of a comprehensive definition impact the ability to create an incontrovertible profile for the wider economy and, ultimately, a mutual goal for a global energy-efficient construction strategy, but it also poses serious problems in evaluating various strategies from different backgrounds [45–47]. Among countries, regions as well as communities, both descriptors as well as criteria of the zero energy structures differ, such as almost the zero energy building in the Europe [48], net ZEB in the United States of America [49], zero emission building in Australia [50] and zero carbon emission building of the C40 Cities Climate Leadership Group [51]. While these concepts differ, their intended objectives are to reduce fossil commodities usage, make maximum utilization of sustainable energy and exert energy-saving capacity for construction. On the basis of the European Union European Data Protection Board (EPBD), near- zero energy building energy efficiency should be exceptionally high and energy usage from on-site should be zero or very low [50,51]. The Sustainable Building Institute Europe has defined 10 huge obstacles impeding the principles zero energy structures becoming realistic as well as relevant [52]. According to cost-optimality concept of the directive, primary energy usage of >0 kWh/(m2 •y) [47] is proposed almost as the total cost of zero energy building. Even under such conditions, no standard definition of the zero-energy building in EU countries has been specifically configured [53].

Zero energy building has been described in the US Energy Independence and Security Act [54]. The criteria are outlined below:

(1) the need for a substantial reduction in energy consumption over duration of service [55,56], (2) balancing energy demand from energy sources, (3) minimal net carbon dioxide release as well as (4) financially feasible.

Henderson and Mattock [57] also explained the boundary-building, campus, portfolio as well as society energy estimates, and split the concept of zero energy building into 4 groups. Korea presented an approach to zero energy structure design in the Zero Energy Construction Action Plan on Climate Change and described zero energy building as structures that can optimize structural insulation efficiency, reduce unnecessary energy utilization by buildings as well as accept sustainable medium of energy generation.

In addition, zero energy building was categorized into 3 groups, namely the low-rise, high – rise and town for zero energy structures. The "Energy-Saving Technology Strategy 2011" was officially adopted by Japan, which aims to continue to limit both structure energy and emissions to zero [58]. In Germany, under the guidance of German Passive House Institute, zero energy structures were established as greenhouse. ’Passive home’ was understood as the requirement for building heating being reduced towards 15 kWh/(m^2•y) [59]. After the setting up of the Sino-German Building Energy-Efficient Cooperation, the passive house became famous. Other concepts were also proposed in Germany, such as "self-sufficient solar house" and "3-L oil construction". Danish and French analysts argue the "active house" idea, which centered on "adopting solar radiation and storage (rather than enhancing the envelope to reduce heating and cooling energy consumption) to improve indoor thermal comfort during wintertime."

The general premise is to construct zero energy building between the energy needed for its activity as well as the energy generated, onsite or off-site, by the structure on its own in compliance with a set of primary determinants, such as energy conservation and energy generated from renewable sources, for example. The definition of the distinct traits describing the zero energy buildings definition, starting from the declaration, is heavily reliant on the approach chosen as well as the objective being explained in a rather logical fashion. The development of a building is often influenced by the problems associated with the zero-energy building definition: models of single pieces, and the construction of structural design solutions, are now commonly studied and documented in detail. Due to the sophistication of the assessment criteria, the estimation of the final balance suffers. Almost all of the theories suggested for the assessment and description of the zero energy building consider the energy efficiency of buildings in their conceptual self-sufficiency: the energy consumed, for example, is typically taken into account for general system-integrated utilities (lighting, atmosphere, thermal insulation and the availability of hot water) without considering commitment of end-user to energy utilization. Lately, a number of studies are using life cycle studies (LCC and LCA) [60] to answer the zero energy building issue. A zero life cycle for a structure implies, over it’s own lifetime, the amount of the energy production used in service and the energy contained in its functional groups must be equivalent [60,61]. This method greatly affect the efficiency of the zero energy structure. The need for resources as well as the mitigation of possible potential pollution are strictly related. While this can be considered a decent description of the zero energy building principle, the variance, normally a loss, of output related to both aging or user activity is still ignored.

In addition to the Zero energy building definitions published by national initiatives, several scholars too have submitted Zero energy building descriptions in order to provide the similar research with a standard one. Crawley et al. [62] separated the net Zero energy building into various categories on the basis of sustainable energy sources. This designation system will support developers as well as stakeholders in cost-effectively allowing maximum utilization of sustainable energy and nearby. In several activities, concept of zero energy structures has focused solely on time of operation, while carbon emissions have been overlooked in the construction process. Building output in the entire structural life cycle must be considered via a stricter ZEB definition [63]. This designation system will assist developers as well as stakeholders in cost-effectively allowing maximum utilization of sustainable energy. The initial term was reinterpreted according to Hernandez and Kenny with a zero energy building lifecycle (LC-ZEB). The energy production (including materials and energy systems) of the LC-ZEB is equivalent to that provided by sustainable energy technology over the lifetime of the building [64].

For rational cost options, cost-optimization estimates can be straightforward if green technologies are not implemented. It is expected that rapid advances in renewable technology will render such estimates uncertain [65,66]. As a consequence, compared to the discrepancies in the measurement methods, the definition of ’zero energy’ has been dismissed for being vague and contradictory, which is more clearly expressed in the aspect [67].

A reasonable ZEB description is still hard to get. A detailed review was performed by many scholars on the different meanings of ZEB. Sartori et al. [68] established a coherent structure for the establishment of net definitions for ZEBs. The analysis of the parameters in the definition context as well as the collection of relevant options is a technique for systematically defining net definitions of the ZEB. The design structure for reaching net zero energy industrial buildings was built by Hyde et al. [69]. In an Australian case study, Wall et al. [70] explored eco-efficient production methods for Net Zero. In order to redefine net ZEB, Srinvasan et al. [71] conducted research on renewable emergency balance in sustainable construction method. An analysis of definitions, strategies as well as construction activities was taken out by Panagiotidou et al. [37] on the success of the ZEBs.

The key conclusions are as follows: While ZEB was a popular issue worldwide, no concept or solution is still widely recognized. The ZEB concept should be defined locally by each nation according to real and unique contexts.

Construction energy use is mostly affected by weather conditions, envelope configuration, energy schemes, installation as well as maintenance facilities, efficiency of the indoor environment, as well as the ac-

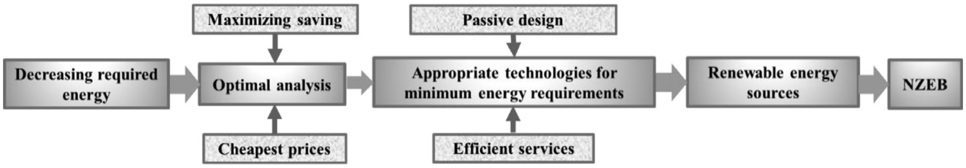

Fig. 3.. Zero energy building design consideration.

tions and activity of residents [72]. The balance between passive building design, green energy technology as well as building managers, or management practices, has not been well considered in current concepts. It is pointed out that ZEBs not only provide construction efficiency, but also require active cooperation from users.

The Ministry of Housing and Urban-Rural Development (MOHURD) formally presented a Procedural Guideline on Passive as well as Low Energy Sustainable in November 2015, mainly for enhancing energy efficiency of China's buildings. The sustainable ultra-low-energy green building is described as structure that can generate a friendly coupled with safe indoor air quality with lower electricity usage via enhancing efficiency of the envelope's thermal insulation as well as minimizing air conditioning demand.

One form of near ZEB in this guidance is the passive sustainable green structures. It is the first time that nearly ZEB's China version has been officially reported. For commercial structures, no specific formal description has yet been provided by the central government [71].

As such, ZEB are made up of 2 methods: reducing demand by adopting sustainable steps (passive design) as well considering sustainable energy generation medium coupled with other technologies (active design) to satisfy additional energy needs, as depicted in Fig. 3. Second, the passive methods that can decrease the ZEB's energy requirement as much as possible are passive. The techniques of passive methods include shade, now-thermal bridge, design of air tightness, efficient ventilation as well as lighting, coupled with high efficiency.

The active architecture includes powerful lighting, environmentally friendly appliances, as well as a fresh air heat recovery technology. It is imperative to critically determine cost-optimal design of ZEBs based on passive as well as active techniques. The technical standard sets out minimum criteria for the compliance of ZEBs with the related energy demand indicators, air tightness measures as well as standards of the indoor climate. Fig. 4 (adapted with permission from [72]) demonstrates circumstances of ZEBs. To define the "zero" condition of constructions, there are many varying terms that need to be considered. The correlation between these concepts and construction boundaries corresponding to the various evaluation metrics is clearly shown in Fig. 4.

2.1. Characteristics impacting zero-energy building efficiency

The variables influencing zero-energy building efficiency could be generally classified as environment, manner of construction, as well as activities of occupants, which are clearly outlined as follows.

2.1.1. The weather

China for instance is situated on the east side of the continent of Eurasia. Climatic styles in China varies as well as complex. China is classified predominantly into 5 geographical conditions. Temperature variations between areas have led to unequal geographic variation [74]. In Shenzhen, Wuhan, and Beijing, the number of cooling degree days are 2107, 1189, as well as 840, approximately [75], indicating that the percentage of cooled energy usage declines from south to north. Parameters example climate represent variation in the atmosphere. The strength of global irradiance influence the energy efficiency of a building [75]. Climate conditions therefore have a critical effect on structural efficiency. It is important to adjust to local site conditions in the establishment of zero-energy structures and allow reasonable use of the environment.

2.1.2. Sort of structure

In advanced nations, many zero-energy structures are low-rise structures of up to 3 levels. It has been reported that during energy generation solely via photovoltaic panels mounted on rooftop, the largest number of floors for net-zero energy usage in houses is 3 [76].

It was however noted that energy usage saw an increment with an increase in the elevation of each building as well as that for suburban domestic structures in Guanzhong, the acceptable elevation for each story is nearly 3.0 m. Most of China's city buildings, on the other hand, are predominantly high and medium buildings [77].

Again, for most structures in China, having large public areas as well as low airtightness, resulting in quantities of air infiltration, the structure shape coefficient is small in comparison to other advanced nations. It is also difficult to achieve zero energy usage in China for medium- as well as high-rise structures. The influence of height on zero-energy buildings is the subject of current research in China. We recommend that the vertical facade be completely used [78].

While China's remote regions have a good ecological landscape as well as a reduced population relative to towns, because of the fairly dispersed structures, low energy consumption density as well as high transport fares, the cost of traditional commodity energy is greater compared to cities. As a consequence, it is hard to support zero-energy buildings in rural areas [79]. Also, for such areas, energy-autonomous residences may therefore be an acceptable choice.

2.1.3. Correlation between Energy demand of a building and human activities

Explanatory figures offer broader understanding of the significant impact of structures and their inhabitants in the global environmental issues. During their activity, structures uses nearly 80% of their lifecycle energy [80], which is almost four times greater than the energy embodied [81]. In total, 36% of world final energy usage is due to existing structures as well as development and approximately 40% is attributable to carbon dioxide being emitted into the atmosphere directly or indirectly [82]. Several scholars, have highlighted the role of occupant attitude in the energy efficiency of homes [83–87]. Annex 53 of the IEA Study on occupant attitudes propose reasons for occupant behavior, such as genetic, social as well as psychological factors, day of the month, characteristics of construction/installation as well as physical environment [88]. In considering energy use in buildings, this investigation places occupant attitude as solving the first stage of Maslow's pyramid of necessity. In a research directly related to occupant attitude, IEA Annex 66 [89] stated that the behavior of occupants contributes a significant role in their level of comfort as well as their use of resources.

Construction energy demand is greatly affected by the activity of the inhabitants [90]. Yu et al. [91] describe 7 key characteristics affecting the overall energy usage of structures , namely weather, Structure-related features, user-related features, structures as well as operations of structural facilities, actions as well as behavior of occupants, social coupled with economic influence, and the nature of the indoor atmosphere. Inhabitants have a positive impact on the efficiency of the structures in terms of their energy usage. Through utilization of heating, ventilation as well as air conditioning (HVAC) systems, coupled with domestic service, inhabitants are also accountable for energy demand, pollution as well as waste generated, and used energy in structures for various factors to optimize their comfort.

In housing study, occupancy is hard to quantify as well as model, despite the fact that it may be classified as a significant contributor in the

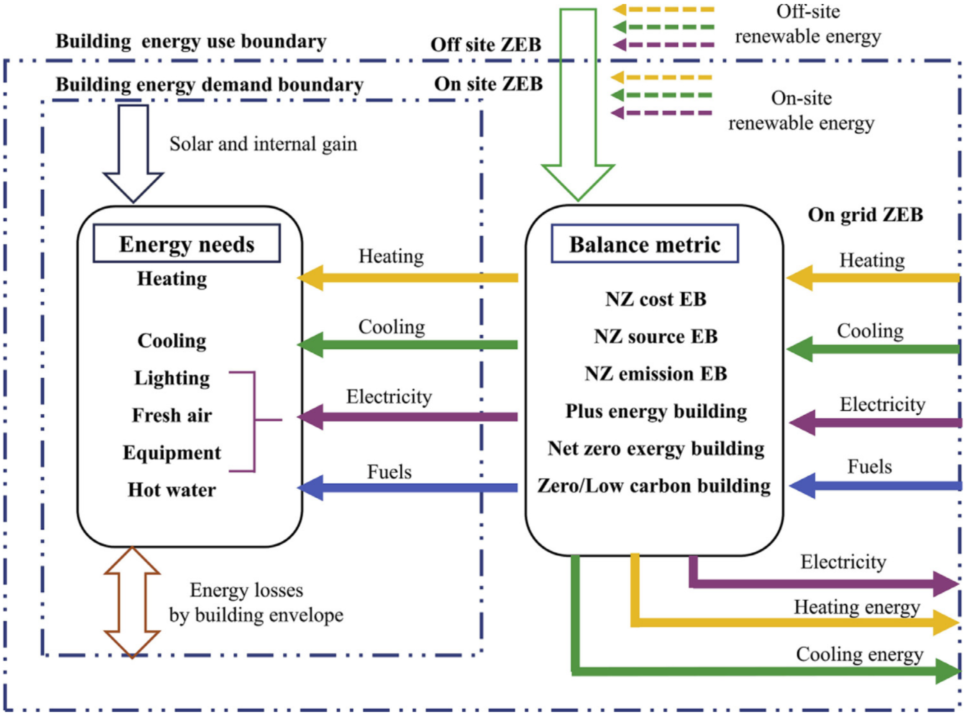

Fig. 4.. Boundary specifications of applicable concepts [73] “open access”.

utilization of energy in structures [92]. As main driver of construction efficiency for domestic structures, D’Oca et al. [93] describes occupancy patterns. They are also relevant for measurements as well as simulations related to energy, taking into account [93].

To further establish energy saving strategies unique to specific sectors of the global economy [93], the generalized profile of inhabitants may be utilized. As a result, while trends are often used for independent task, for grand scale applications, models are often required. Subject to forensic data evaluation as well as country-wide statistical study [94], occupant demographics coupled with trends can be created. Even though in investigations focused on Europe as well as the United Kingdom (UK), the literature failed to capture an accepted description or trends for community populations [95].

2.2. Novel structures

The introduction of energy conservation methods in relation to structural envelopes, utilities coupled with indoor conditions and power self-sufficiency subject to sustainable energy generation sources are the two primary criteria for achieving the zero energy building goal. Both the intrinsic as well extrinsic parameters of the structure itself and the context rely on the development strategy to satisfy these necessities.

Novel structures must be developed to the criteria aligned with the constraints associated with the structure itself thus referring to the context as well as current characteristics. Typology of the structure, with regard to positive, substantive as well as functional performance, is yet another varying factor in addressing energy characteristics, affecting the option of energy saving techniques to be utilized. Despite similar criteria enacted by varying local legislation, traditional methods to reducing energy requirement can be identified. The most popular technical recommendations [96] are insulated envelopes, mechanical ventilation etc. as suggested in literature [97]. In order to enhance both the accessible technological solutions as well as the limitations placed by regulatory measures. The structures considered in other investigation have varying purported uses and are situated in hot, cold as well as mild climatic conditions marked by different climatic regions. The nature of geometry as well as morphology enables the loads to be treated in new structures.

In colder areas, structures are typically built to be as compact with lower shape factors aimed at maximizing thermal flows. Research work conducted revealed that the values observed as well as reported are generally between 0.16 m^{-1} [98] and 0.47 m^{-1} [99]. Other researchers also developed structures whose shape factor exceeded 0.50 m^{-1} despite the structure being situated in a colder environment [100]. The work on the envelope as well as device output was followed by the fulfilment of the zero energy structural needs. Strategies to analyze the danger of overheating are studied in warm areas, in terms of the position of the house. In several research approach, the typical method recommended is to decrease the window to wall ratio by reducing solar gains hence reducing the value far below 0.50.

The selection of the best technological approach to meet energy demands is highly law- based. The structures analyzed are predominantly located in European states. Building envelopes are being built in these places with the goal of decreasing energy losses in colder seasons as well as reducing overheating in summer. The plan of envelopes with higher thermal efficiency for both opaque as well as translucent elements in winter is important prerequisite for meeting the zero energy structure criteria. Insulating function of the envelope relies on microclimate environments in hotter weather: low insulation level is advised [101]. The regulation of solar radiation via transparent materials in mild climates enables the impact of free gains to be optimally exploited as well as guarantees a fair level of internal environment. Usually, these effects are obtained via the application of internal or external systems for shading (blinds, overhang components, etc.) working in tandem to the location of the elements.

Zero energy building requirement, free movement of air in the structure as well as power supply systems emerge as a key feature. A remedy to this is via Natural ventilation. This approach utilises natural ventilation for a reduction in the cooling load as well as electrical consumption from sustainable medium. With regard to energy source, the analysis of the literature stresses that the common diffused solutions are ground source heat pumps (HP) equipped with photovoltaic (PV) panels. In recent years, the efficiency of this approach has largely improved, allowing for a broader diffusion of PV in most countries as opposed to existing power generation systems, but the performance depends heavily on the latitude, so that the surface ought to fulfil the structural power

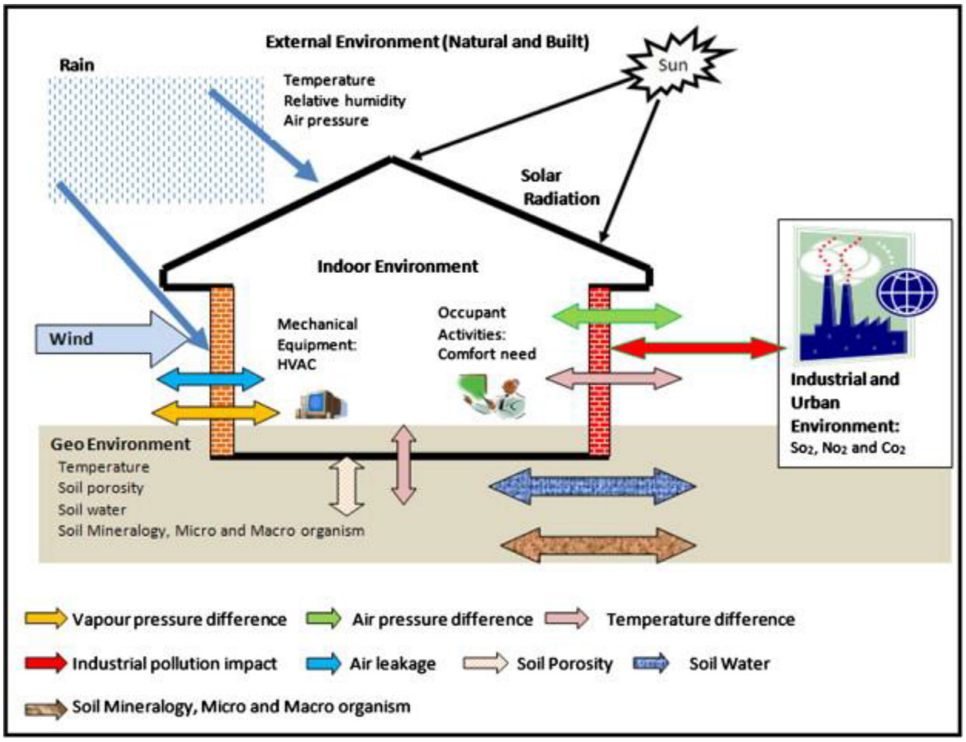

Fig. 5.. Building envelope design [104] “open access”.

requirements when heading north. The value of energy use as well as environmental sustainability in structures is illustrated by several writers. Using sophisticated as well as smart controls for structural systems, these objectives can be accomplished. When assessing real structures, the preference of the writers falls on the methods of the Building Energy Management System (BEMS) to handle technological structures inside the building [102,103]. Heating, cooling and ventilation management techniques are focused on maintaining interior occupant comfort.

2.3. Building envelope design

Envelopes for housing comprise of walls, doors, windows, roofs, and floors as depicted in Fig. 5. The key elements of a house that obstruct the indoor as well as outdoor spaces are the walls, exterior windows, a well as roofs. Thermo-physical characteristics of the materials used in constructing the building and the airtightness of the structure are key thermal characteristics for the design of the envelope. The thermal efficiency of a structural envelope has a direct impact on its energy utilization.

2.3.1. External wall

Approximately 30% of the overall energy use of a structure is energy used due to heat loss from the exterior wall [105]. Raising the wall’s thermal efficiency is therefore a critical step for the conservation of energy in buildings. At present, implementing external wall insulation method is the predominant energy-saving technique for zero-energy structures. In the 1980s, investigations on conservation of energy for structural walls in China started. In terms of wall form, most of zero-energy structures especially in China are now utilizing novel kinds of walls. For instance, the Huazhong University of Science and Technology’s "000 PK Building" [106,107] embraced the development of walls that were hollow in shape. Further investigation has shown that the wall’s thermal conductivity may increase to 0.078 W/ (m^2.K). For exterior wall of the Eco-House [108] in Shanghai, recycled wall material made up of solid waste was introduced, lowering the heating as well as cooling load of the construction. The heat transfer efficiency of a wall having higher thermal mass in zero-energy structures was evaluated by Zhu et al. [109]. The findings gathered showed that it is ideal to be used in regions with significant temperature variations.

The efficiency of various insulation materials differs greatly when utilized in wall. This usually leads to various energy-saving benefits. Deng et al. [110] analyzed the efficiency of 6 insulation materials in China considering location, shearing, as well as fire resistance of external walls of almost zero-energy building. It was however concluded from the investigation that suitable types of insulation techniques and materials will be ideal for this climate area for almost zero-energy buildings.

A key component of the exterior wall with a massive influence on energy usage of a house is thickness of insulation. A logarithmic correlation between various thickness of insulation and was suggested by Miao and Zhang [111]. There is an ideal insulation thickness which enhances a structure’s energy efficiency. In order to investigate the ideal insulation thickness for external walls of passive low-energy house in extreme cold zone, a theoretical life-cycle cost evaluation was carried out [112]. It was found that the extended polystyrene (EPS) board’s optimum insulation thickness was 220 mm.

2.3.2. Window

Window is the least factor to oppose the transfer of heat via envelope of the house. Energy utilization because of loss of heat caused by the window is approximately 24% of the overall energy demand of a house [113]. The key factors influencing the energy usage of windows are heat transfer coefficient, position, as well as window-to-wall ratio.

There are no universal criteria for the coefficient of heat transfer distribution. In some parts of China, design requirements for ultra-low, nearly zero, as well as zero-energy domestic structures indicated a high limit of 1.0 W/(m^2.K). Attaining this this specific heat transfer coefficient is challenging especially when materials like steel, thermoplastics and wood are used. Novel kinds of windows are being encouraged in Asia example bridge-cut-off aluminum alloy. Research works show that double-layer glazing in comparison to standard single-layer transparent glass, can minimize heat loss by about half [100]. A group of researchers introduced electrochromic glazing with a coefficient of heat transfer calculated as lower than 0.3 W/ (m^2.K) [114].

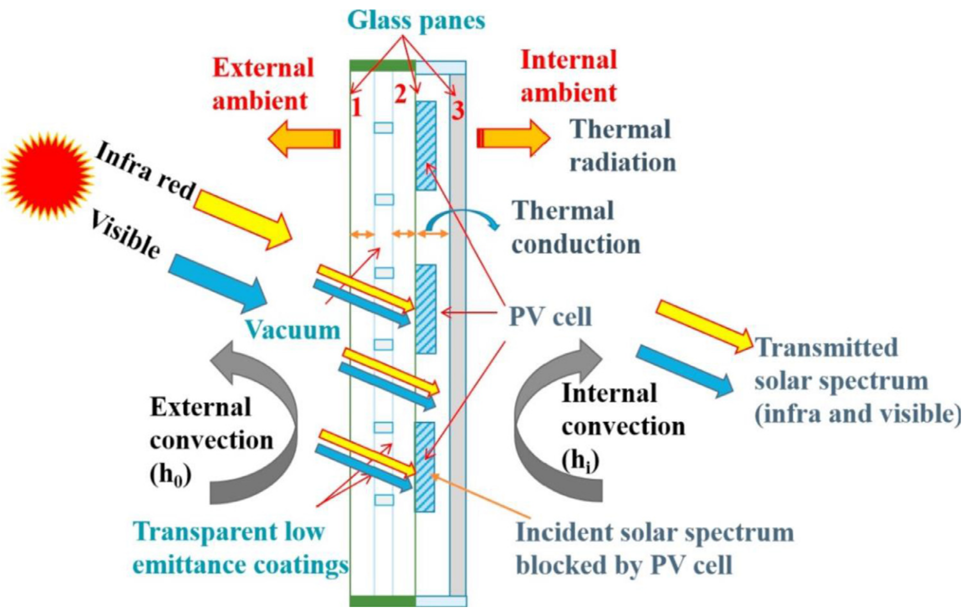

Fig. 6.. Investigation into solar glazing [116] "open access".

Two other critical parameters influencing structural energy usage are window position as well as window-to-wall ratio (WWR). The use of sunshine, natural air circulation as well as harnessing energy from the sun in structures is mainly done by windows. It is therefore important to decide an optimal window-to-wall ratio based on local weather for energy-saving [114]. The Design Criterion for Energy Efficiency of Domestic Structures in Hot Summer and Cold Winter Zones' (JGJ 134-2010) [115] mandates that the window - to - wall ratio must not go beyond 0.40, 0.35, and 0.45. A summary of a comparative study on solar radiation glazing is captured in Fig. 6.

2.3.3. *Roof*

Energy usage as a result of heat loss via the roof is responsible for nearly 8-10% of multi-story structures' overall energy usage [117]. Several elements, such as the building type, insulation, colour, thickness, as well as thermal resistance, influence the thermal efficiency of the roof [118]. The energy-saving model for zero-energy house roofs must therefore be driven by the strategies below: choosing novel insulation materials as well as higher compressive strength [119]. An investigation in Asia on the roofs of zero-energy structures dwelled mainly on the efficiency of thermal insulation. Improving a roofs' thermal insulation efficiency will minimize heat loss [120]. The temperature intensity coupled with time lag of green roofs on the variations of ambient air temperature were studied [121]. The outcome showed a green roof's temperature attenuation multiplier is greater than doubled as well as the time lag relative to a non-green roof is reduced [122].

2.4. *The construction material's thermo-physical characteristics*

When reacting to the ambient climate, the thermo-physical characteristics of envelope of a structure greatly impact the indoor conditions. The thermal mass of the structure, for example, will influence fluctuating intensity of the temperature of the indoor air hence the activity of air conditioners [123]. In order to model the cooling load of residential structure in a province in China, a group of researchers utilized the eQuest software to analyze the impact of the thermal inertia index in various modes of operation of air conditioners. It was found that the impact on the accumulative cooling load was not noticeable when the thermal inertia was way lower than 3 [124]. An experimental as well as numerical investigation was conducted in 2003 to ascertain impact of various thermal masses on the air-start/stop conditioner's duration period [125]. It was however concluded that the air-operating conditioner's time can be modified based on the building's thermal mass to minimize energy utilization while preserving indoor thermal conditions [126].

Thermal inertia, the decrement factor, as well as time lag can characterize thermal storage efficiency of a house's envelope. A research work was conducted to examine the architectural features of conventional houses under varying climatic areas. It was however concluded that the performance of thermal storage had the greatest effect on the energy efficiency of structure in very - cold as well as cold areas; natural ventilation during sunny weather conditions as well as warm-winter region's most successful passive strategy [127]. The impact of various wall position on the decrement factor as well as time lag of indoor-temperature variation in Lanzhou was studied [128]. They found that various wall alignments have major impact on the decrement factor as well as time lag of indoor-temperature variation via the study of on-site experimental results. A research into various wall types coupled with their thermal characteristics was performed by Wang and Liu [129]. It was however deduced that the thermal inertia as well as the total heat transfer coefficient together was not able to fully ascertain the thermal efficiency of the wall. The energy-saving efficiency was calculated via the degradation rate of the structural material. A decrease in the total heating load as well as an increment in the cooling load could lead to an improvement in thermal insulation.

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2.4.1. *Airtightness*

The airtightness of a structure is simply the opposition to accidental air penetration or exfiltration via the envelope of the structure [131]. Due to the contrast between the enthalpies of the outside and indoor air, airtightness adds substantially to the energy usage of a house. Most countries like China for instance do not have a national criterion for measuring airtightness. Instead for a 10- Pa difference between indoor and outdoor air, the Chinese criteria specifies eight airtightness ranges [132]. Much of the studies concentrate on improving air tightness to limit the energy usage of buildings. For instance, by using the DeST structural model program, Zhang et al. [133] investigated impact of window as well as door airtightness on the energy demand of a structure for domestic buildings in Nanjing; they highlighted that the thermal loads reduce as the level of airtightness improved appreciably during heating, cooling, as well as transition conditions. The reductions in the heating load, cooling, as well as annual thermal loads were 51.5%, 32.6% and 46.7% respectively, when airtightness level improved from level 1 to level 8. The reductions in the heating load, cooling, as well as yearly loads were 51.5%, 32.6%, and 46.7% respectively, when airtightness improved. Zhou et al. [133] examined the effect. It was concluded that the rate of air change dropped down from 1 to 0.1 ACH. In a remote community in Northern China, Gao et al. [134] carried out field investigation on structural airtightness and found that the airtightness of the structure was as high as 13.8 ACH. The researchers concluded that 74% of energy can be preserved by structural energy simulation using DeST via an increment in the airtightness of the structure. The unnecessary reduction of fresh air via the structural envelope will result in bad impact on the health of the inhabitants as well as mechanical ventilation requirements to provide the building with adequate fresh flow of air to sustain a good quality of indoor air.

A group of researchers analyzed the impact of the level of airtightness on the heating energy usage of a structure in China's warmer and colder location. It was however reported that an increment in airtightness levels led to an increment in the energy consumed by the fan in the structure. This in effect led to an increment in the heating energy usage. In changing environmental areas in China, Xiaohanget al. [135] examined the effect of the degree of airtightness as well as ventilation mode on heating coupled with cooling energy utilization. It was reported that flexible window opening resulted in decreases in the reduction of cooling energy in Harbin etc, in comparison to completely closed windows. In the TRNSYS setting, Lu et al. [136] established an almost zero-energy structural model for warmer as well as colder regions. It was however concluded that free movement of air can be used to improve the energy performance of a structure when the rate of air transition is equal to or lower than 3.0 ACH.

2.5. Energy usage by electrical as well as mechanical gadgets

Heating, cooling, residential water heater, lighting, home gadgets, lifts, as well as airflow are included in the energy use in a building [137]. In China, use of heating as well as air-conditioning installations has seen an incremental growth dramatically as the economy expands, rendering heating as well as air-conditioning the 2 largest structural energy users. The energy utilization per unit area is 2,3 times greater compared to industrialized nations with the same weather conditions as well as level of indoor comfort [137]. Fuel as well as electricity are presently the key forms of energy consumption for air-conditioning as well as heating systems in China, and the rate of electricity consumption in warmer weather conditions can reach 82.35% [138].

China has implemented aggressive energy-saving strategies in construction design via the use sustainable medium of energy generation to reduce the consumption of electricity as well as reliance of fossil commodities as medium of energy generation [139].

2.5.1. Energy-saving equipment for applications for heating as well as air conditioning

A primary measure of whether a structure is energy efficient is the type of power an air-conditioning device uses. The ground source heat pump (GSHP) device is probably the most commonly utilized energy saving innovation in zero-energy structures. Shallow geothermal energy is used by ground source heat pumps to heat as well as cool the structure coupled with providing domestic hot water [140].

Energy efficiency initiatives allow the energy requirement for structures to be reduced. The key passive as well as active solutions needed to achieve zero energy building goals are analyzed in this section. A design process aimed at optimizing the effects [141] is needed to minimize energy needs. In addition, the nature of passive compositions impacts the production of active energy management solutions as well as the regulation of operating modes to optimize them.

Passive building design literature is comprehensive [142] and similar technological solutions are widely analyzed as well as implemented [143]. Reducing energy needs, enhancing the thermal efficiency of materials, the buoyancy effect, thermal inertia as well as evaporative effects are the key objectives of passive systems [144]. The energy needs of a structure connected to morphological, geometric as well as thermophysical parameters, are influenced by a variety of varying conditions. The construction fabric design has a direct influence on the efficiency of the house.

The authors measure a wind – to – wall ratio weight of about 20% and 11%, respectively, on cooling and heating loads [145]. The easiest way to minimize heating and cooling usage, irrespective of the climatic influence, is to limit the WWR to nearly 10%. However, if the efficiency for the structure is considered in terms of both energy resources, the outcome would change [146,147].

2.5.2. Technological advancement for ventilation

In most parts of the world, there are two primary construction ventilation techniques: natural as well as mechanical ventilation [148]. To maintain indoor conditions, natural ventilation is powered by wind as well as thermal buoyancy. There is therefore the absence of any extra energy required. It is therefore widely utilized in buildings that are zero-energy structures. Efficient passive structural designs are needed for free movement of a naturally as well as the design approach that can be implemented [149]. Fig. 7 depicts some newly improved ventilation duct.

Wind hoods are also mounted on the roof of structures with heat recovery functions to minimize heat loss because of air changes. The indoor air is extracted by thermal buoyancy with the aid of wind hoods. This ensures incoming outside air is heated with the aid of exhaust air through the heat exchange system inside the hoods. There is reduction in air conditioner's energy utilization to heat the fresh air. Research findings have shown that the rate of heat recovery via passive wind hoods could go up to 70% [151].

2.5.3. Source of light

Energy for providing sustainable illumination for the structure is responsible for 15% of the energy needed to keep the building running [151]. Creating an energy-efficient illumination system to decrease energy demand of a building is therefore essential. The following criteria should be followed in the illumination concept for zero-energy buildings. Completely use of daylight: decrease the energy demand for illumination via incorporating light harnessed from the sun by general structural design as well as optimization of building form, reflection, coupled with shading [152]. Fig. 8 depicts the utilization of day lightning

The use of light emitting diodes (LEDs) as sources for lighting can significantly cause a total reduction in the energy of a building because the heat they generate is low but have higher luminous intensity. The energy required to sustain LEDs are lower and they are also friendly to the environment [154]. It has however been reported that the utilization of LEDs can reduce the energy demand for a building by 33–50%. Similarly, LEDs usually have longer life span compared to incandescent bulbs [155]. Using intelligent control: Advanced technology for lighting control will help save energy from illumination. Lighting energy savings are achieved by fairly regulating illumination time, lighting intensity as well as the number of lighting fixtures while maintaining lighting efficiency coupled with demand as well [109]. An adaptive illuminous control system was investigated [156]. With the aid of a fuzzy logic method, they deduced that to attain a thermal comfort as well as energy saving, different types of management modes were explored to ascertain the lighting as well as shading systems of a structure. Novel ARM technol-

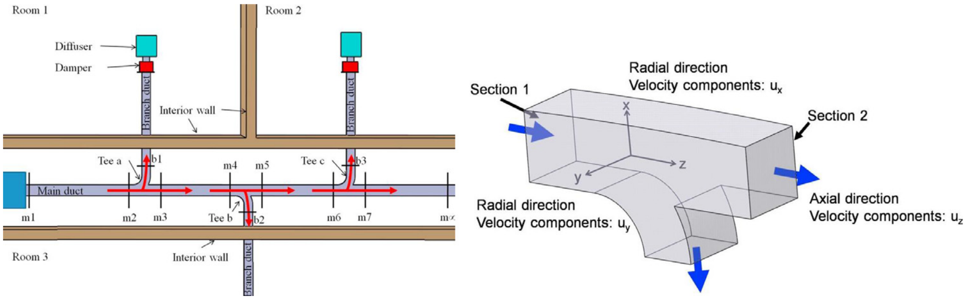

Fig. 7.. Newly improved ventilating duct reproduced with permission [150].

Fig. 8. (a) Light ducts penetrates building vertical voids and (b) side emitting ducts reproduced with permission [153].

ogy has been established for light tracking illumination of a building. This technology is ideal for energy lighting 24 h in day.

2.5.4. *Water system*

Water resource is a key parameter required in zero energy building especially when the building is situated in a country with poor water systems like China. Harvesting rainwater is a pragmatic technique that can be utilized in zero energy buildings to augment water demand for the building [157]. The harvested water is often useful for general house cleaning, irrigation etc. Rainwater infiltration is also ideal in the limitation of runoff of rainwater hence reducing urban waterlogging hazards as well as curbing water pollution [158]. For instance, a siphonic drainage technique was adopted in the collection as well as purification of rainwater mainly for agricultural purposes as well as washing vehicles in the 'O – House'. This was adopted to ensure the resources were utilized efficiently [148]. A transition from green University structures to zero energy structures have also been proposed. This was carried out via the usage of water saving gadgets, improved technology for the supply of water as well as harvesting rainwater to augment the demand of water to run the building.

3. Sources of power

Currently, PV solutions are the most commonly used green energy systems in construction industry, from the utilization of active solar energy is a key method for the supply of on-site renewable energy [159]. It is well established as well as studied for the performance features, performance as well as critical factors affecting PV efficiency [160]. Due to its high degree of readiness achieved [161], the technology has drawn considerable interest from legislators in various countries. In fact, PV technology has the key merit of simple scalability. Several scholars have documented the prospects of PV technology, showcasing good findings from both energy [162] as well environmental [163] viewpoints. Positive technical aspects, along with a favorable regulatory environment, have helped the PV sector to expand rapidly as the preferred renewable energy generation mechanism. Several innovations have evolved alongside the classic PV panels in order to optimize their capacity as well as allow dissemination in various contexts. Using thermoelectric cooling modules, photovoltaic-thermal (PVT) technology allows solar cell temperature control to take advantage of heat waste [164].

Due to its versatility [165], building-integrated photovoltaic (BIPV) has lately attracted interest of construction industry. To turn them to power generators, these photovoltaics are planned to be built inside building envelope as replacement for conventional passive construction components. Several factors affect the energy efficiency of BIPV modules: ambient temperature, shadowing effect etc. While the technological characteristics as well as efficiency of BIPV have improved over the last few years, the major obstacles to the proliferation of this technology [166] are high manufacturing costs and high labor charges.

Another significant constraint to solar energy is the efficiency of the systems' power production. As complex meteorological mechanisms add major timing uncertainty in supply, solar-generated electricity can not be accurately predicted. In addition, the production as well as use of PV electricity doesn't have the same profile. Proper architecture of an energy storage system has been shown to result in a significant decrease of energy supplied as well as utilized from the grid in the warm Mediterranean region [167,168].

The Solar Heating/Cooling System (SHS) is common term for variety of technologies planned to transform solar energy [169,170]. The heat demand of houses that limit CO2 emissions at the same time is effectively met by SHSs. The broader distribution of solar collectors is linked to houses, where the output of electricity for domestic hot water (DHW) plays a significant role in the building's total energy needs. So many reports suggest that because of the specific heat power of water, thermal efficiency of solar thermal collectors that functions with the aid of water is higher than that operated with air. Similarly, the flat plate collector tends to be widely used alternative [171]. Research has been performed using nano-materials [172] coupled with nano-fluids [173] to enhance the efficiency of SHSs. To boost thermal energy storage of both systems [174], phase change materials can be used. Thermal Energy Storage tends to be primary factor for such solar energy utilization [175,176]. Solar technology meets cooling requirements better compared to heating applications, particularly in conjunction with solar peaks [177]. Al-Alili et al. [178] offer a comprehensive overview of the innovations used in advances in solar cooling. A comprehensive study of the costs required with this technology remains unavailable considering the vast number of installations reported. Existing data tend to suggest that this is not yet cheaper solution to conventional vacuum compressor. Emerging technologies for small-scale solar cooling are integrated modules that follow either adsorption or desiccant cycles.

To meet the zero-energy building goal, wind energy may be deemed a supplementary sustainable medium of energy generation. A net benefit to the structural energy balance is given by wind turbines, which convert mechanical energy into electrical energy. The design of the turbine plant as well as the form of both the building coupled with its surroundings in relation to the wind pattern are the most significant considerations about the efficacy of a wind system. With regards to the ability to orient the wind turbine, there are two approach; the yawning and the non-yawning mechanism [179].

If properly built, a non-yawning incorporated turbine structure will produce at least two times more energy from wind as a 'free-standing' comparable turbine because of local wind velocity acceleration [180]. Lee et al. prove that the output capacity of a small vertical axis wind turbine (VAWT) [181] may be influenced by vertical wind flows resulting from strong turbulence in urban areas.

In general, vertical axis wind turbines welcome wind from either angle with the benefit of eliminating a yawning mechanism that is expensive and may fail through operation [182], minimizing power losses owing to transient shifts in the trajectory of the wind [183]. Due to this, vertical axis wind turbines are usually recommended for urban locations with a specific country. The level of noise produced during its operation is also low compared to the horizontal axis turbine as well.

3.1. District heating and bioenergy

Aerothermal, hydrothermal as well as geothermal energies are defined as sustainable medium of energy generation by the European directives. By altering normal distribution of heat from elevated to lower temperatures [184], heat pumps (HP) leverage these medium to transfer heat to houses. Based on heat sources as well as heat sinks, heat pumps are categorized. In the construction industry, air-to-water heat pumps (ASHPs) are common. These types of heat pumps are simple to install as well as relatively inexpensive, but their efficiency, especially in winter, struggles from bad weather environment [185]. Investigations conducted on residential structure stocks suggest a possible energy saving of between 20 and 40% [186,187].

A cross-country study in Europe supports average opportunity for energy savings, with values varying between 20 and 40% [188]. Overall, when related to other sustainable sources, HPs have proved advantageous in terms of cost and performance. Field experiments as well as research show that the combination of multi-energy sources, such as renewable energy sources [189,190], will increase the energy efficiency and economic viability of HPs [191].

In reality, as opposed to individual heating and cooling systems, district energy systems have greater reliability due to the potential to better monitor as well as regulate the entire energy grid. The Combined Heat and Power (CHP) device is predominantly utilized in DH/DC for generating thermal energy as well as electricity at the same time, resulting in a decrease in Cardon dioxide emissions [192,193].

The tri-generation technique is an excellent solution for increasing the power plant's running cycle, decreasing the level of carbon dioxide emissions but boosting the efficiency of economic investments in comparison to conventional gas-based Combined Heat and Power technologies [194]. The incorporation of green energy sources such as solar, Heat pumps as well as biomass into the district energy system increases energy, environmental as well as economic efficiency of the system [195,196]. As they have a clear reduction in carbon dioxide emissions as well as an increase in economic savings, biofuels and biomass could be considered as zero energy building medium of energy generation [197]. Biomass plants are the most beneficial options defined by the current criteria. The actual biodiversity of these resources, however, remains an open topic: some nations, such as Denmark as well as Switzerland, prohibit the use of biomass as fuels via the formulation of laws and policies to curb energy harness via this medium. Bio-fuels are useful for CHP/CCHP plant in the heating mode, for the output of DHW as well as in the mixed mode. Biomass stoves are mounted as the primary generator or as secondary heating technology in low-energy houses [198].

3.2. Control and management approach

The Building Automation System (BAS) as well as associated optimization and control systems are important for achieving the zero energy building goal but retaining user-acceptable levels of comfort [199]. At the same time, Building Automation System is still considered an obstacle for zero energy building goal growth. Inside the house, Building Automation System is widespread and applied to the optimum management coupled with regulation of various facilities and equipment: HVAC, DHW, lighting and shading systems [200]. Compared to the traditional control strategy focused on static routines and fixed internal set points, the saving power in HVAC utilization, linked to the comfortability obtained by multiple control techniques, reveals a remarkable proportion of up to 40% of energy savings linked to effective occupancy-based control strategies [201]. Theoretically derived by structural simulations, these findings must be tested in operating environments by conducting an analytical building study. In Germany as well as Greece Michailidis et al. [202] applied an existing concepts optimization method to 2 distinct office buildings, showing how thermal comfort coupled with energy saving can be increased by adaptation in a context that tends to vary.

Another approach in which control algorithms are implemented is the Building Energy Management System (BEMS), as summarized by McGlinn et al. [203]. Its framework is made up of numerous layers [204] : the "sensor and actuating" framework is the first step, enabling links to the built environment by detectors to sense parameters as well as actuators to modify the state of the environment. Then there is the "middleware" causing integration of a standard configuration of the previous structure; "process engineering" reflecting the system's computational heart, obtaining sensor input but communicating the related behavior to the actuators; as well as the "user interaction interface" facilitating interaction with final users. In terms of both power saving [205] as well as environmental influence [206], the capacity of BEMS is well known. Thanks to a broad communicating-acting network where computers are profoundly linked together [207], the emergence of the Internet of Things offers new insights. Scientific literature anticipates that this technological advancement is the future [208].

4. Factors impeding commercialization of nearly zero energy buildings

This section will to seek evaluate and explore key factors impeding the commercialization of zero energy buildings and some possible mitigating strategies will be proposed as and when necessary.

4.1. General definition for nearly zero energy buildings

The definition of the architecture as well as efficiency appraisal of zero-energy buildings is the key parameter to see the future commercialization of the technology [209]. Different meanings can lead to different specifications and standards for energy saving. From an international viewpoint, according to their national requirements, several developing countries have suggested common but distinct concepts of zero-energy buildings. Until lately, zero-energy houses in China were identified by the procedural standard for nearly zero-energy structures as houses with yearly sustainable energy output equal to or greater than their power utilization.

4.2. Novelty of technology

Since most local companies in the zero-energy construction sector lack technical engineering capabilities, research as well as production of novel products and facilities remain insufficient, and the implementation of new technology is focused mainly on international requirements. Furthermore, for most countries, the size of related enterprises is limited hence unable to meet standardized and automated production criteria. Any energy-saving appliances and construction materials that are highly productive would depend on imports [210]. Therefore, in the building of zero-energy structures in China, increasing potential of independent science and market development [211].

4.3. Public sensitization

Although the advancement of zero-energy buildings is limited and the policy funding for zero-energy demonstration projects is inadequate, social effect of zero-energy buildings in most countries is marginal [212]. Consequently, since they have insufficient knowledge of zero-energy structures, many property developers as well as user groups remain generally ignorant of energy efficiency. Zero-energy structure is also a recent idea that hasn't expanded in many countries globally [212]. Zero-energy structures are also a recent idea that has not yet been commercialized in most part of the world. Zero-energy buildings are generally viewed as expensive, making it impossible to encourage zero-energy buildings globally.

4.4. Formulation of policies and incentives

Despite the progress of zero-energy buildings being limited, policy for funding of zero-energy demonstration projects is inadequate hence making the social impact of zero – energy building highly insignificant. Again, since they have an insufficient knowledge of zero-energy buildings, most stakeholders as well as user groups remain generally ignorant of energy efficiency. It is importing that governments across the group supports the growth of zero energy building by giving some tax incentives and rebates to encourage more investors into the sector to accelerate its commercialization.

5. Conclusion

Zero energy structures are designed to limit the energy consumption of a building as well as improve the energy efficiency of the entire structure. This novel construction evolution is perceived by the scientific community as the future for sustainable buildings. The concept is currently under various developmental stages subject to the country being considered. This is due to key issues pertaining to the absence of incentives and policies to draw more investors into the sector, some of the technology being novel hence will require further rigorous research into the area, public perception in terms of cost of zero energy buildings as well as unstable public sensitization of zero energy structures. It is therefore suggested that when designing criteria and recommendations for zero-energy structures, consider national requirements and the attitudes and activities of residents. Similarly, it is important to study from effective lessons as well as apply emerging technology adopted in most advanced countries to sustain their companies' capacities for technical advancement, encourage manufacturing improvements, as well as eventually form a structured and commercialized zero-energy building development structure. Again, it is necessary to enhance the effect of zero-energy buildings by raising public consciousness of energy efficiency as well as encouraging emerging technology and goods that conserve energy. Furthermore, widen the size of zero-energy buildings on the market and improve the sustainability of the industry through the formulation of appropriate incentive policies and enhanced financial supports. Finally, it is imperative to provide scientific as well as technological guidance for zero-energy building growth by growing investment in basic zero-energy building science.

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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