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Sustainable energy performances of green buildings: A review of current theories, implementations and challenges

AmirHosein GhaffarianHoseini [a,*], Nur Dalilah Dahlan [a], Umberto Berardi [b], Ali GhaffarianHoseini [a], Nastaran Makaremi [a], Mahdiar GhaffarianHoseini [c]

[a] Faculty of Design and Architecture, Universiti Putra Malaysia (UPM), Malaysia
[b] Civil and Environmental Engineering Department, Worcester Polytechnic Institute, MA, USA
[c] Faculty of Environmental Design (EVDS), University of Calgary, Canada

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ABSTRACT

This study targets to elucidate the essence of sustainability in green building design implementations. In this regard, the study draws attention to the sustainable energy performances of green buildings to identify the influential parameters based upon the contemporary successful accomplishments. The study elaborates on the contemporary trends and applications of green building design and the respective impacts on sustainable developments. As a result, the analytical review confirms that the sustainable energy performance of green buildings has been transformed to a sensible and practical resolution to alleviate the CO2 emissions and diminish the building sector energy consumption. In addition, with view to the current challenges and barriers, the study concludes that; it is still crucial to identify and develop efficient energy solutions associated with green buildings for addressing the future energy demands. Likewise, the findings highlight that the sustainable energy performances associated with integrated technologies and renewable energy systems are still intertwined with significant challenges related to the fundamental parameters of cost, maintenance, and operation. In conclusion, the contemplations of the research findings are recommended to be taken into consideration by architects, engineers and developers for the development of future eco-cities with an explicit viewpoint towards developing greener and smarter built environments.

Contents

1. Introduction

Sustainable architecture and green design have become one of the most widespread areas of focus in the scholarly studies related

* Corresponding author. Tel.: +60173178104.
E-mail address: Amirhosein_ghaffarian_hoseini@yahoo.com (A. GhaffarianHoseini).

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to build environments. Accordingly, with view to the environmental assessment and energy performance of buildings, it is vital to develop an overview of current theoretical perspectives, trends, applications and constraints towards the development of green environmentally sustainable buildings. To confirm that, previous studies put forward a theory representing that the performance of green buildings is substantially related to the level of their environmental assessment, thus, versatile studies highlight the necessity of the identification and consideration of sustainable energy performance indicators in the environmental evaluation and any green implementations. In this regard, the building energy efficiency, the thermal performance of buildings and the material efficiency are considered as significant parameters of sustainable energy performance indicators to be fully taken into consideration during the performance evaluations [1]. According to the study by Joelsson [2], with view to the effectiveness of green buildings towards decreasing the use of energy and its negative impacts on the environment, there are fundamental strategies including 'reducing the energy demands', 'enhanced energy efficiency' and 'application of passive design techniques'. Likewise, the utilization of appropriate building envelopes is influential in more than half of the embodied energy distribution in a building, particularly in residential buildings [3].

1.1. Renewable energy applications in green buildings

It has been internationally recognized to promote innovative approaches for mitigation of carbon dioxide (CO2) emissions due to energy consumption associated with building construction and operation. In view of that, the energy performance of green buildings has an immense effect on the sustainable development of the built environment. According to Kothari [82], 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 substantial 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 [82].

Reviewing versatile studies with focus on the concept of green buildings [1,2,3,83,84,85,86,87,88,89], the study demonstrates that the green buildings (including low energy, ultra low energy and zero energy buildings) are significantly 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.

With view to the sustainable energy performance of green buildings, the appropriate application of renewable energy supplies in buildings is a fundamental criterion. In this regard, solar sustainability systems have always been a key factor towards development of green buildings. Respectively, the study by Esen [90] performs a theoretical-experimental study on the cylindrical phase change storage tank connected to a solar powered heat pump system as represented in Fig. 1.

The study reveals a significant technique towards development of sustainability, hence improving the accuracy of respective measurements through development of a corresponding model. Furthermore, the study by Esen [91] develops and analyzes the performance of a solar cooking system utilizing vacuum-tube collectors with heat pipes containing a refrigerant as working fluid as shown in Fig. 2. Cooking ability was obtained while highlighting that the respective cooking time is dependent on the collective selection of refrigerant, meteorological conditions and constructive parameters. Eventually, the significant efficiency of the fabricated cooking system compared to the conventional concentrators and box cookers was proven specially in case of preheating the system.

Solar connectors have been utilized as a main component of green progressions. The respective research by Ensen [92] experiments the effect of utilizing dissimilar refrigerants on the thermal performance change of a two-phase thermosyphon solar collector. Refrigerant-charged domestic hot water systems can be simply manufactured through encompassing general flat-plate solar collectors while providing superior energy deeds. Therefore, it is recommended to exploit the respective results in further design and development of solar domestic hot water systems.

Cooling and heating systems are considered as a major focus point of recent researches related to green buildings. The study by Ensen [93] accordingly examines the energetic and exergetic effectiveness of ground-coupled heat pump system for heating applications. This research proves that significant improvements

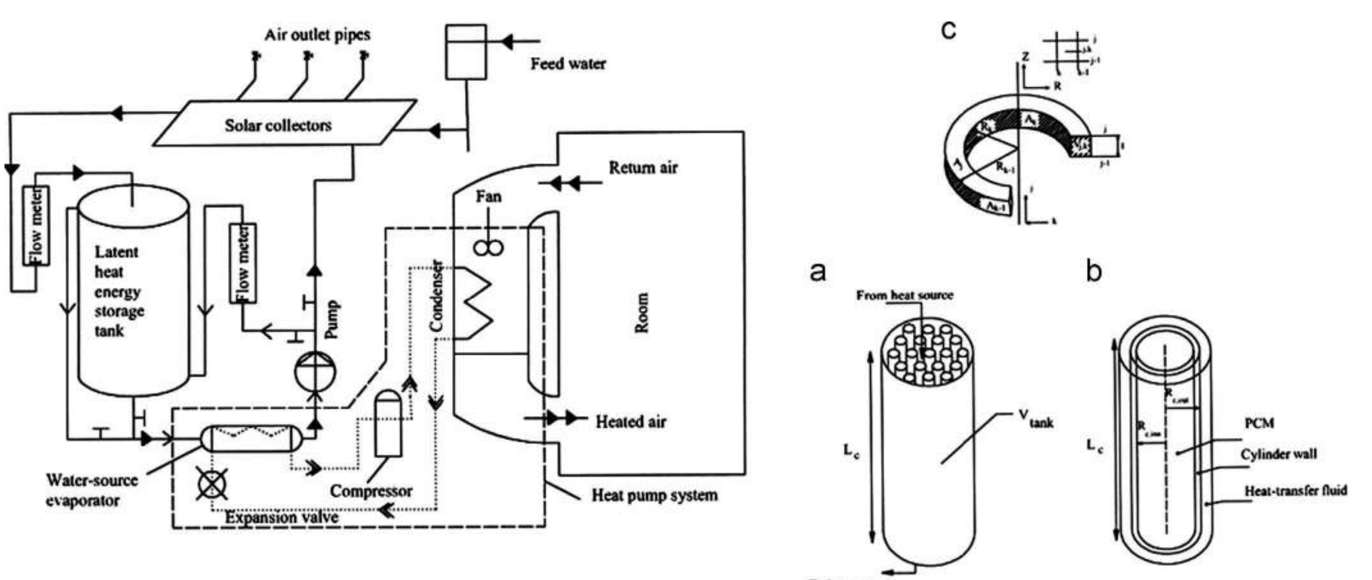

Fig. 1. The proposed system details [90].

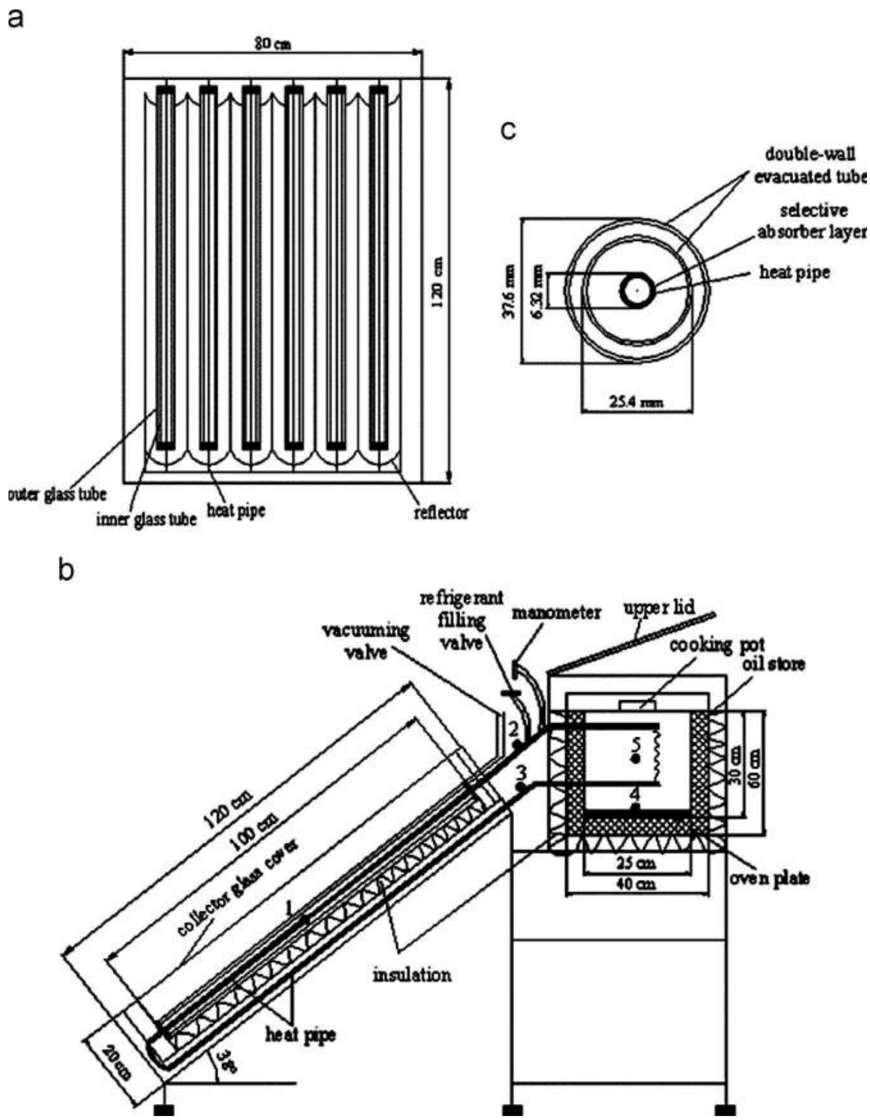

Fig. 2. The proposed system details [91].

of exergy efficiency can be obtained while focusing on alterations of the source temperature due to the fact that energy content of a substance is practically just down to the ecological circumstances.

Innovation has played a significant role towards noteworthy contributions within the field of green building intensification. Correspondingly, the study by Ozgen [94] developes a method for slotting in an absorbing plate prepared from aluminum cans into the double-pass channel in a flat-plate solar air heater to considerably enhance the collector efficiency through escalating the fluid velocity and improving the heat-transfer coefficient between the absorber plate and the air. Therefore, their study supports the likelihood of performing various experiments to discover the effect of versatile variables on the effectiveness of solar air heaters.

Green developments are capable of being implemented in various platforms. The study by Balbay [95] accordingly proposes an alternative methodology for avoidance of snow on bridges and pavements. They utilize a ground source heat pump (GSHP) while supporting its functional effectiveness while utilized in Turkey. The respective system is capable of preventing various accidents from occurrence accordingly. Consequently, it is highly recommended to consider the application of renewable energy technologies for development of future eco-cities. It is denoted that the application of renewable energy technologies could be considerably beneficial in terms of social, environmental and economic concerns. Reviewing the recent scholarly attempts, the main concentration is on the utilization of wind power generation and the use of solar energy with view to the solar photovoltaic and solar thermal energy systems, however, it is still crucial to look into the circumstances of developing new renewable energy generations.

2. Sustainability in built environments

2.1. Introduction

It is believed that 21st century cities must be greener and smarter; hence, promoting sustainable cities has become a key issue for many developing countries. The concept of sustainability is a broad global issue comprising various interrelated studies about people, the environment and society [4]. The significance of sustainable cities could be elucidated by identifying the role of sustainability. Indeed, this sustainability represents a new approach that embraces the concepts of 'green infrastructure', based on a rethinking process designed to link the entire implementation of current cities to the environment, technology, the economy, society and people. It is ultimately concluded that sustainability encompasses three fundamental constituents as environmental, socio-cultural and economic sustainability while the respectively mentioned components are substantially bound up with the circumstances of the enhancement of well-being for the inhabitants as represented in Fig. 3 [4,5].

2.2. The essence of sustainability

For emphasizing the substantial negative impacts of buildings on the environment, a comprehensive analysis [99] represents the respective impacts in US as shown in Fig. 4 which is claimed to be very similar in other developed countries. The energy consumption and the gas emissions are therefore the most considerable negative consequences which require innovative solutions.

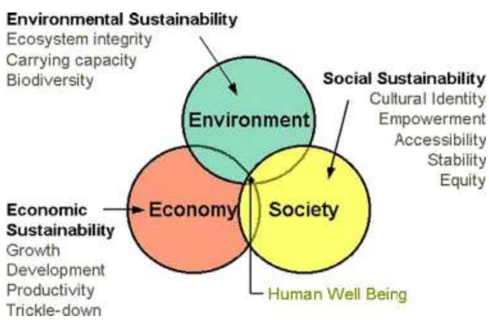

Fig. 3. The Basis of Sustainable Developments [5].

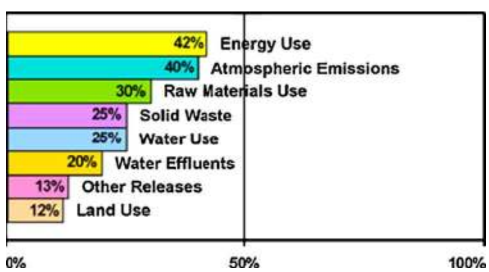

Fig. 4. The Environmental Impacts of Buildings [99].

In essence, sustainability of built environments is recognized as a holistic approach to the adaptation of environmental, economic and socio-cultural concerns in the design and built evolution of architecture. Sustainability trends also encompass economic competitiveness specifically while considering hybrid energy systems [6]. Sustainability can also be achieved through consideration of respective features during the early stages of conceptual design process [7]. A sustainable built environment is achieved once the local attributes of a region, in terms of the aforementioned issues, have been considered during the entire implementation process. Recently, the consideration of natural resources and energy conservation has become a global issue as a result of the global warming, climate change and the incompatibility of natural resources and energy demand due to the depletion of energy resources. Various studies have been carried out in relation to this subject, focusing on the concepts of energy maintenance, embodied energy and renewable energy resources, leading to the concept of the green sustainably built environment [8,9]. Research by Omer [10] argues the necessity of green built environment development, stating that 40% of the entire energy consumption around the world is linked to buildings. This study demonstrates the substantial importance of environmental sustainability within green built environments for striking a balance between energy demands and energy resources. With regards to the significant role of green buildings on sustainability of future cities, it is important to pay sufficient attention to the sustainable construction. Thereby, the sustainable construction criteria must be introduced to the architects and developers in order to be used in the entire cycle of construction process of green buildings. The major criteria for sustainable construction are introduced by Kibert [11] and accordingly, reducing the resource consumption, reusing the resources, utilization of recycled materials, conservation of natural environment, removing toxic, considering the economic efficiency, and reinforcing the quality are substantially recommended for ensuring sustainable construction. Meanwhile, it is deduced that the main sustainable key factors for sustainable construction are encompassing four main parameters including reduction

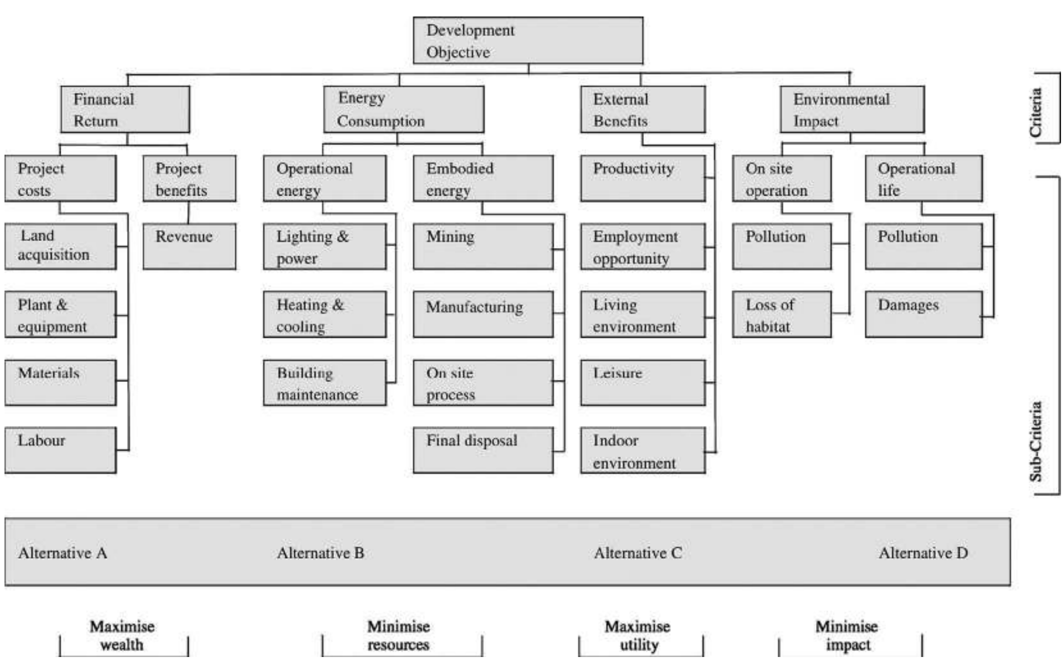

Fig. 5. Key Factors for Sustainable Developments [12].

of environmental impacts, decreasing the utilization level of resources, increasing the utility, and exploiting the economic considerations [12]. The respective sub-categorize of the aforesaid key factors for sustainable construction are presented according to the Fig. 5.

A critical task is also to educate the users towards the importance of sustainable design for reducing the energy consumption level of buildings and their harmful influence on the natural environments. Ultimately, it is highlighted that the sustainable buildings must be developed based on a clear understanding of the main targets of sustainable developments for a low-carbon future as elaborated in Table 1 [13].

3. Sustainable energy performances of green buildings

3.1. Background

Back to US Congress 1992 towards assessment of building energy efficiency, there has been attempts to educate the professionals and ordinary people towards the considerable substance of building energy, level of consumption and conservations for future. The study states that this level of consumption and conservation is highly correlated with technological innovations, technology adoptions, user's lifestyle, economic growth, etc. In regards to the significant importance of this research, it is repeatedly cited that approximately 20–40 percent of the entire energy consumption in developed countries (40 percent in Hong Kong, 37 percent in US, 39 percent in UK, & 31 percent in Japan) refers to the energy usage of buildings [14]. Globally, this high level of energy consumption leads to environmental crisis including the climate change, global warming, lack of energy resources, difficulties in energy supplies, and ozone layer deterioration [15]. Hence, it is prudent to express the severe necessity for analyzing the energy consumption level of buildings and to innovate new solutions for achieving sustainability in built environments. Referring to the role of materials, the use of kenaf-fibres insulation boards is highly recommended for application in green buildings according to the study by Ardente [16]. Highlighting that kenaf could absorb a high percentage of produced CO_2, it could be widely used for thermal insulations. In regards to the mentioned values, according to the Table 2, the energy and environmental performance of kenaf boards are compared with the other alternatives.

Table 1
Main Targets of Sustainable Developments, Developed by [13].

1	Resource efficiency
2	Energy efficiency (Including greenhouse gas emissions reduction)
3	Pollution prevention (including indoor air quality and noise abatement)
4	Harmonisation with environment
5	Integrated and systemic approaches

3.2. The implications of sustainable energy performance

Recent scholarly studies have shown the implications of sustainable energy performances for green buildings and accordingly, the concept of zero energy building (ZEB) has been developed to ensure considerable reduction of energy consumption, gas emissions and the respective environmental impacts. ZEB is not a conceptual prototype but it is becoming a substantial basis of sustainable energy determinants [17]. With reference to US Energy Independence and Security Act of 2007 (EISA 2007), half of the entire commercial buildings in US must be in comply with the standards of ZEB by 2040 while it will applicable to the entire commercial buildings in US by 2050 [18]. Referring to the European Energy Performance of Buildings (EPBD), as of 2018, the respective buildings owned by public authorities or the buildings used by public sectors must be in line with ZEB standards while from 2020 it will be applicable to all new buildings [19]. The aforementioned targets represent the critical necessity to consider the zero energy criteria for ensuring enhanced energy performances of buildings. In order to provide an explicit comparison between the zero energy buildings and the other types, the developed graph as shown in Fig. 6 confirms the

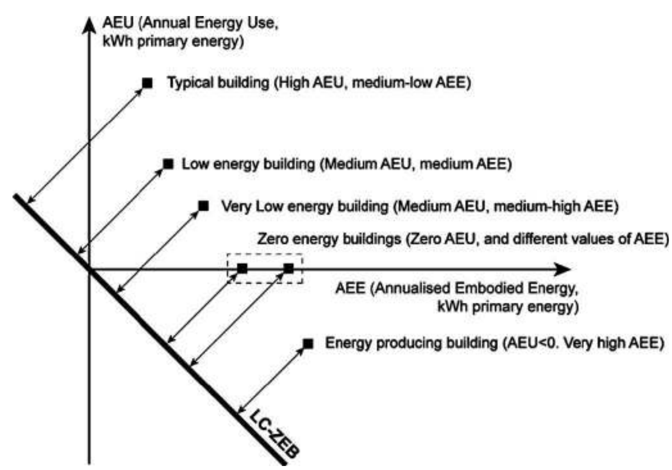

Fig. 6. Comparison between Different Types of Energy Buildings [20].

Table 2
Energy and Environmental Comparison, Developed by [16].

		Kenaf	Stone wool	Flax	Paper wool	PUR	Glass wool	Mineral wool
Energy consumption								
Energy use	MJ	28.4	17.4	26.9	11.8	57.6	39.9	25.0
Feedstock, fossil	MJ	8.8	2.5	7.5	0.4	36.0	7.4	0.2
Feedstock, renewable	MJ	22.2	0.9	15.3	14.0	0.0	0.0	0.0
Total	MJ	59.4	20.8	49.7	26.2	93.6	47.3	25.2
Environmental impact indexes								
Global warming potential	kg CO_{2eq}	3.2	1.45	2.36	0.82	3.2	2.2	1.7
Acidification potential	g SO_{2eq}	27.4	12.3	17	5.5	27.9	8.4	4.9
Nutrification potential	g PO_{4eq}^{3-}	2.4	1.16	1.22	0.7	2.94	1.30	0.8
Photochemical ozone creation potential	g C_2H_{4eq}	2.2	4.6	0.5	0.2	1.4	2.5	3.7
Water consumption	kg	10.7	3.9	5.7	0.8	297.7	27.0	25.6
Wastes								
Total wastes	kg	2.0	0.054	0.122	0.032	0.32	6.6	2.7

significant difference between the respective types [20]. While acknowledging the effectiveness of low energy buildings, the study represents that it is essential for governmental sectors and policy makers to consider the ZEB concept for the future energy targets of cities developments.

3.3. The evaluation of building performance and energy use in green buildings

To provide a clear understanding of the energy consumption process in buildings and the respective relationship between the building and energy grids, the following Fig. 7 is presented. Furthermore, the concept of net ZEB balance is presented through Fig. 8 [21].

According to Wang [22], the evaluation of energy use in a building and the respective level of efficiency could be carried out based on a careful review of the energy performance of buildings. Referring to UNEP and EPA [23] and Wang [22], energy efficiency is defined as "*using less energy without compromising the performance of the building*" while energy performance is defined as the quality of building towards energy consumption. To assess the energy performance of buildings, there are six substantial areas of focus encompassing climate, building envelope, building services, user's attitudes towards energy consumption and indoor environmental quality [22,39]. The study by Juan [14] encourages improving the existing buildings to comply with the main parameters of sustainable energy performance indicators in order to improve the energy performance for reducing the energy consumptions.

Thus, considering the consequences of CO_2 and NO_X emissions on environments, sustainability in buildings must lead to acceptable building energy performance and looking retrospectively to the identified interrelated parameters, indoor environmental quality, cost efficiency and energy efficiency enable the buildings to reach the acceptable level of performance [10]. From another viewpoint, Chwieduk [24] indicates three main constituents as energy efficient buildings, environmentally responsive buildings and sustainable buildings for reducing the level of energy conservation.

With respect to the evaluation of building performances, the primary energy usage is a significant parameter to be taken into consideration. Referring to the study by Heiselberg [25], the primary energy usages of buildings (except residences) must be calculated in order to not exceed the the following developed equation (A is the heated floor area).

$$\left(95+\frac{2200}{A}\right)\ \text{kWh/m}^2\ \text{year}$$

Nevertheless, with a view to the study of Heiselberg [25] regarding the assessment of building performances in Denmark, for being considered as low energy building representing the expected level of energy efficiency, the primary energy usage must not be higher than the following amount.

$$\text{Class 1}: \left(35+\frac{1100}{A}\right)\ \text{kWh/m}^2\ \text{year}$$

$$\text{Class 2}: \left(50+\frac{1600}{A}\right)\ \text{kWh/m}^2\ \text{year}$$

3.4. Initiatives in sustainable energy conceptualization

One of the most fundamental factors for successful sustainable developments is an accurate balance between energy demands and energy supplies. The following graph as represented in Fig. 9 delineates the inconsistency between the energy demands and supplies in a selected building in UK with 48 hours of focus [26]. Accordingly, meeting the respective balance is essential for improving the sustainable energy performance of buildings.

It is also vital to investigate the substantial criteria for sustainable energy as a basic concept for sustainable developments. Thereby, the respective criteria are deduced to have six main constituents as shown in Table 3 [27].

Likewise, considering the significant role of renewable energy as per discussed, the most widespread types of renewable energy and the respective advantages are clearly highlighted in Tables 4–6.

In this regard, versatile energy evaluation systems were developed (including LEED, BREEAM, EQUER, QUANTUM, CASBEE and ATHENA) in previous years in order to contribute to the

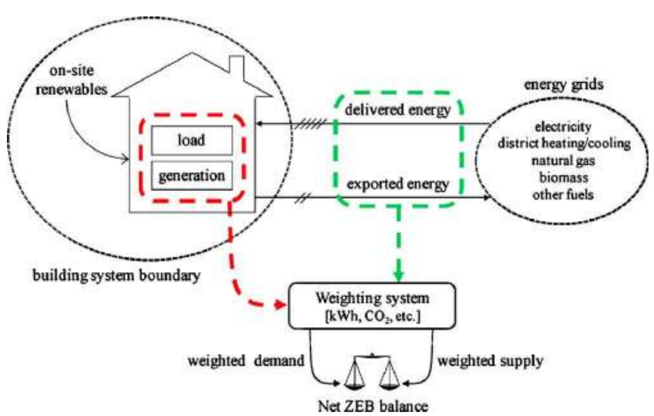

Fig. 7. Connection between Buildings and Energy Grids [21].

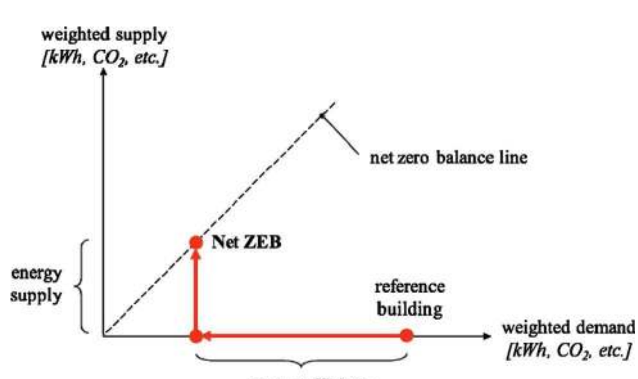

Fig. 8. The Basis of Zero Energy [21].

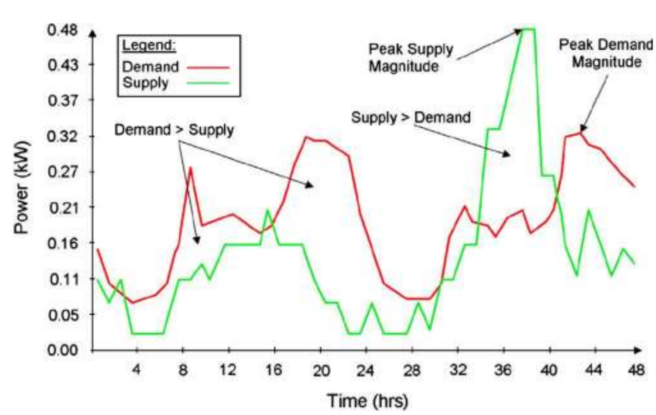

Fig. 9. Analysis of Energy Demands and Energy Supplies [26].

Table 3
Sustainable Energy Performance Indicators, Developed by [27].

No.	Criteria	Explanation
C1	Renewable energy	Encourage and recognize increasing levels of on-site renewable energy self-supply in order to reduce environmental and economic impacts associated with fossil fuel energy use.
C2	Minimum energy performance	Establish the minimum level of energy efficiency for the proposed building and systems.
C3	Fundamental commissioning of the building energy systems	Verify that the building's energy related systems are installed, calibrated and perform according to the owner's project requirement, basis of design and construction documents.
C4	Enhanced commissioning	Begin the commissioning process early during the design process and execute additional activities after system performance verification is completed.
C5	Measurement and verification	Provide for the ongoing accountability of building energy consumption over time.
C6	Optimize energy performance	Achieve increasing levels of energy performance above the baseline in the prerequisite standard to reduce environmental and economic impacts associated with excessive energy use.

Table 4
Versatile Types of Renewable Energy, Developed by [27].

Renewable energy	Description and Benefits
Active solar energy	– Convert solar energy into another more useful form of energy. – This would normally be a conversion to heat or electrical energy. – Inside a building this energy would be used for heating, cooling, or off-setting other energy use or costs. – The basic benefit is that controls can be used to maximize its effectiveness. – Photovoltaic solar panels are in this group.
Passive solar energy	– In passive solar building design, windows, walls, and floors are made to collect, store, and distribute solar energy in the form of heat in the winter and reject solar heat in the summer. – The key to designing a passive solar building is to best take advantage of the local climate. Elements to be considered include window placement and glazing type, thermal insulation, thermal mass, and shading.
Wind energy	– Wind power is the conversion of wind energy into a useful form of energy, such as using wind turbines to make electricity, windmills for mechanical power, wind pumps for water pumping or drainage.
Geothermal energy	– Geothermal energy is thermal energy generated and stored in the Earth.
Fuel cell	– A fuel cell is a device that converts the chemical energy from a fuel into electricity through a chemical reaction with oxygen or another oxidizing agent. Hydrogen is the most common fuel.

Table 5
The Strengths of Renewable Energy Types, Developed by [27].

Renewable energy	Ranking		Feasible use in urban areas and buildings	The amount of fossil fuel consumption reduction	The amount of initial construction cots enhancement	The amount of maintenance and operation costs reduction
	AS	N				
Active solar energy	4.57	1.00		√		√
Passive solar energy	4.43	0.95	√		√	
Wind energy	2.79	0.43		√		
Geothermal energy	1.79	0.11			√	
Fuel cell	1.43	0.00	√		√	

Table 6
The Challengers Towards the Use of Renewable Energy, Developed by [27].

Renewable energy	Ranking		High initial costs	Lack of government support	Lack of public awareness	Lack of technical technology	Lack of proper and required equipment	Poor planning approach
	AS	N						
Passive solar energy	2.38	1.00	4	2	3	3	5	1
Wind energy	2.36	0.97	1	5	6	3	2	4
Active solar energy	2.31	0.89	1	4	3	6	5	2
Geothermal energy	1.75	0.15	1	5	2	4	3	6
Fuel cell	1.64	0.00	1	4	5	3	2	4

enhancement of the level of sustainability in buildings as well as the proliferation of green buildings. Nevertheless, it is inferred that the respective systems are not designed based on universal origin while several sustainable energy performance indicators have not been taken into account during the development of systems [1]. More recently, Green Building Tool (GBTool) was developed to be used for the evaluation of building performance. Nonetheless, other similar studies critically argue that the respective building performance system evaluators must be derived from the locally regional values of each country [28]. Referring to this viewpoint, Hill [29] attempts to utilize the universally developed systems for environmental evaluation of buildings in developing countries to verify if there would be any sorts of incongruity due to the different socio-economics and locally regional values. The results clearly show that it is necessary to develop a local green tool for the respective evaluation before the utilization of universal green tools. According to these contemplations, this study reviews the current theories, implementations and challenges of sustainable energy performances in sustainable buildings. Looking retrospectively, the study by Maile [30] highlights the increasing use of energy simulation techniques for calculation of the building energy performances and the respective thermal comfort conditions. The energy simulation software are predominantly using particular data input including the *building geometry, HVAC systems, internal loadings, operating strategies* and *simulation factors* besides *the weather conditions;* in order to predict the energy performance of buildings and thermal comfort levels [30]. Nevertheless, it is ultimately expressed that it is not just sufficient to predict the level of energy consumption, as the simulation of building energy performances is operative once versatile design solutions are compared according to their features associated with energy performances. Incorporating the simulation of building energy performances with the actual performance of buildings could highly increase the effectiveness of such analysis. On the other hand, there is a new attention to the considerable role of user behavior during the building simulation for ensuring the effectiveness of sustainable design in building according to the user's presence, activities and controls [31]. Similarly, Janda [32] argues that the users have an immense effect on the energy performance of buildings and therefore, this is a critical task for architects to consider the user behavior and attempt towards encouraging the users to contribute to the enhancement of building energy performance. Reviewing other studies, it is reflected that the user's behavior and particularly, careless attitude could significantly increase the level of energy consumption compared to the conventional level (See Fig. 10).

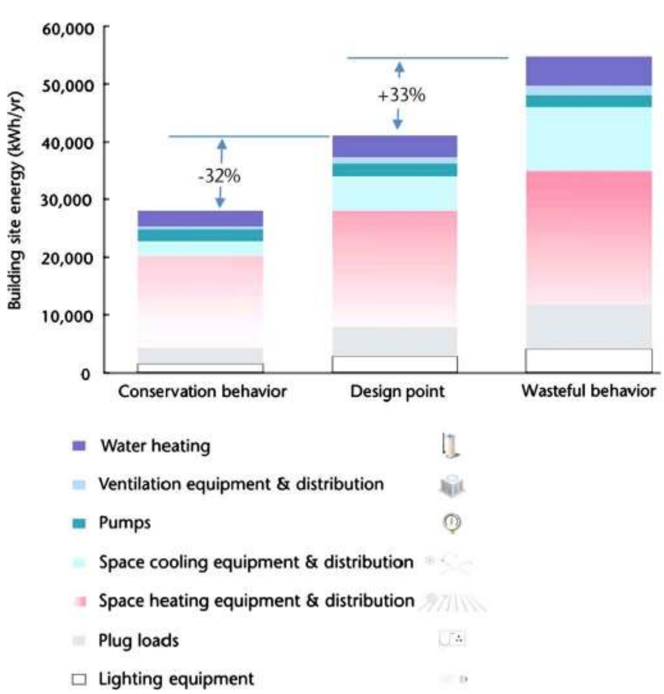

Fig. 10. Increased Level of Energy Consumption based on Careless attitudes [100].

3.5. *Final remarks towards the energy performance of green buildings*

According to the contemplations of this study, it has been continuously discussed and highlighted that buildings consume approximately 30–40 percent of overall energy consumption in developed countries [96]. Thereby, the sustainable energy performance of green buildings encompassing low energy buildings (LEB), ultra low energy buildings (ULEB) and zero energy buildings (ZEB) is principally the ideal focused area of current endeavors. The reviewed theories and implementations as well as the following viewpoints explicitly overstress the substantial necessity to move forward for the development of green buildings as the standardized basis for national and international building policies.

While the majority of the findings derived from the analysis of current scholarly studies are associated with the circumstances of innovating sustainable design approaches for improving the building energy performances, there are studies with other interrelated concerns about energy conservation. Recent research by Masoso [34] describes and analyses selected commercial buildings to confirm that there is a great level of energy wastage by users representing the necessity to take the issues related to user behavior and energy wastage users into consideration.

On the contrary, the study by Schlueter [35] argues that the energy performance simulations are analyzing the current buildings while the respective simulation and analysis of performances must be embodied in the design process of buildings in order to assess the form, material and integrated systems of buildings during the design stage.

With view to the analysis of sustainable energy performance indicators, the study draws attention to the current attempts and researches for development of environmental system models for evaluation of building performances. In this regard, the study by Al Waer [36] looks into the overview of energy performances and therefore, it identifies the main sustainable energy performance indicators as environmental, socio-cultural and economic parameters. Supporting this fact, the study by Mwasha [1] highlights that it is essential to consider the economic and energy efficiency of buildings, besides their socio-cultural advantages as the sustainable building performance indicators. The recent studies by Lombera [37,38], fully concentrate on the sustainable environmental index of buildings and the role of building materials, location, energy usage, construction process and waste management as significant parameters of sustainable energy performance indicator for industrial buildings.

On the other hand, referring to the research by Kibert [11], energy conservation and reduction of energy consumption requires an efficient design for green buildings. It is therefore claimed that this design must primarily embrace the integration of an appropriate building envelope, besides the use of renewable energy resources, and passive techniques for using the natural resources of energy. Referring to the study by Molin [40], the building energy simulation (IDA ICE) confirms that use of low energy buildings that are equipped with passive technologies is highly recommended for decreasing the level of energy

Table 7
Potential Strengths and Challenges of Exergy Systems, Developed by [41].

Reasons for applying LowExx: – Esthetical – Improved indoor climate/comfort – Conservation of cultural heritage – Lower energy use – Use of renewable energy – Energy efficiency – Integration of heating and cooling systems	Opportunities for applying LowExx: – Large scale renovation in combination with: – Acoustic matters – Upgrading the building more luxury - Cooling can be added - Improving indoor climate - Adjusting office to modern IAQ standards:
Limitations/Threats for applying LowExx: – Low price of fossil fuels, low electricity prices – Availability on the market/market price – No checking of regulations – Comfort criteria isn't that high in existing houses – Stick to tradition – Lack of knowledge	increased productivity of employees Moisture problems – protection of art work - Extended use of the building - Flexibility - CO_2 saving potential - Uncertainty of energy prices - Awareness is raising - Energy performance standard (EPS) based on primary energy

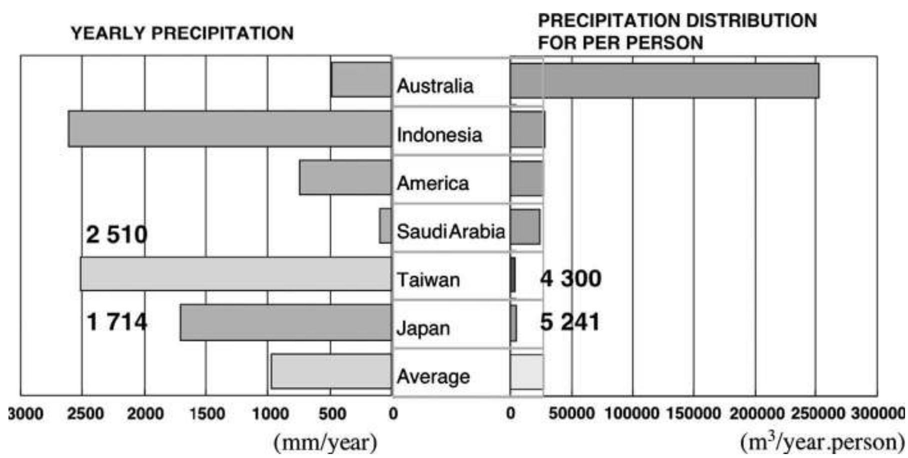

Fig. 11. The Average Rainfall and Distribution Level to the Population for Selected Countries [43].

consumption. Other studies propose the application of low exergy systems for cooling and heating as an influential mechanism for effective sustainable developments. To utilize the low exergy systems, it is vital to be well aware of its potential strengths and challenges. Thereby, Table 7 represents the respective issues which must be taken into consideration during the design, development and application of such systems [41].

Referring to the findings of Schmidt [41], users are highly satisfied with the indoor air quality while residing in houses integrated with low heating systems. At the same time, other studies denote that the low energy cooling systems could provide adequate thermal comfort. These could be considered as positive attempts for enhancement of sustainable built environments. To elucidate the relationship between thermal comfort, building design, outdoor space design and energy performances, it is inferred that the designers must be mindful about the psychological aspects of user's perception towards the preferred level of thermal comfort as fully described by Makaremi [42].

From a different point of view, the study puts forward the concept of water conservation as another phase for the enhancement of energy performances of green buildings. It is denoted that the use of rainwater as water supply could be significantly contributive to sustainable development of buildings according to the average level of rainfalls in countries. The following Fig. 11 represents the average rainfall and its distribution level to the population for selected countries [43]. To elucidate the relationships between storing the rainwater and the consumption of it, Fig. 12 is shown.

Referring to the essence of sustainable developments, the use of renewable energy is a substantially significant approach towards decreasing the level of energy consumption in buildings. The energy which is derived from the natural resources such as wind, solar, rain, etc; is called renewable energy as one of the most influentially common principles [44]. One of the most commonly used integrated renewable energy systems is the solar-based energy application of photovoltaic systems [45]. According to Figs. 13 and 14, the application of photovoltaic panels on roofs, walls and windows and the respective details of structure are represented as the main basic design approaches [44].

It is proposed to consider to utilizing the solar energy based integrated systems for enhancing the sustainable energy performances. A similar study by Zhai [46] confirms the effectiveness of the application of solar energy based systems in china based on the inferences derived from the analysis of an office building as the single case model (See Fig. 15). The respective solar system provides an effective floor heating and air-conditioning as well as the natural ventilation as represented in Figs. 16 and 17 [46].

As another integrated solution, the use of green roofs, which is integrated with solar shading devices, are proposed by Kumar [47] according to the provided detail (See Fig. 18). Supporting the proposed application, the study by Jaffal [48] confirms the effectiveness of green roofs towards indoor enhanced thermal comfort and energy performance of building based on the analysis of a residential case model (See Fig. 19).

It is verified that such application could be influential better thermal performance as well as being contributive to the reduction of energy consumption. The simulation results explicitly represent the effectiveness of the application of green roofs and the integrated solar shading devices as shown in Fig. 20.

With view to the role of roofs in preventing the extra energy consumption, it is necessary to be aware of the appropriate materials to be used for covering and insulations. In this regard, various studies express that vernacular buildings are efficiently design to respond to the natural climate of region and therefore, this study represents the used materials for versatile vernacular settlements in difference regions with view to their energy performance [49] (See Fig. 21).

Likewise, the level of energy consumption for heating, cooling and the overall usage of energy are compared and represented (Fig. 22).

Analyzing a sample of zero energy houses in UK, it is identified that there are three main constituents including solar hot water system, as well as lighting and space heating systems. The use of solar hot water system is deemed to be a widespread integrated approach with substantial influences towards achieving zero energy levels [50]. Within such system, the relations between the solar collector, the temperature sensors, the heat exchanger and heater besides the controller systems are shown according to Fig. 23.

From a different perspective, Kensek [51] proposes the utilization of kinetic facades, which are automatically responsive to the environment as a new solution for sustainable design of buildings. It is highlighted that the efficient design of kinetic facade could provide improved day lighting, natural ventilation and thermal comfort while enhancing the aesthetical features of buildings [51].

In a similar study, the utilization of double-skin facades is proposed by Haase [52] as an innovative approach towards sustainable energy performance of buildings. This additional layer could be influential in the following targets.

- *Decreasing the acoustic impacts*
- *Decreasing the heat gain*
- *Providing natural day lighting*
- *Providing airflows*
- *Responsiveness to the surrounding*

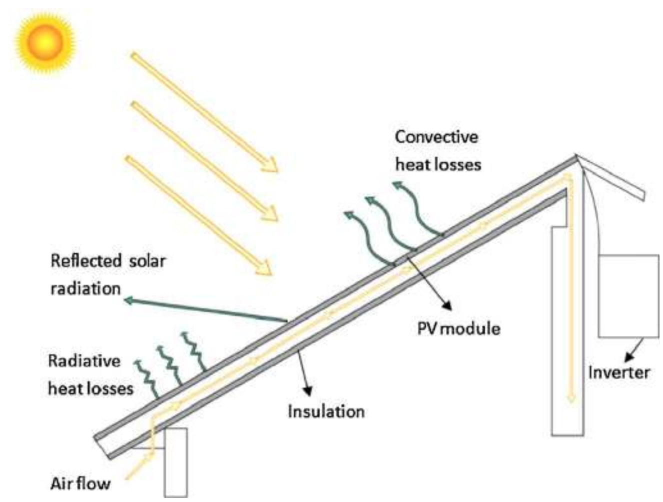

Fig. 14. The Conceptual Detail of Photovoltaic Panels [44].

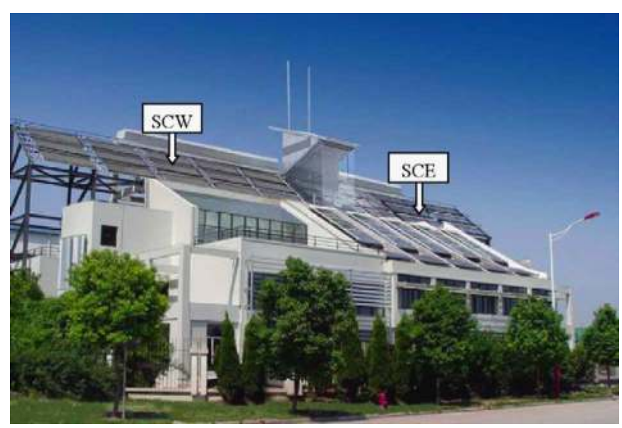

Fig. 15. A Sample of Solar Energy Green Building [46].

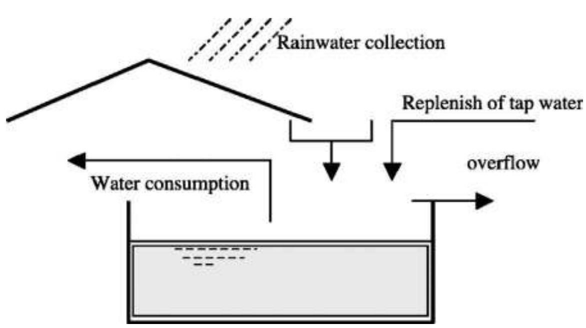

Fig. 12. The Relationship between the Storage and Consumption of Rainwater [43].

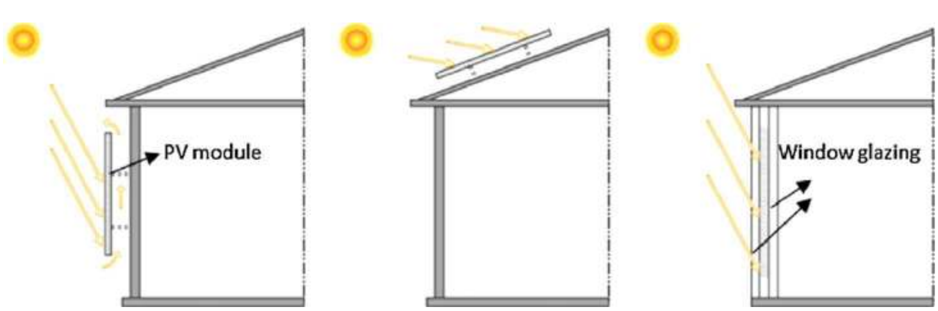

Fig. 13. The Application of Photovoltaic Panels on Roofs, Walls and Windows [44].

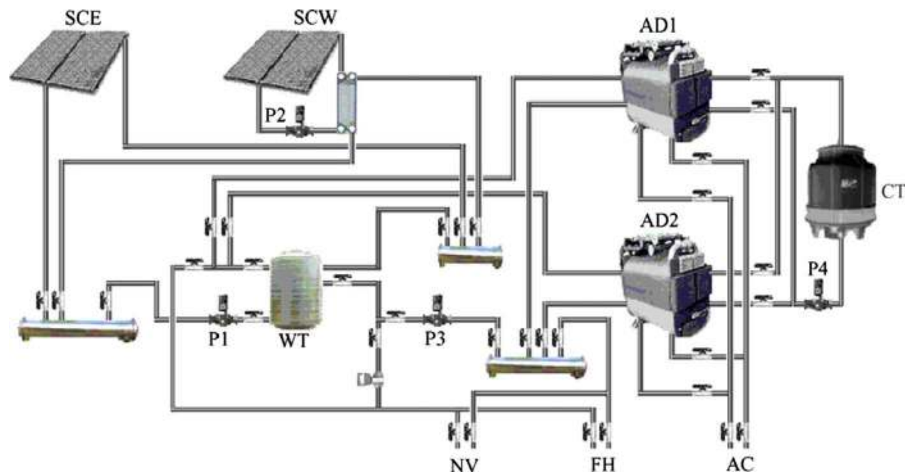

Fig. 16. Operation of Solar Energy Systems [46].

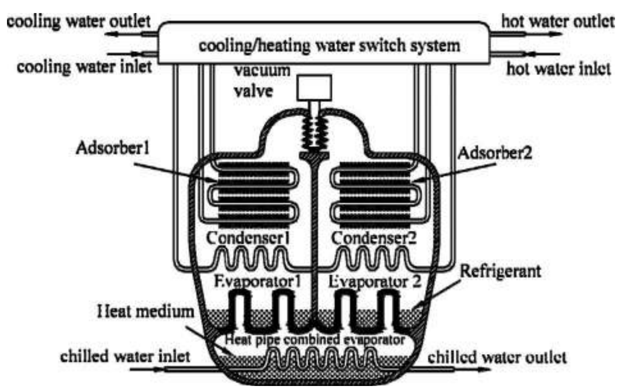

Fig. 17. A Conceptual Detail [46].

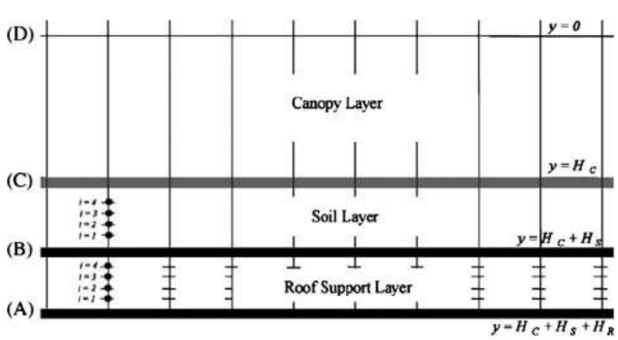

Fig. 18. Conceptual Detail of Green Roofs [47].

According to the following Figs. 24 and 25 versatile types of double skin facades and the circumstances of airflow movements are represented [52].

Meanwhile, use of ecologically sustainable design (ESD) is repeatedly suggested by versatile researchers for ensuring proper sustainable performance for the buildings [11,53]. In view of that, the study by GhaffarianHoseini [4] theorizes that the concept of ecologically sustainable design (ESD) is an approach towards development of green built environments and must be considered as one of the main targets of governmental sectors and policy makers in the creation of a better and greener environment for the population. Moreover, due to the hazard of global

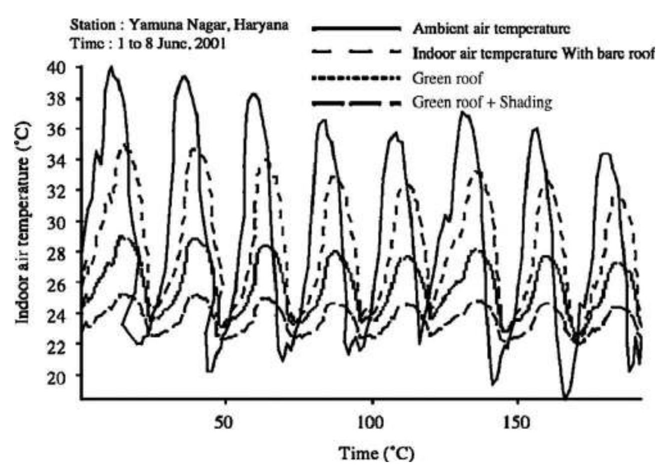

Fig. 20. The Comparison of Indoor Air Temperature [47].

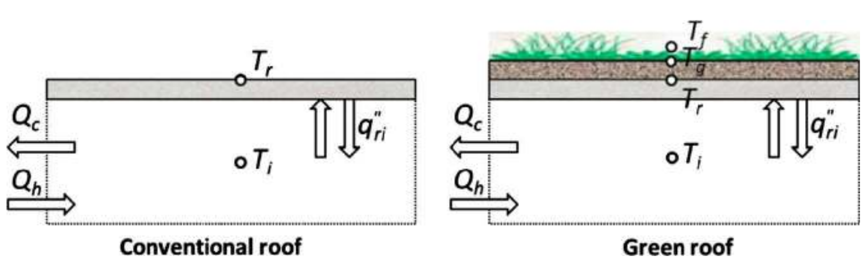

Fig. 19. Conventional Roof vs Green Roof [48].

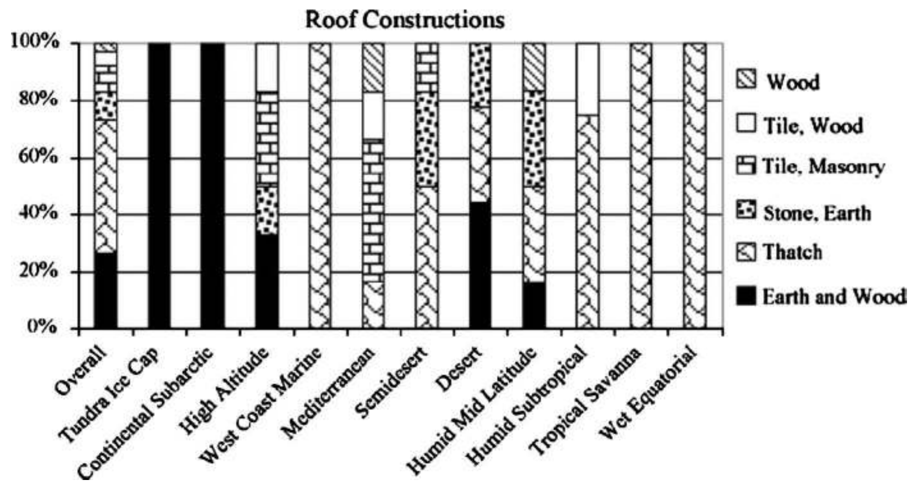

Fig. 21. Use of Roof Materials for Vernacular Settlements [49].

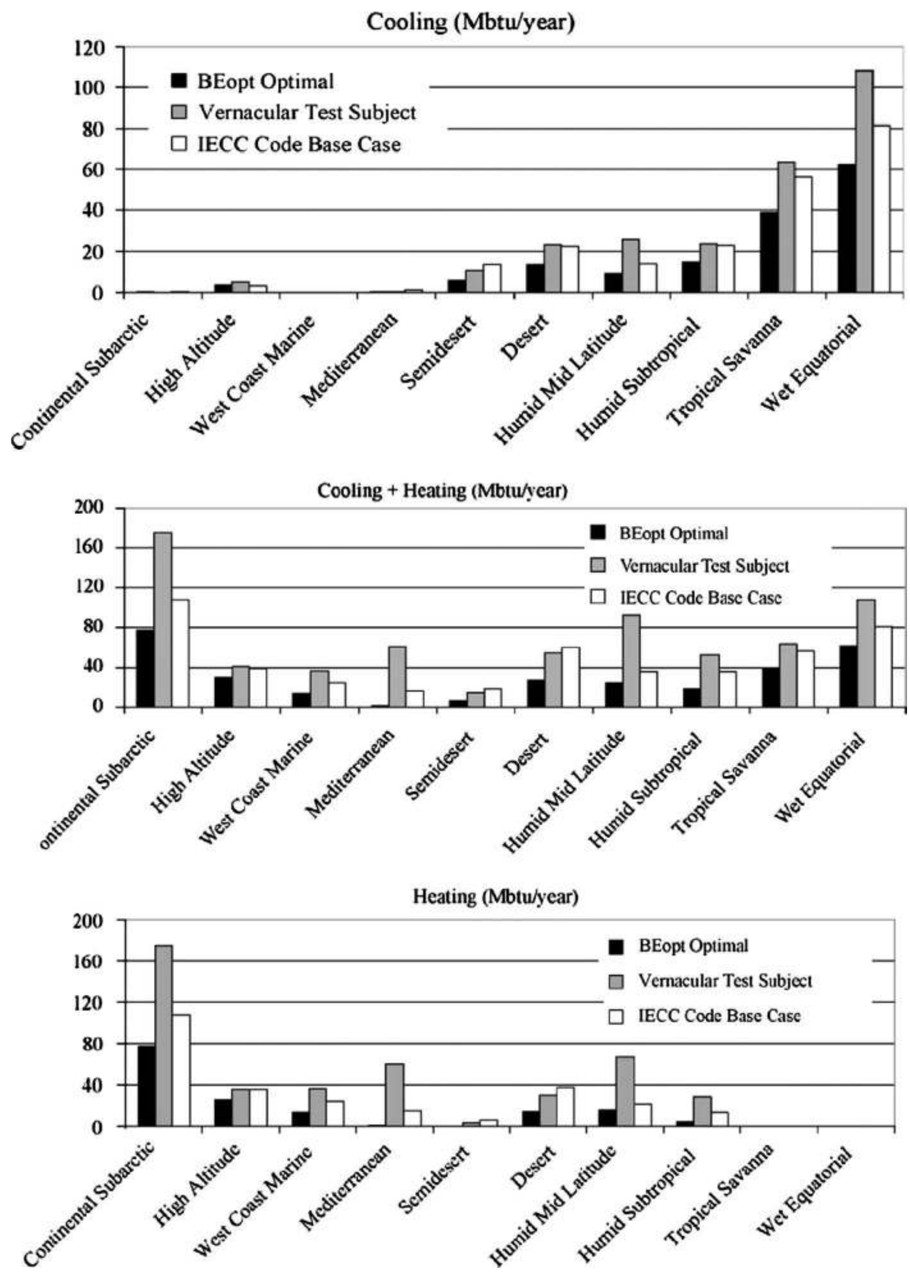

Fig. 22. Representation of Energy Consumption for Heating, Cooling and the Total [49].

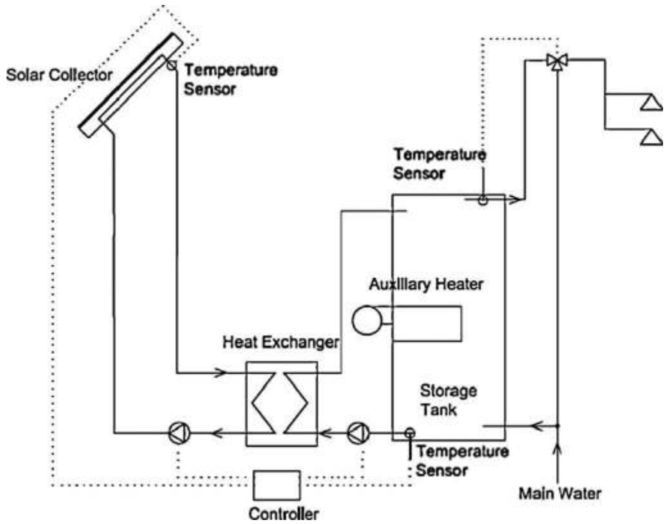

Fig. 23. The Relations between Solar Collector, Temperature sensors, Heat Exchanger, Heater and Controller Systems [50].

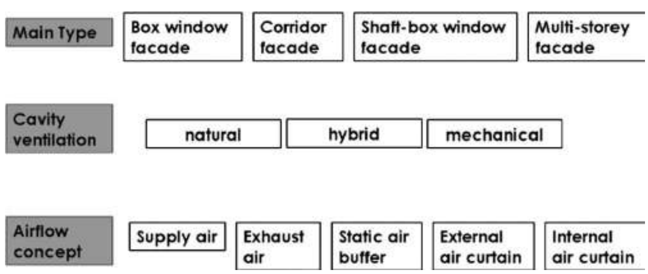

Fig. 24. Versatile Types of Double Skin Facades [52].

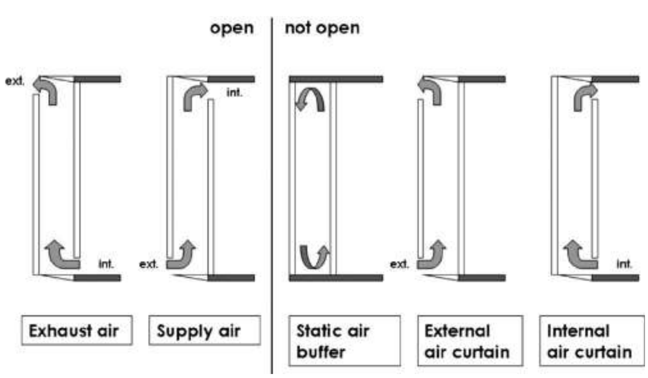

Fig. 25. Air Movements in Versatile Types of Double Skin Facades [52].

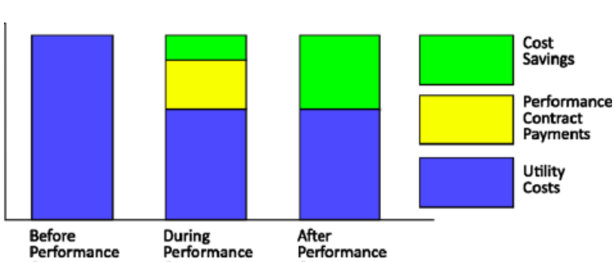

Fig. 26. Energy Performance Contracting (EPC) [55].

Table 8
Operative Factors for EPC towards Sustainable Developments, Developed by [55].

Groups	Factors
External factors	Economic environment
	Social environment
	Policy support
	Nature environment
	Available technology
Project-self factors	Hotel operation status
	Project complexity
	Building age
	Site and location limitation
	Tourism season and operating time limitation
Leadership and team factors	Clients' awareness of to EPC
	Organizing skill of leader
	Team members' technical background
	Communication skill
Sustainable development factors	Clients' and ESCOs' awareness of to sustainable development (SD) theory
	Sustainable development strategy planning
	Control mechanism of sustainable development strategy
Financing factors	Available financial market
	Awareness of financing institute to EPC
	Credit of ESCOs and clients
	Project financial status
Contracting factors	Saving share
	Task and risk allocation
Partnership factors	Trust
	Effective coordination
Project process factors	Develop appropriate organization structure
	Project objectives control mechanism
	Accurate M&V

warming, the integration of ESD into the respective building designs could facilitate reducing the greenhouse effect while developing green sustainable built environments for present and future communities. The term ‘ecological’ is a terminology related to the interactions between two living organ- isms, or the interactions between living organisms and physical surroundings [54]. Accordingly, the relations between the respective two sides must remain in balance while none of the sides takes full advantage or disadvantage. Likewise, in the context of architecture and built environment, it reflects the interactions between human, buildings and the environment. The aforementioned aspects are the criteria for creating ideal sustainable ecological living conditions for the future. This ecological living requires preserving and protecting the natural environment with awareness of ecological footprints. ESD is theorized to be a substantial standard in the modern architectural and construction developments in order to ensure the reduction of negative environmental impacts. Accordingly, the integration of ESD is deemed to become a prominent basis to set criteria for the setting and orientation of the buildings, eco-materials usage, landscape integration design, interior space design, building details and bioclimatic of surroundings [54].

In order to ensure an operative and effective approach for sustainable development of buildings, Juan [14] with particular focus on office buildings indicate five main parameters to be taken into account during the design and construction of buildings. Thus, it is primarily essential to consider the location, and characteristics of the land where the building will be located in with view to its greeneries. Secondly, it is important to consider the energy efficiency of the building with regards to its energy performance, indoor air quality, thermal comfort, daylighting, HVAC systems and innovatively integrated energy saving technologies. Meanwhile, it is implied to consider the significant role of material suitability and the application of recycled materials

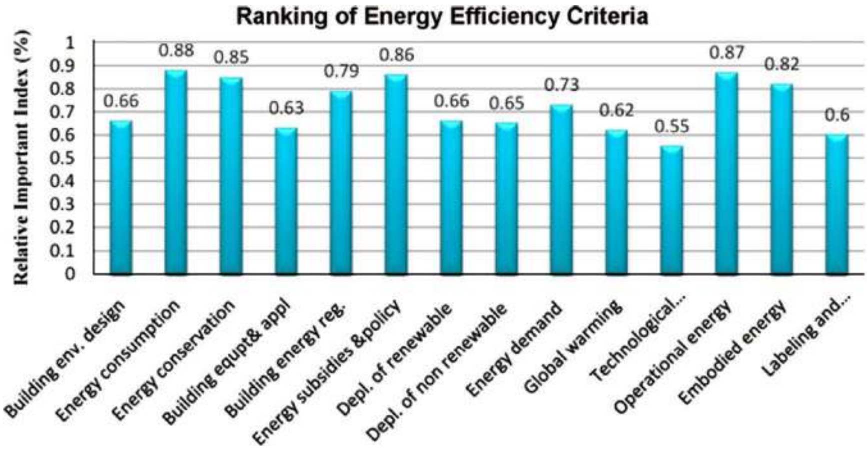

Fig. 27. Energy Efficiency Criteria [1].

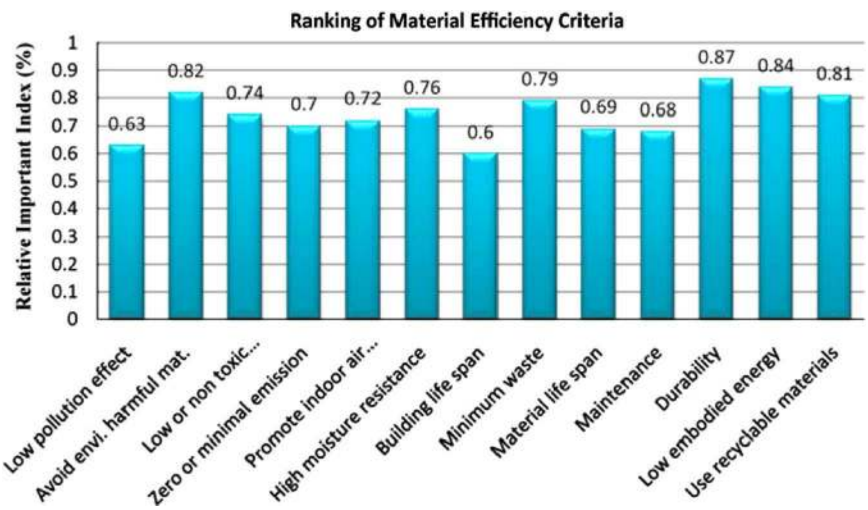

Fig. 28. Material Efficiency Criteria [1].

as well as the effectiveness of wastewater technological approaches and the efficiency of decreasing water usage while enhancing the indoor environment quality. From another perspective, it is highlighted that hotels are one of the main type of buildings with a high rate of energy usage; hence, the application of sustainable development for the sake of better building energy performance is vital for them. The study by Xu [55], discusses about the concept of energy performance contracting (EPC) in China, for ensuring building energy efficiency in hotels. According to the Fig. 26, it is clearly shown that through application of EPC, cost saving will be increased based on the reduction of utility costs. Energy performance contracting (EPC) is a mechanism which was initially developed in North America (1970) and indeed, it is a finance package for guarantying energy saving through the respective designs, installations and services [55].

In view of the application of EPC for sustainable development of hotels, Xu [55] represents the main parameters that are potentially affecting the effectiveness of this mechanism as shown in Table 8. It is recommended to the developers and designers to consider these parameters during their sustainable developments.

The study by Mwasha [1] develops a new ranking system for sustainable energy performances based on the responses of building professionals as represented in Fig. 27. The findings represent that the level of energy consumption is the top-ranked parameter with the highest level of importance index followed by operational energy, energy subsidies and policies. Meanwhile, the study reveals the ranking of material efficiency based on their level of importance index as shown in Fig. 28. This part of finding confirms that the parameters of durability, low embodied energy and avoiding environmentally harmful material and use of recycled materials. In conclusion, the analytical review confirms that the sustainable energy performance of green buildings has been transformed to a sensible and practical resolution to alleviate the CO_2 emissions and diminish the building sector energy consumption. Moreover, with view to the current challenges and barriers, the study demonstrates that it is substantially crucial to innovate and develop efficient energy solutions associated with green buildings for addressing the future energy demands. Meanwhile, the findings highlight that the sustainable energy performances associated with integrated technologies and renewable energy systems are still intertwined with significant challenges related to the fundamental parameters of cost, maintenance, and operation.

4. Conclusions

The study discussed about the essence of sustainability for enhancement of building energy efficiency. The findings clearly represent versatile parameters for improving the energy performances of green buildings. These parameters are derived from interdisciplinary studies with view to the design, construction, maintenance and user studies. It is believed that the proposed solutions for enhancement of sustainable energy performances of buildings could be widely used for the sake of creating environmentally responsive cities [100].

To summarize, the study refers to Berardi [101] with regards to the analysis of recent interpretations on sustainable buildings. Accordingly, the respective study states: “sustainable building is characterized by the following fundamentals:

- demand for safe building, flexibility, market and economic value;
- neutralization of environmental impacts by including its context and its regeneration;
- human well being, occupants’ satisfaction and stakeholders’ rights;
- social equity, aesthetics improvements, and preservation of cultural values.”

In conclusion, green buildings are ranked based on various green building rating (GBR) systems which are diversified in accordance with their different scopes [56] such as the Building Research Establishment Environmental Assessment Method (BREEAM) [57]; Green Star from Australia [58]; the Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) from Japan [59], the Building and Environmental Performance Assessment Criteria (BEPAC) from Canada [60], and the Leadership in Energy and Environmental Design (LEED) from the United States [61]. On the contrary, all BGR systems incorporate the concepts of recyclability and reusability [62]. This section describes different applicable approaches towards these main features within the content of green buildings and energy.

To conclude, a major key component of green building-based design is considered as the capability of electricity generation; cooling and heating applications [63]. Recently, versatile developments such as thermal-powered cooling methodologies [64]; high performance cogeneration systems [65]; and renewable energy source heat pumps [66] have been utilized. Governments contemporarily highlight the mentioned green technologies to promote sustainability [63]. Nevertheless, in order to optimize the building overall performance; combination of renewable energy employment techniques [63,102] and heating, ventilation and air-conditioning (HVAC) methods [67] are advised. On the other hand; utilization of photovoltaic has been widely discussed since last decades [68]. The importance of investment on photovoltaic research was highlighted to be essential for the new millennium [69]. Nevertheless, Although it was proven that; optimized solar cell structural usage (Higher amount of produced energy calculations) is not necessarily achieved based on respective high temperature optimizations [70]; Mousazadeh [71] expressed the inevitable effectiveness of solar cells through representing that; in case of coating 0.16% of the soil on earth with 10% efficient solar conversion systems; 20 TW of power which is almost double the utilization rate of fossil energies in the world would be generated. Thus; the significant importance of exploiting solar cells through photovoltaic implementations is essential [72]. Furthermore, execution of green roofs has been proven to beneficial in terms of rainwater management [73]; decreasing air pollution [74,75]; noise reduction [76]; carbon footprint reduction through photosynthesis [76,77]; and improving the thermal shift through roofs [78,79]. In addition; application of green facades (Vertical green systems) plays a considerably imperative role in fossil energy consumption reduction [80,97,98]. It is also recommended to develop energy-intelligent buildings for the sustainable development of future cities. Referring to reviewed studies and the recent attempts; the energy-intelligent buildings, which are responsive to the building's region, and user's attitude, are inextricably intertwined with the eventual objectives of sustainable energy performances in green buildings [33]. Eventually, the notion of innovation is highlighted to be significantly beneficial within the field of sustainability; green building systems and energy efficiency [81] hence resulting in development of additional subjectiveness to the ongoing research implementations while sustaining the dynamism.

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