Chapter

Solar Energy and Its Purpose in Net-Zero Energy Building

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Abstract

The Net Zero Energy Building is generally described as an extremely energy-efficient building in which the residual electricity demand is provided by renewable energy. Solar power is also regarded to be the most readily available and usable form of renewable electricity produced at the building site. In contrast, energy conservation is viewed as an influential national for achieving a building's net zero energy status. This chapter aims to show the value of the synergy between energy conservation and solar energy transfer to NZEBs at the global and regional levels. To achieve these goals, both energy demand building and the potential supply of solar energy in buildings have been forecasted in various regions, climatic conditions, and types of buildings. Building energy consumption was evaluated based on a bottom-up energy model developed by 3CSEP and data inputs from the Bottom-Up Energy Analysis System (BUENAS) model under two scenarios of differing degrees of energy efficiency intention. The study results indicate that the acquisition of sustainable energy consumption is critical for solar-powered net zero energy buildings in various building styles and environments. The chapter calls for the value of government measures that incorporate energy conservation and renewable energy.

Keywords: net zero-energy building, electricity demand, renewable electricity, bottom-up energy analysis, solar energy

1. Introduction

The general description of a net zero energy building that can be found in the documentation is: "Net Zero Energy Building (NZEB) is a residential or industrial building with substantially decreased energy needs by productivity improvements, so that the balance of power requirements can be provided by sustainable technology." Even so, the researchers note that the "absolute zero energy structure" can be described in many forms, both on the parameter and the standard [1]. This description showed that energy conservation would be one of the techniques to achieve a net zero energy building output. The need for energy efficiency methods in NZEBs was already highlighted in several research sources. For example references of [2]. Focus were put on the preference for power conservation in the development of the NZEB and established the principle: 'first take up demand, then supply,' which implies that, in attempt to reach a net zero energy balance in buildings, it is important, first, to reduce power usage and power losses by energy conservation steps, lighting, ventilation, passive solar energy, high-efficiency appliances, thermal comfort, passive cooling, etc., instead and then using green electricity options to fulfill the energy requirements of buildings. Energy efficiency usually provides cost effective solutions for lowering electricity demand that significantly reduces the scale and thus the expense of the clean energy systems required and associated distributed technology [3].

This chapter aims to analyze synergy among power efficiency and on-site solar energy supply to move toward certain net zero energy quality. The results are taken based on the creation of the Building Integrated Solar Power System and the evidence from two other well-known field researches. The purpose of this study is to demonstrate that energy conservation and sustainable energy production are inseparable solutions and that the inadequacy of each of them has an enraging effect on the ability to reach a net zero energy target.

2. Research methods

Energy modeling is commonly used to estimate future energy consumption or the production of electricity in various industries. Two main types are generally reported in the literature: top-down and bottom-up [3]. Top-down methods utilize collated macroeconomic variables, including historical patterns, to create large-scale relationships between sectors in the economy [4]. The bottom-up studies depend on forecasts focusing on comprehensive technical and cost details from different sub-sectors, reflecting the total energy use of a nation or segment of the market [5]. Although bottom-up methods usually have even more comprehensive and consistent outcomes, the exposure and processing of disaggregated data needed for these models are sometimes tricky and often impossible.

Some studies develop the findings of a regional bottom-up approach that enables energy simulation of building energy usage and on-site solar energy generation with GIS techniques utilizing a variety of geographic information systems (GIS) techniques. GIS platform provides a broad range of methods for capturing, processing, extracting, and visually presenting geographically related results.

This modeling exercise's principal goal is to measure the full feasible hypothetical technological ability of building-integrated solar energy to satisfy the building energy needs and achieve a net zero value of building energy efficiency. The model assumes significant technical (and policy) advances to realize this solar energy promise by 2025. The simulation method, which is discussed in this article, consists of 3 key steps in tandem with various data sources. Although the author's BISE design is the key empirical tool for the findings provided in this section, the other two key components include only some of the data required to draw application provides and are thus defined in far less depth in this study. The mathematical descriptions of such models can be derived from the references seen in **Figures 2** and **3**. BISE method estimates the capacity for building-integrated solar energy supply, together with the findings on building energy usage from 3CSEP-HEB and BUENAS simulations, providing the ability to draw insights as to how much of these energy requirements can be fulfilled by solar energy in various regions and building styles.

2.1 CSEP: model of the HEB

3CSEP model of the HEB was established by the team of researchers (including the author of this chapter) at the Tarbiat Modares University to estimate the future usage of thermal energy building between 2015 and 2050 under a variety of policy-driven scenario. The design's central concept is a performance-based method for building energy consumption research, which views the buildings as a comprehensive structure rather than a collection of individual operating systems. In this method, the input variables of the main model has been the actual final energy efficiency of ideal houses (for each field, weather region, building size, vintage house) per square meter of its floor space obtained by the team of researchers from a variety of different sources recorded in [5]. Some rather building energy intensity levels are then compounded by the corresponding building floor space figures to measure the total energy usage independently for space heating, cooling and heat water in various countries, temperature zones, based treatment and vintages. That floor space has a different measurement formula for industrial and residential buildings that considers typical development activities such as relocation, reconstruction, and new growth, guided by demographic trends and economic growth shifts. This model integrates three scenarios, that imply specific levels of policy commitment in the area of energy performance construction and, accordingly, varying types of buildings energy efficiency in the national housing stock:

- The deep capacity paradigm presupposes an aggressive expansion of quality standards in energy conservation in buildings globally. Building energy efficiency is at the standard of passive design energy output (15–30 kilowatt hour/sqm for air conditioning based on the location).

- Strong performance scenario is poor continuity of current government patterns and small developments in energy quality construction in some developing countries. Built energy efficiency is at the standard of local building codes (100–200 kilowatt hour/sqm for air conditioning systems based on the location).

- Cold performance scenario suggests that the existing state of energy performance in buildings would stay constant throughout the studied span without implementing new policy tools or technical changes relevant to energy efficiency and conservation.

An in depth scenario has been used mainly to study the net zero energy building capacity because it implies substantial increase in power quality required to meet the NZE purpose. The effects of the energy usage from such a scenario are further compared to the projections of the BISE method's built in solar power capacity, as mentioned following.

2.2 Bottom-up energy analysis system (BUENAS) model

The BUENAS model presents the conclusion for energy usage in applications and illumination in the construction industry in order, which along with the findings of the heat energy use of such a 3CSEP-HEB method, render it possible to quantify the overall energy consumption in buildings.

- Lawrence Berkeley National Lab (LBNL) has established the BUENAS model for the end-use energy market scenario in the United States. This plan was sponsored by the Joint Marking of three Association Department.

This model approach produces outcomes for more than ten countries and the European Union with 27 members as a common area, including different energy-consuming goods (excluding appliances, such as TVs, laptops, etc.) in the domestic, commercial and industrial markets. The energy consumption prediction approach in BUENAS is focused on three main factors:

Two main scenarios mean the differences between the two models: Business as usual and best practice scenario. Under its scenario, energy consumption development is guided by market behavior and intensity. At the same time performance, is "frozen", the BP case focuses on catching future impacts of improvement-related policies, predicting that all governments can reach aggressive output goals by 2015. Standards will also have strengthened in 2020, ensuring whether the same degree of progress is attained in 2020 as in 2015 or which a particular goal, known as the new "best possible technology," is met by 2020.

2.3 Building integrated solar energy model

The author of this chapter, which considers different geographic, structural, morphological and climate conditions variables, has developed an alternative approaches Building Integrated Solar Energy model to assess the extent to which energy consumption could be met.

The BISE framework's primary goal is to analyze the highest allowable technical capacity and dynamics of solar power provided by built-in hybrid solar technologies. For this purpose, detailed climate data were taken from the NASA repository for some key variables (ambient temperature, top atmospheric irradiation, global irradiation, humidity data, wind speed, etc.).

The BISE method's additional advantage is exposure to high-resolution climate details, analyzing it via an advanced measurement method, extracting estimates for the future solar thermal and electrical performance of solar technology, and visualizing the estimates. This has been generalized for each area, outdoor environment, and site plan employing the roof area's various estimations to implement solar systems. The usable roof area is calculated by adding roof-to-floor ratios to the correlating floor area figures from the 3CSEP model as well as other access considerations extracted from the reference to compensate for the shaded areas and the gaps filled by roofing facilities. The RTR levels at each zone and buildings style are obtained by Geographic information systems datasets on regional urban development areas produced by Esmaeili Shayan [3] as well as further analyzed by the authors of this chapter utilizing Geographic information spatial analysis and zoning statistical techniques (see [3]). The spatial analysis's main objective is "to meet the demands and relationship issues, taking into consideration the spatial location of the phenomenon under investigation in a direct manner" [6].

While the roof area calculations primarily are using the floor area findings of the 3CSEP method as source evidence, the BISE method's configuration is quite close to that of the 3CSEP model in terms of areas, housing styles, temperature zones, and vintage architecture and simulation horizons. These elements of the layout are listed in more depth below.

2.3.1 Geographic coverage (GC)

In place to encourage a link between the results of the BISE and the 3CSEP designs, the analysis is carried out for whatever divisional division as presented in [7]. These areas of the country have included the following: Western Europe (WEU), Middle East (MEA), Centrally Organized Asia (CPA), Pacific OECD (PAO), Latin America and the Caribbean (LAC), Sun-Saharan Africa (AFR), former the Soviet Union (FSU), North America (NAM), Eastern Europe (EEA), South Asia (SAS), Other Pacific (PAS).

2.3.2 Timetable

The initial GIS data details were gathered for each hour of each year for 5 years from 2001 to 2005, and the 5-year estimate was determined for each level. Such data collection was used in the 2005 base year selected for compatibility with the 3CSEP model. The methodology considers every period and every year from 2005–2050.

2.3.3 End-use of energy

The Building Integrated Solar Energy model argument predicts that solar heat generated by PV/T systems can also be used for water and space heat generation. In contrast, solar electricity is used for lighting, space cooling, and appliances.

2.3.4 Climatic factors, construction vintages, housing styles

The Building Integrated Solar Energy model distinguishes between different types of buildings (residential: single- or multifamily; public and industrial: school, office, hotels and cafes, retail, health care, other housing, or buildings), vintages (retrofitting, modern, new, existing, and advanced retrofitting), seasonal conditions which are the same as the 3CSEP model.

2.3.5 Solar energy technology

The Building Integrated Solar Energy design focuses primarily on building-integrated on-site solar power. These systems can usually be broadly classified into two categories: solar thermal and photovoltaic (PV) systems. The latter produces heat, while the latter generates power. As the house needs both, maximizing the development of solar energy on the construction sites may demand the configuration of both kinds of processes. This might induce the "battle on the roof" (not enough space on the roof for both PV and solar collectors to meet energy demands) and lead to increased costs, esthetic problems, and a boost in the energy of the solar systems [3]. While solutions to this challenge currently exist by integrating solar systems with other innovations (e.g., photovoltaic + heat pump), since this chapter emphasizes exclusively on solar power, a thermal + photovoltaic hybrid solar system is perceived to be one of the most "fully solar" approaches to this problem. A solar hybrid photovoltaic/thermal system (PV/T system) is a mixture of photovoltaic (PV) panels and solar thermal elements. PV/T is a system that allows PV cells as a heated substrate to transform radiation into electric power; the solar thermal collector converts solar heat into electricity and removes waste heat from the PV module. These elements' goal is to use the heat produced in the PV panel to generate not only electrical but also thermal energy [8]. Such a hybrid setup generates an electrical utilization of the system as heat extraction and utilization reduces the systems' temperature and thus improve their performance. Configuration of photovoltaic plus thermal systems provides an opportunity to significantly increase the generation of solar energy for various end-uses compared to separate systems in the same roof area. As this chapter focuses on estimating the maximum possible technical potential of renewable energy in building structures, photovoltaic plus thermal technology was considered to be the most efficient model-long exercise workable alternative. In order to evaluate the hypothetical technological potential of built-in solar power, it is expected that photovoltaic plus thermal systems will be mounted on the available roof places during the construction or renovation of structures, beginning with some of those feasibility studies in 2014 then slowly expanding the number of installations before they become standard practice for all retrofits and housing developments by 2025.

The Building Integrated Solar Energy model assumes that thermal and electrical solar power production are modeled differently that use the same hourly in days' radiation exposure measured on 1 m^2 of the solar system site, but specific thermal and electrical formulations and performance variables and losses of different systems (see [3]).

2.3.6 Strategic partnership of electricity and energy performance in buildings

The Building Integrated Solar Energy model calculates the amount of solar renewable energy (electrical and thermal) produced in any buildings on an everyday hourly basis by BIPV/T systems, which is further compiled on a monthly basis. The present version of the product suggests the absorption of generated solar energy power within one period (month or more) at the rate of each city, buildings form, and temperature area, that makes it possible to equate the monthly amounts with the monthly projections of construction power consumption under the shallow scenario for space cooling, water heating and space heating and also with the Bottom-Up Energy Analysis System case formulation for home appliances. This scenario did not include industrial buildings. Consequently, the expectation that nearly 50 percent of cost savings attributed to energy efficiency changes in all end-uses should be reached by 2050 has been created. To achieve monthly results for equipment and lighting, it was presumed that these users would consume the same quantity of electricity every month. Monthly study results determined by the Building Integrated Solar Energy framework for the possible use of solar thermal energy have been evaluated by comparing to the construction energy consumption statistics for water heating and space heating. In contrast, the possible use of solar power for appliances and lighting, cooling was contrasted. Such a similarity forms the basis for assessing the extent to which advanced energy-efficient buildings with energy technologies can move toward the net-zero emissions energy systems target.

3. Calculation of the Shayan model

The novelty of the Building Integrated Solar Energy model integrates a comprehensive measurement process (acceptable for calculating the efficiency of the particular solar system) for hourly solar energy production per 1 m2 of the surface of the solar system and comprehensive coverage of the effects. The shayan model incorporates various forms of solar radiation, considering the tilting of the device (going to assume optimal tilting), the orientation of the earth, altitude, time of year, and location of the sun. The approach described here for measuring the energy obtained by one square meter of the solar system every hour has been modified from [1, 8–11]. There are many measurement benchmarks in the method. First, the total roof size was calculated in each area, outdoor environment, and building, which is mainly contributed by applying the accessibility variables.

3.1 Climate zone, building style, and area

$$AR = FR_{ratio} \times AF \tag{1}$$

where AR is area of roof and FR_{ratio} is floor of roof ratio and AF is area of floor. The Area Calculator (can be free use in: https://www.calculator.net) tools calculate

Figure 1.
The complex shape rooftop [3].

the area of the roof and the number of resources necessary to design the roof of the building. The "Home Foundation Field" is the land region that the building covers, which can be measured for more complicated forms using the Area Calculator. The measured area is an estimate only. In situations where a rooftop has a complex shape, such as **Figure 1**, calculating the measurements and areas of each part of the rooftop of a building to determine the total area would result in a more precise calculation of the surface.

3.2 Roof area for the integration of solar panels for each different environment region

Receiving energy from the sun is based on radiation. If the consumer is in the northern hemisphere, the sun's rays will be on the south side, and if objects are on the north side of the roof, they will cast shadows on the solar system. For various seasons, this impact would be different. Eq. 2 shows the space available for the use of the solar system.

$$AR_{Accessible} = F_s \times F_{rf} \times AR. \tag{2}$$

where $AR_{Accessible}$ is an accessible roof area for use in solar system installation and F_s is a factor of the impact of roofing facilities and F_{rf} is shading effect factor and AR is an area of roof accessible for use by solar systems.

Second, hourly solar radiation obtained by 1 m^2 of the solar system area is measured, considering the various forms of usable solar radiation.

3.3 Hourly solar energy on the plane

Complete radiation is one of the parameters for calculating the radiant energy of the sun. Global radiation depends on the variability of radiation and reflection in the environment. The following factors are: beam radiation, diffuse radiation, and reflective surface radiation. If I_{total} = full direct radiation from the atmosphere of the solar system and I_{global} = global radiation and ρ = the part of global solar radiation reflecting from the ground and $\left(\frac{1-\cos\alpha}{2}\right)$ is a factor of view to the ground and I_D = diffuse radiation and R_b is radiation ratio of the beam to the solar array on the flat plane, I_b, equal to beam radiation, then Eq. (3) can calculate the total radiation on beam.

$$I_{total} = I_{global}\rho\left(\frac{1-\cos\alpha}{2}\right) + I_D\left(\frac{1+\cos\alpha}{2}\right) + R_b I_b \tag{3}$$

The installation location of the solar system and the solar angles can affect the performance of the system. If this angle deviates from the vertical, the intensity of the radiation will also decrease. According to the definition, $\left(\frac{1+\cos\alpha}{2}\right)$ is a view element to the sun, that is, the proportion of the sun visible from the observation point (surface of the solar array) [3]. This variable can then be used to determine the thermal and electrical solar energy production independently by one square meter of a solar energy system per hour, bearing in mind the properties of the solar energy system and the ambient temperature, system errors, etc. Typical calculations for the electrical and thermal performance of individual solar energy systems have been used to achieve these tests. After this, solar electrical and thermal outputs are defined per square. The meter multiplies the estimates for the accessible roof area. Solar energy systems are configured based on geographical area, climatic zone, and type of construction. The hourly data for solar supply is then combined within each month of the year, implying the potential of solar storage systems within one month, and contrasted to the monthly predictions for building energy systems use for each month. Final uses (solar energy thermal production is compared with tests for room and water heating, solar energy electrical performance for ventilation, lighting, and appliances). This same full methodology of the BISE method is considerably further complicated and requires the further calculation of a variety of parameters described in this article. For further information, access to [12] is suggested.

4. Results

In order to emphasize the value of energy conservation for solar-powered NZEBs under the BISE model, the results for solar energy balances (i.e., solar energy supply vs. any building energy use) were compared to two 3CSEP scenarios: Deep conservation and medium efficiency categories for each of 11 countries, temperature areas, and based treatment. The essential purpose of such a study is to evaluate the effect on the solar fraction of the energy efficiency level change (i.e., the portion of building energy consumption that can be offset by solar energy output) in various regions and buildings. As noted above, extreme scenario presupposes very ambitious changes in energy quality (Approximately passive household energy efficiency), while moderate scenario assumes standard building energy output that can be attained by 2050 if existing government patterns proceed without significant innovations modifications.

The deep scenario results were combined with the energy use estimates of the appliances and lighting from the BUENAS model's BAU scenario with a 50% reduction in their energy intensities by 2050 to illustrate potential improvements in energy efficiency from these end-uses.

The result shows that the odds of meeting the net zero energy target in certain types of buildings are significantly smaller under the medium scenario than under the Extreme one. Tables also reveal that emerging regions can attain the NZE production over a more significant number of months than existing ones. The reason can be twofold: lower energy consumption in developing-country buildings due to more restricted access to modern energy infrastructure and a much greater abundance of solar energy supplies than in developed countries, most of which are concentrated in the northern hemisphere. This also demonstrates that in emerging regions (SAS, PAS, MEA, LAC, and AFR), the gap between the room and water heating energy usage is negligible. In these cases, electricity requirements for such end uses of most building styles (with some exceptions) in these regions can theoretically be fulfilled during the year by solar power supply only.

Full coverage can only be reached in other, primarily low-rise building forms (e.g., retail or single-family buildings) in all the months of 2050 in developing areas. The highest-rise structures, usually represented by multifamily and office buildings, display the lowest NZE capacity in developing regions among other building forms.

The number of months in which solar thermal is not adequate to satisfy the thermal energy demand in these buildings ranges from Low to high , depending on the location. PAO indicates the most significant potential for satisfying solar thermal energy demand across developing regions: Under the deep scenario, 100 percent thermal energy consumption coverage will be reached across all months and in all types of buildings. The great abundance of solar energy can explain this for most of the year in this area.

Results for the medium scenario explicitly demonstrate a substantial rise in the number of months, at least for developing countries, when thermal energy demands need additional energy sources and on-site solar power generation. Some of the situations in these countries, where a large amount of building energy consumption may be met with solar energy during the deep scenario for much of the months, would have some months in the medium scenario where it is not feasible. In the Medium case, only five building forms in PAO, single-family buildings in CPA, and residential buildings in WEU show the possibility in replacing thermal energy consumption with solar in all months.

Developing regions have ample solar power to meet solar heat thermal energy requirements during the year for most types of buildings, even with modest levels of energy efficient construction. In these countries, energy issues are still observed in some styles of tall and modern buildings. This is difficult to achieve monthly zero-energy ratios during the year (e.g., office and hospital buildings in SAS, PAS, and MEA, multifamily and school buildings in MEA).

As for electrical capacity, the disparity between scenarios in developed regions is more apparent—in the intermediate scenario, the number of months in which all electricity requirements can be met with solar energy than in the deep scenario in virtually all regions and building styles (exceptions are some categories of houses in the PAS and single-family homes throughout the LAC area, where maximum coverage age is possible in all cases during the month of the year).

Under the deep scenarios, emerging areas display a strong probability of supplying the bulk of building forms with ample solar electricity volumes. Nonetheless, the results for two high-rise building forms in MEA and office buildings in LAC indicate that solar power will not be adequate to satisfy the energy the building needs over the months. The mixture of thermal and electrical results provides an understanding in which regions and forms of buildings NZE efficiency can only be accomplished with solar energy based on the 2050 monthly energy balance. These cases would include:

- All styles of construction at PAS.
- The single-family PAO, SAS, EEU, CPA, MEA, LAC, and AFR buildings.

- SAS, LAC, AFR market constructions.
- The 'other' SAS, MEA, LAC, and AFR buildings.
- LAC educational institutions and hotels and restaurants AFR.
- LAC multifamily homes.

The findings set out in this document are predictions for (**Figure 2**) potential energy consumption in buildings by 2050 for different regions; building forms and end users and (**Figure 3**) the highest possible technological capacity for producing solar energy from advanced construction technologies.

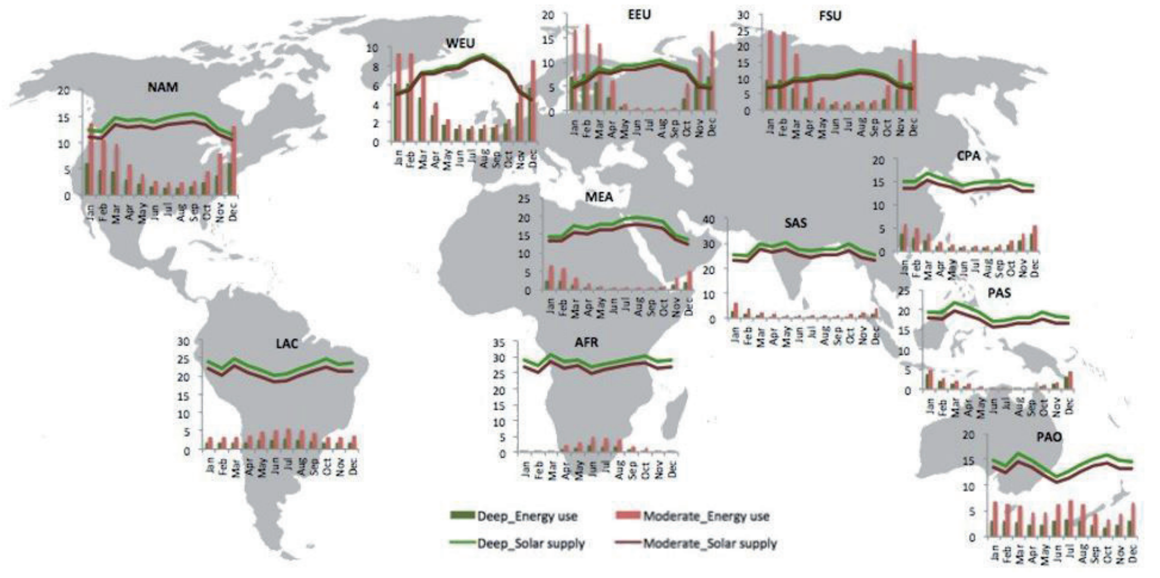

Figure 2.
For single-family buildings in 2050 in kilowatt hours per square meter of floor space, shown in deep versus medium conditions and the use of thermal energy versus solar thermal output [3].

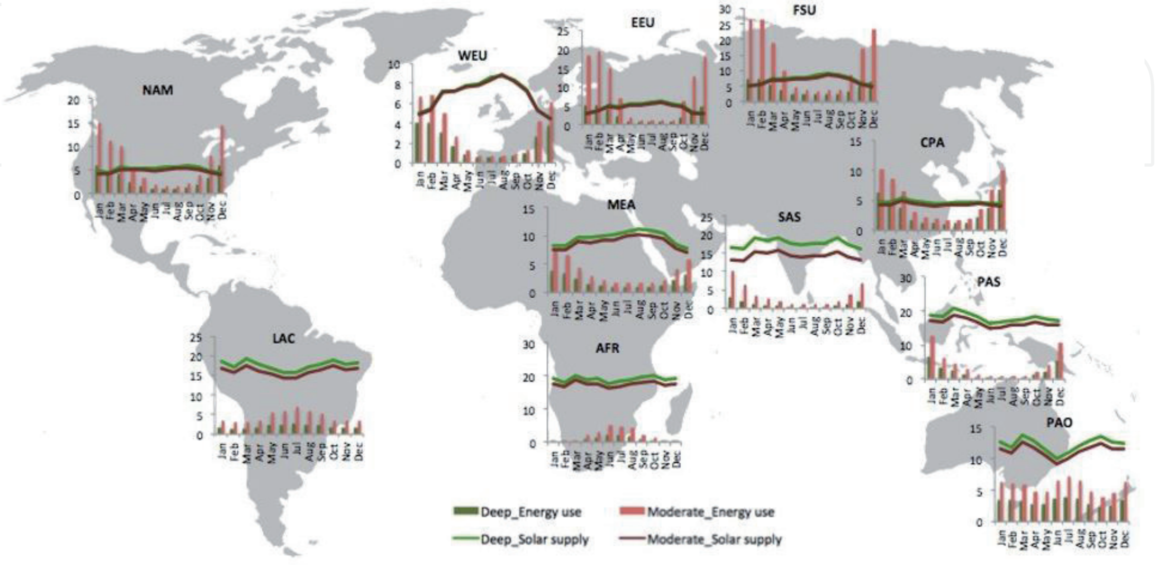

Figure 3.
Thermal energy usage vs solar thermal energy output in 2050 for industrial & public buildings, kWh / m2 of floor space, Extreme vs intermediate scenarios [3].

This chapter's key purpose was to compare the effects of building energy usage under two conditions with different levels of building energy efficiency to the amount of solar energy, which can theoretically be produced by advanced hybrid technology from the rooftops of these buildings. While solar energy capacity measurements have been conducted for each hour, the relation between solar energy supply and the building energy consumption is made monthly (due to the lack of more accurate statistics on building energy usage at the global and national level). It is estimated that generated solar energy will be accumulated at the construction site within 1 month at the level of each area, building type, and climate zone.

Five key messages can sum up the outcomes of such a comparison:

1. Synergies between energy conservation and on-site solar energy generation play a key role in bringing electricity output from building to net zero energy level.

2. Via "strong" energy conservation steps, the same volume of solar energy will support a more significant share of electricity demand, minimize the need for more energy from fossil fuels, and thus trigger greenhouse gases.

3. To exploit the net-zero energy performance capacity of all building services, including lighting and appliances, should be confirmed. New and updated buildings' thermal energy efficiency must meet passive house standards (about 15–30 kWh/m^2 depending on location and type of building). As for lighting and appliances, even halving their use of electricity by 2050 would not be enough to enable maximum solar coverage of the respective electricity needs in some regions (particularly developed ones).

4. Developing countries are seeing greater solar energy efficiency in buildings because of the availability of solar energy resources and lower electricity requirements. However, energy conservation is also critical in these regions to offset the substantial rise in energy usage anticipated in certain regions in the immediate future.

5. Low-rise buildings usually have a higher capacity to meet a significant portion of their solar energy requirement than high-rise ones. Yet modest energy efficiency standards make reaching the NZE target more difficult in most styles of buildings.

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