Chapter

Energy-Efficient Retrofit Measures to Achieve Nearly Zero Energy Buildings

Nimish Biloria and Nastaran Abdollahzadeh

Abstract

Considering the 2021 IPCC report that justly attributes our deteriorating climatic condition to human doing, the need to develop nearly zero energy building (nZEB) practices is gaining urgency. However, rather than the typical focus on developing greenfield net-zero initiatives, retrofitting underperforming buildings could create significant scale climate positive impacts faster. The chapter accordingly discusses energy-efficient retrofitting methods under three categorical sectors—visual comfort (daylight-based zoning, shadings); thermal comfort and ventilation (solar radiation-based zoning, central atrium plus interior openings, insulation, and window replacement); energy consumption (efficient lighting system, and controllers, material and HVAC system optimization, PV panels as the renewable energy source). This chapter further substantiates these theoretical underpinnings with an implemented design scheme—an educational building within a cold semiarid climatic condition—to showcase the on-ground impact of these retrofitting strategies in reducing the energy used for heating and cooling and lighting purposes.

Keywords: architecture, energy retrofit, environmental quality, nZEB design methods, energy optimization

1. Introduction

The IPCC's sixth assessment report [1] has laid to rest any doubts about the genuine and very urgent impacts of climate change that our planet is facing. Global temperature change and changing precipitation patterns due to climate change have resulted in an increased frequency of extreme environmental events. Such devastating events have already taken up the form of large-scale forest and bush fires, hurricanes, increase in heat waves, droughts, water scarcity, and extreme storm conditions globally. According to the United Nations [2], climate and weather-related disasters have increased five-fold over the past 50 years. The impacts of this exponential increase have been clearly articulated by the World Meteorological Organization's Atlas of Morality: Economic losses from weather, climate, and water extremes (1970–2019)—between 1970 and 2019, natural disasters have accounted for 50% of global disasters (11,000 in total) resulting in 45% reported deaths (91% in developing countries) and 74% reported economic losses globally (amounting to $3.64 trillion) [3].

Interestingly, the WMO and the IPCC report have rightfully attributed the underlying cause for such widespread natural calamities to human doing. The WMO, after conducting a thorough review of the Bulletin of the American Meteorological Society concludes that within a time frame of 3 years (2015–2017) alone, a staggering 62 of the 77 disastrous natural events can be attributed to human influence. Sever heat waves impacts being the most apparent of these human impacts have even soared since 2015. The IPCC report further emphasizes the role of human doing attributing to global temperature rise and continued sea-level rise, which are seemingly irreversible over years to come. Human-made and natural wonders in the form of dense low-lying mega-cities, beautiful islands, delta regions as well as coastal regions are all now under-threat and are increasingly feeling the impact of climate change. The recent outcry from some such impacted countries for climate justice has been voiced in the recent COP 26 summit held in Glasgow.

Reducing current emissions by 45% is the new global challenge that must be attained to limit warming to the 1.5°C mark by 2100. This limitation is not surprising considering that most of the energy produced globally has been reliant on burning fossil fuels (primarily coal). A clear trend can be seen in the increase of atmospheric carbon dioxide concentration since the end of the eighteenth century and the beginning of the nineteenth century—this coincides with the time when coal came into everyday use [4]. The scientific principle behind the global warming trend is relatively simple to comprehend—burning fossil fuels, biofuels, and biomass release carbon that was otherwise sequestered, thus exponentially adding to the current stock of carbon globally. This burning process releases gases accompanied by tiny carbon particles (ranging from PM 10 to PM 2.5)—black carbon that tend to trap the sun's energy in the atmosphere (at a much higher rate than CO_2), resulting in an increase in temperature. Forest fires, transportation, industries, buildings, electricity, and heat production are all black carbon and greenhouse gas (GHG) sources.

Fossil fuels and the associated use of coal and petroleum play a vital role in contributing greenhouse gasses (GHG) and black carbon and are fundamental to be discussed in the context of this chapter. However, industries, such as agriculture, including animals, chemical-intensive farming, clearing forests for agricultural land, etc., are among the highest contributors of GHGs to the atmosphere. For instance, according to the United States Environmental Protection Agency (EPA), methane gas, produced during combustion processes and anaerobic decomposition, has 28–36 times more potential to result in warming than CO_2 [5]. Similarly, nitrous oxide, fluorinated gases, sulfur hexafluoride are all GHGs with higher potential to retain warmth in the atmosphere.

Within this context of climate change and the increasing responsibility on the shoulders of all citizens of planet earth, the building sector, coupled with the behavioral change we need to acquire toward the production, usage, and storage of energy, is of high importance for the future of our existence. According to the World Green Building Council's "Bringing Embodied Carbon Upfront" report [6], building and construction activities together account for 39% of energy-related CO_2 emissions while they use 36% of final global energy. Besides this, the building also accounts for approximately one-third of black carbon emissions [7]. Of particular, importance within this emission is the 72.5% share belonging to the residential sector owing to its propensity for energy consumption—the third-largest energy consumer sector in the world. According to the IPCC's report, energy consumption-related indirect emissions in residential buildings have quintupled while it has quadrupled for the commercial building sector (from 1970 to 2010). With a projected increase in the world population by half—almost 3.6 billion people toward the end of this century and a total of 11.6 billion people by the year 2100, the demand for housing and thus the increase in energy consumption and emission production could lead to disastrous climatic scenarios. Upfront carbon or the carbon emission released before the built asset/building is in-use is projected to constitute half of the carbon footprint of new constructions until 2050. The grave responsibility on the building sector thus revolves around addressing the tension between dwindling fossil fuel reserves and the ever-increasing energy demand. The Global Status Report 2017 published by UN Environment and the International Agency [8] further proposes that to address this complexity, the energy intensity per square meter of the global building sector needs to be improved by a minimum of 30% by 2030. Efforts to decarbonize the building sector or, in other words attaining a net-zero or nearly-zero building target is thus quintessential.

The chapter adheres to a hybrid methodology involving empirical research and simulation-driven design. A systematic review and data extraction from scientific journals, environmental organization websites, governmental regulatory bodies, and informational data specifically meant for the builder community are interfaced with a simulation-driven design for retrofitting an existing building. This interface was established to test theoretical and professional advice rendered through the study of literature and the actual impact of these propositions in the retrofitting of a common existing building typology. Section 2 of the chapter firstly reasons and establishes the need for retrofitting existing buildings. Once established, Section 3 systematically describes the concept of nearly-zero and situates the building industry within it. Section 3 emphasizes three essential components that need consideration while retrofitting existing buildings: Visual comfort (daylight-based zoning, shadings); thermal comfort and ventilation (Solar radiation-based zoning, openings, insulation, and window replacement); energy consumption (efficient lighting system and controllers, building material and HVAC system optimization, PV panels as the renewable energy sources). Section 3, while elaborating upon the technicalities involved in the three components, simultaneously presents the findings of the simulation-driven design as a proof of concept, thus elaborating upon the effectiveness of the promoted solutions. Section 4 serves as the conclusion of the chapter and future suggestions for developing a nearly-zero building future.

2. Retrofitting existing buildings vs. building new buildings

Given the context of climate emergency and the pivotal role that the building industry must play in reducing carbon emissions, the question is whether to focus on retrofitting existing buildings or tearing down existing buildings and building new net-zero buildings? Retrofitting existing buildings could offer an excellent opportunity for reducing our carbon emissions at a faster pace. The low rate—1% per year of building demolition and rebuilding in most parts of the world [9] and the fact that almost two-thirds of the existing global building stock will still constitute buildings that exist today are reasons enough to opt for the retrofitting path. Not attending to this significant building stock would imply continual carbon emission even in 2040, resulting in a failure in achieving the 1.5°C target set forth via the Paris agreement. The 2021 Pritzker Architecture prize laureates Anne Lacaton and Jean

Phillipe Vassal echo this view of retrofitting via their unique approach to building a smarter, greener, and inclusive built environment—never demolish, remove or replace, always add, transform, and re-use [10]. Countries like Australia, with almost eight million homes constructed from the 1950s onwards (like buildings elsewhere in the developed and the developing world), were built during a time with far less stringent regulations around energy and building standards, insulation, and material quality. This resulted in buildings either on the verge of collapse, being poorly designed, containing hazardous materials (such as asbestos), or consuming high amounts of energy to maintain comfort levels for their inhabitants. In the Australian context alone, buildings are associated with 18% GHG emissions and 20% final energy use (COAG Council report) [11]. According to an editorial published in The Guardian, the United Kingdom's trend to demolish 50,000 buildings per year to construct new ones is responsible for two-thirds of the total waste production of the entire country. The construction of new buildings is additionally associated with 10% of the UK's carbon emissions [12]. In the United States, almost seven million buildings are estimated to undertake remodeling and renovations in addition to commercial buildings undertaking capital improvements [13]. Such large-scale building alterations offer an excellent opportunity to include energy performance enhancements while conducting renovations one architectural element at a time (wall, roof, windows, floors, etc.)—Opportunistic Retrofitting. It is projected that three measures—re-siding, window replacement, and re-roofing, can cut result in 25% more energy savings alone. Bloomberg presents an easy to comprehend comparison for how much impact this 25% reduction will entail. Suppose this 25% energy saving potential is harnessed by even 1% of the US's 83 million existing single-family homes. In that case, it will reduce carbon emissions by more than 1.6 million metric tons yearly, which is equivalent to removing 350,000 passenger cars from highways. Besides savings on energy bills worth $400 billion each year, this positive environmental impact provides compelling arguments to transition to a nearly zero carbon building practice.

Besides this, it is essential to note that refurbishing and restoring existing buildings result in saving the embodied carbon footprint of the material used while constructing these buildings. This saving results in negating costs for mining, manufacturing, shipping, etc., of new materials that would otherwise be used for new constructions. In the long run, retrofitting thus becomes cost-effective with respect to CO_2 rather than building new. However, what is also vital to consider is the positioning of the building sector within the bigger landscape of energy and climate change debates. Retrofitting on its own, though beneficial, would benefit immensely if it harnesses an energy upgrade involving the following: Incorporating improvements in the energy efficiency of building operations; embracing a shift from fossil fuel to electric or district heating that is backed by carbon-free renewable energy generation practices; generation of carbon-free renewable energy on-site.

Within the current context of popular media exploding with discussions around climate emergencies and the need to reduce our carbon footprint and associated emissions, awareness about harnessing renewable energy has strengthened within the general population. However, what does it truly mean to become carbon neutral or, for that matter, what does a zero carbon badge imply for the building sector? The next section of this chapter engages in a short discussion around the concept of zero carbon to base tools and techniques that can be instrumental for reaching a zero carbon or a net zero retrofitting strategy.

3. What does being nearly zero implies in the context of a building?

The discussion thus far identifies why we need to reduce emissions and why we need to become highly energy efficient, especially when it comes to the building industry. The fundamental goal here is to neutralize resource consumption by reducing energy needs and harnessing renewable resources for energy production. This approach will produce buildings that offset the total amount of energy used by the building annually with the amount of renewable energy that can be captured on-site or via renewable energy providers [14]. The concept of net zero buildings (NZEB) was first discussed internationally in 2008 [15] and has been refined over time by the International Energy Agency (IEA) with almost 20 nations globally via the Task 40 initiative. The European Union was similarly discussing the definitions through its EPBD initiative that finally resulted in coining the term nearly zero energy buildings (nZEB) [16–18]. EPBD's recast directive establishes that the nearly zero or significantly less amount of energy required during the operation of the building should be catered to via energy derived from renewable energy sources (on-site or generated nearby). In Europe, the application of the nZEB model has become a requirement since December 31, 2018, for all public buildings. This application has slowly percolated to all new buildings from 2020 onwards. The United States Department of Energy (DOE) further classified zero energy buildings based on their total life cycle energy. This definition included building energy (on-site building energy consumption—heating, cooling, ventilation, indoor and outdoor use, lights, plug loads, process energy, elevators, intra-building transportation, etc.), energy consumed in transportation of primary fuels, thermal and electric losses in generation plants, and loss of energy during transport of energy to the building site [19]. A holistic spin on energy balancing of the building is thus proposed. It is also important to note that as opposed to autonomous zero energy buildings that can generate and consume equal amounts of energy to sustain themselves, nZEBs can connect to the external electricity grid provided that the annual energy export is equal to the annual energy import.

Accordingly, this chapter focuses on the added value of an nZEB by retrofitting the existing stock of buildings by reducing their energy needs and employing appropriate physical improvements to enhance its efficiency standards. In retrofitting existing buildings, three fundamental principles need to be adhered to—reuse, reduce, and sequester. Re-use in this context implies the use of recycled materials, paying specific attention to the end-of-life re-use properties of the materials used during retrofitting, and the idea of designing with an aim for deconstructing. Reducing implies carefully optimizing materials used during the renovation to selectively opt for low carbon materials [20]. Sequestering in the case of retrofitting involves the provision of carbon sequestering locations coupled with materials that can sequester carbon, such as bioplastics, the use of mycelium insulation, recycled plastic, and biomaterials-based carpeting, and 3D printed wood made from sawdust, to name a few. Ideally, retrofitting to reach a nearly zero energy building status can be clubbed into two design strategies—passive and active [19]. Passive strategies incorporate material properties, urban positioning/orientation, envelope design, and shading, to name a few. On the other hand, active strategies deal with improvements within HVAC systems, energy-efficient lighting, etc.

On the material front, though, one needs to comprehend the notion of "Embodied Energy." Embodied energy is typically associated with the total impact of material greenhouse gas emissions during its entire life cycle. Lifecycle covers the dimensions of a material's extraction, manufacturing, transportation, construction, maintenance,

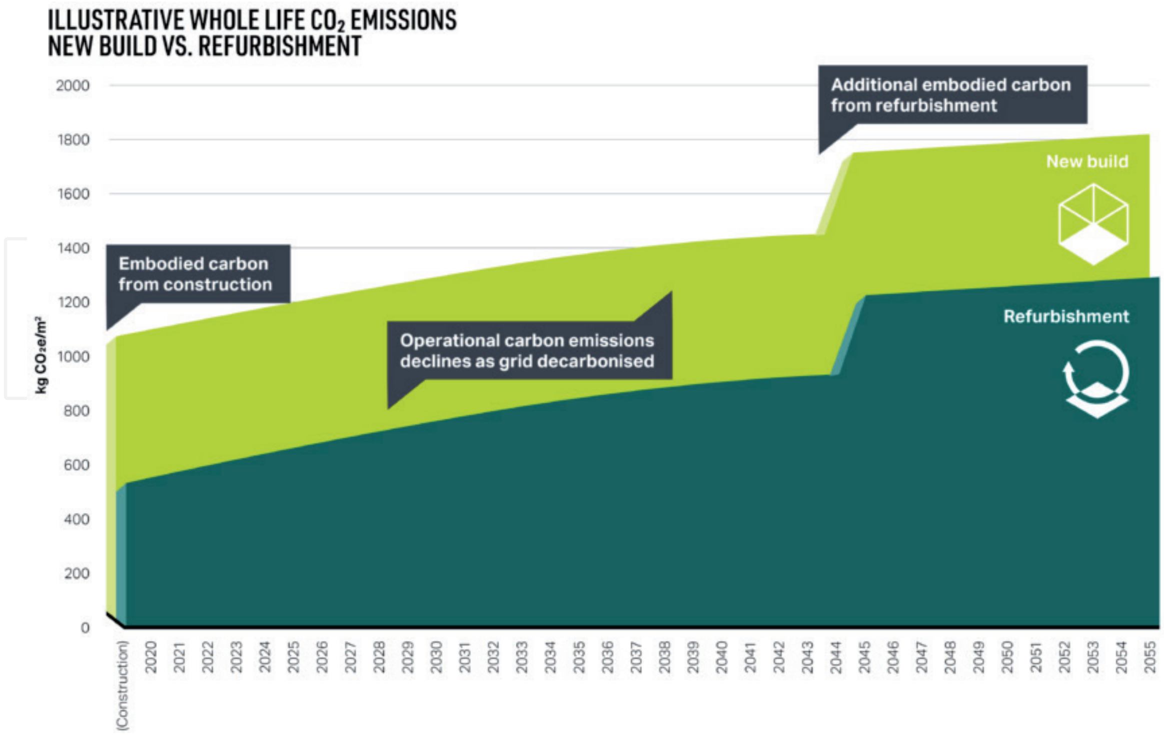

Figure 1.
CO_2 emissions of new build and refurbishment (image source: AECOM, 2021 [22]).

and disposal. If we take the new construction route, it is estimated that embodied carbon alone will be responsible for 72% of the carbon emissions between now and 2030 [21]. Embodied carbon cannot be rectified because it is embedded within the building once it has been erected. It is thus crucial to address the embodied carbon issue during the design or before the retrofitting stage is actualized on any building site (**Figure 1**).

Besides this, the basic building materials which are prevalently used in the construction sector—concrete, steel, and aluminum, are together responsible for 23% of total building emissions in themselves. Portland cement, the primary ingredient for making concrete, is responsible for releasing 40% CO_2 during the burning of fossil fuels for its manufacturing and emits 60% CO_2 during its processing phase. Similarly, the production of steel is a significant determinant of how much CO_2 it generates. Typically, basic oxygen furnaces responsible for producing steel rely on burning fossil fuels—coal or natural gas to melt iron ore, thus contributing to CO_2 emissions at a large scale. Better material alternatives or the alteration of production technologies of such fundamental materials used in the building industry are thus crucial. Embodied energy becomes specifically vital if seen from the context of developing nations, witnessing a boom in the building construction sector at an exponential rate.

Having gained some perspective on the concept of nearly zero energy buildings, the big question then is how do we translate this theoretical thinking into reality via retrofitting existing buildings? The following section provides some perspective on the same.

4. Retrofitting toward a nearly zero energy future

In retrofitting a building, one of the critical aspects to consider is the material properties of the existing building and the carbon content typically residing therein.

The London Energy Transformation Initiative (LETI) proposed an embodied carbon budget of $600kgCO_2e/m^2$ for us to attain our carbon reduction goals [22]. To understand the feasibility of achieving this low figure, one must comprehend the total embodied energy typically present in an old building. Aecom, in a web article titled "The carbon and business case for choosing refurbishment over new build," breaks down the embodied carbon within various components of typical residential buildings: Frame 24%; substructure 19.6%; upper floors (14.9%); building services (13.4%); internal finishes (12.4%); external walls; windows and doors (8.8%); roof (5%); fitting and furnishings (1.2%); internal walls and doors (0.6%). The elements typically associated with the highest embodied carbon (substructure, frame, upper floor, and roof) are candidates that qualify for retrofitting to save on emissions produced during the breaking down of an old building and re-constructing these buildings elements while building anew.

To holistically retrofit existing buildings for enabling the transition toward a nearly zero energy building, three main scopes encompassing passive and active strategies should thus be considered:

a. Visual comfort (daylight-based zoning, shadings)

b. Thermal comfort and ventilation (solar radiation-based zoning, openings, insulation, and window replacement)

c. Energy consumption (efficient lighting system and controllers, building material and HVAC system optimization, PV panels as the renewable energy sources)

To explain these three strategies, the chapter, apart from providing theoretical advice, also elaborates upon the results of a simulated case study—an educational building in Iran. An initial comfort analysis in terms of visual and thermal condition and energy use of this existing building provides insights on the required improvements and thus informs retrofitting strategies. The elaborated project deploys the three-stage retrofit process on an educational building in Tehran (35.6892° N, 51.3890° E), Iran, in a cold semiarid climatic condition (Köppen climate classification: BSk). The process adopted by the authors incorporated radiance and energy plus simulation engines. According to the weather data for a typical year in this area, January is the coldest month, and August represents the hottest time of the year, each with an average monthly temperature of 3.89°C and 30.07°C. The site also enjoys a high level of solar exposure and experiences cloudy sky conditions only 15% of the time.

Situating a to-be retrofitted building within its environmental context is an ideal strategy for understanding the reasons behind its current energy performance. To strive toward an energy-efficient status for an existing building, both interior and exterior aspects are equally crucial to be considered. Visual and thermal comfort components can be primarily linked with the urban positioning of the building itself and imply conducting on-site solar radiation analysis for extracting the degree of solar exposure received by the building's external facades. In addition to this, mapping the demand for lighting and thermal energy of the interior programs of the building is vital. This step aids in making informed decisions to re-position or augment a building's program to take the best advantage of the building's solar exposure while naturally reducing the amount of energy required to heat or cool the building's interiors.

For instance, in our educational Building case study, solar radiation analysis (**Figure 2**) revealed that the Southern zones witnessing the highest solar radiation

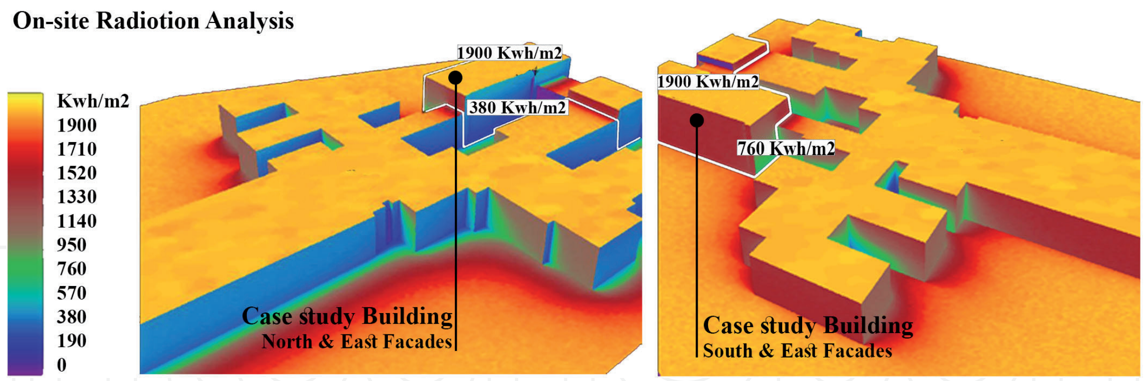

Figure 2.
Solar radiation analysis on building envelope.

constituted of primary programs and were induced to a high level of daylight and solar heat gain. On the contrary, northern zones were the coldest spaces with a pleasant daylight quality without experiencing visual discomfort caused by glare. The Eastern and Western zones were typically dedicated to circulation and service areas. Daylighting and thermal requirement-based zoning and categorization of the building's program are also conducted to determine the ideal spatial distribution of the program within the building (**Figure 3**).

The other important aspect of understanding visual comfort is calculating daylight quality to evaluate illuminance levels and glare probability and subsequently calculate thermal conditions to evaluate the total amount of discomfort hours within the primary programs of a building. It is vital to educate and to understand the importance of using the sun for solar tempering. Working with rather than against natural solar movement and exposure also aids in achieving energy savings otherwise required for heating purposes, and appropriately shading also aids in reducing cooling requirements. A strategic manner of avoiding added costs and energy expenditure for added thermal mass required for maximizing passive solar heating can thus be achieved. Such concerns are primarily best addressed during the design phase of the proposed retrofit.

In the case of the studied institution building, the south-facing spaces tend to receive excessive sunlight and suffer excessive visual discomfort (ASE > 10%, LEED 0 point). Therefore, the use of optimum shadings is suggested in the retrofit process. Despite this, the northern zone achieves all 3 points of the LEED rating system, which indicates that both sufficient daylight level (sDA > 75%) and visual comfort

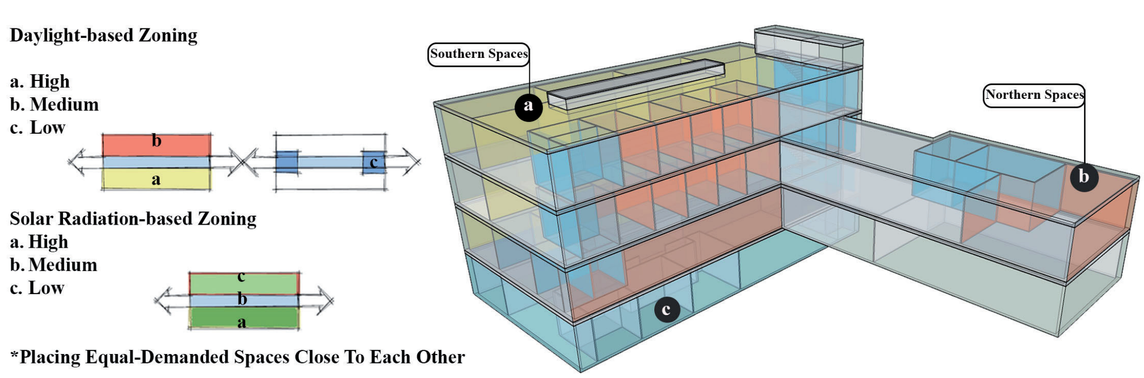

Figure 3.
Spatial zoning based on the solar geometry.

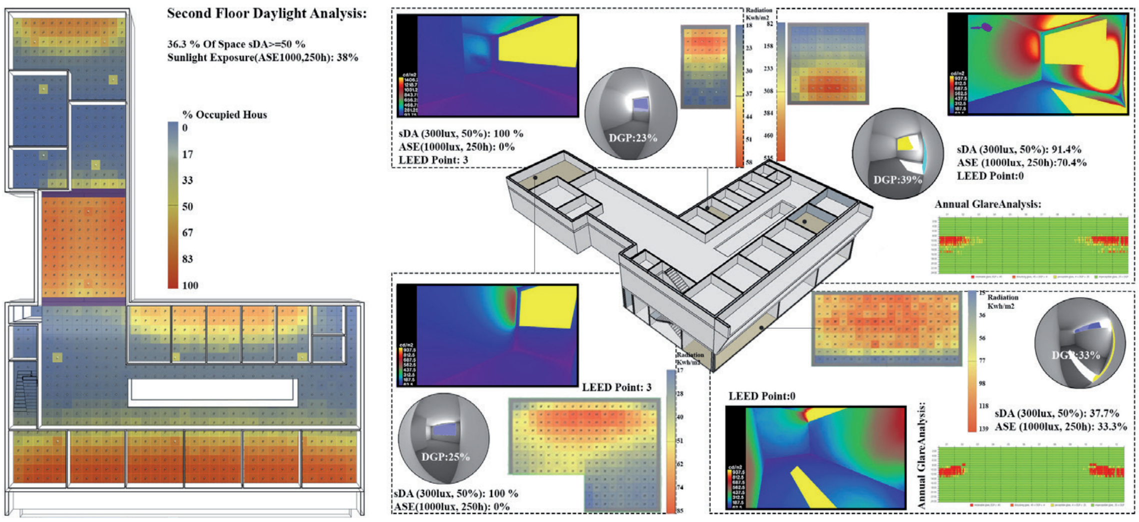

Figure 4.
Visual comfort (daylight distribution and glare) assessment.

(ASE < 10%) is achieved in these zones. Therefore, it is highly suggested to consider solar geometry in the renovation process to establish the feasibility of removing or adding the interior partitions. An overall analysis of daylight distribution on each floor (**Figure 4**) can elaborate on the optimal positioning of the interior program of a building in relation to solar radiation. Such strategic thinking and informed decision-making pertaining to program positioning before beginning the retrofitting process can thus ensure reducing the total energy consumption of a building considerably.

Thermal comfort analysis by assessing the average monthly temperature within an existing building's interior spaces can further help designers to understand overcooling or overheating scenarios throughout the year. Similarly, an annual analysis of discomfort hours also provides information on thermal conditions on a dynamic scale and can show critical thermal condition levels of interior space. Thermal imaging using an infrared camera can also be deployed for measuring on-site thermal conditions in individual rooms. Typically, such analysis can also be categorized under an energy audit of an existing building. For the case of the educational building understudy, the annual discomfort hours were calculated as 988.73 hours (**Figure 5**) and were associated with the average monthly temperature and the percentage of occupancy time that the hours corresponded with. The design phase of the retrofit being a calculated experimental phase also renders itself for making design decisions pertaining to elements such as atriums, window opening sizes, etc., while keeping in mind the window to wall ratio. Such additions, typically aimed at improving natural ventilation, can dramatically improve inside temperature conditions, thus impacting the total energy required for heating, cooling, and artificial ventilation. In the case of the educational building, the insertion of a central atrium combined with interior windows with a window to wall ratio of 20% was experimented with as a designed addition. A computational fluid dynamics (CFD) simulation analysis on a typical spring day (without an HVAC system operational) was able to provide a good overview of well-ventilated zones vs. zones which needed further improvement strategies such as supply vents etc., (**Figure 6**). Such initial analyses of the indoor environmental condition thus offer a basis for taking calculated decisions of the required retrofit strategies on a case-by-case basis.

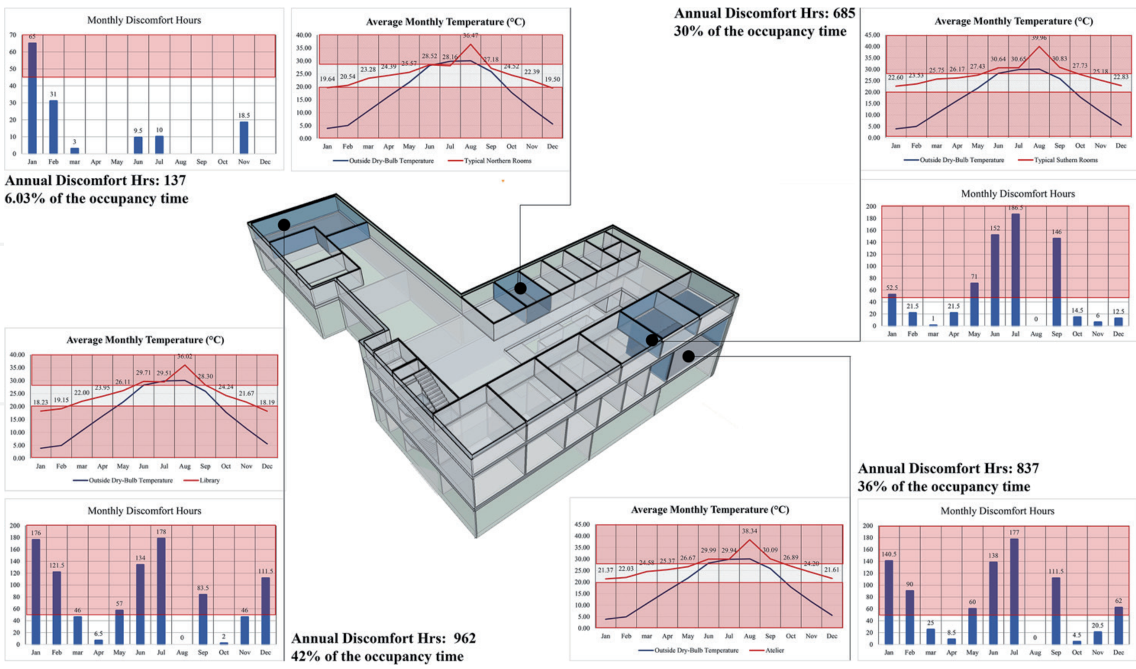

Figure 5.
Thermal comfort assessment.

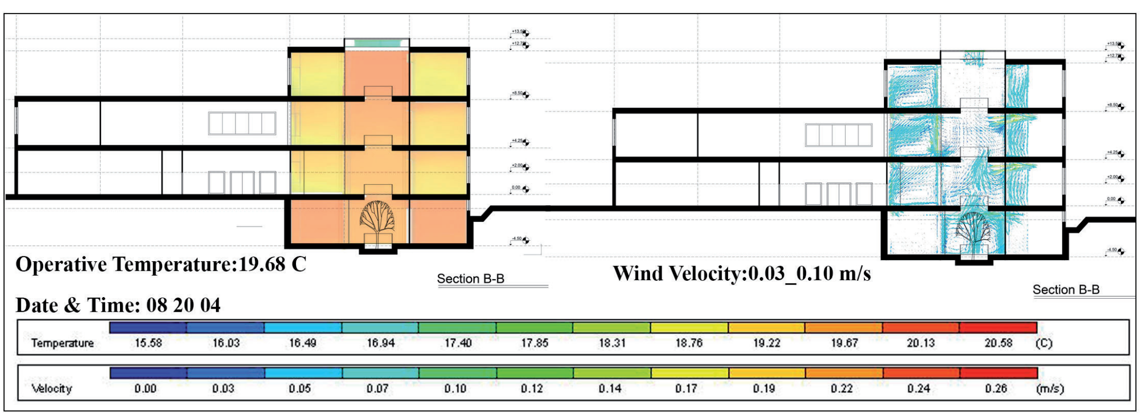

Figure 6.
Ventilation (velocity and temperature) assessment in the central atrium.

Tangible aspects connected with thermal comfort can be further categorized into lighting, sealing, insulation, and window replacement components. Lighting inside a building is equally crucial. Older buildings typically make use of fluorescent lighting and light bulbs. These tend to consume much more energy than contemporary energy-efficient CFL or LED light bulbs that last longer and are mercury-free. Retrofitting should thus ideally involve replacing existing fluorescent lighting systems with LEDs equipped with linear controllers. This simple change can almost halve the energy used for lighting purposes. Using motion sensors in areas where lights are left on often also allows energy to be saved. For the case of the educational building, this small change in lighting coupled with a daylight sensor for controlling the intensity of lighting in real time can halve the total energy consumed (**Figure** 7).

Sealing the building envelope is another step that is a highly efficient and cost-effective measure that can be deployed during the retrofitting phase for any building. Saving valuable energy required for heating and cooling and improving comfort,

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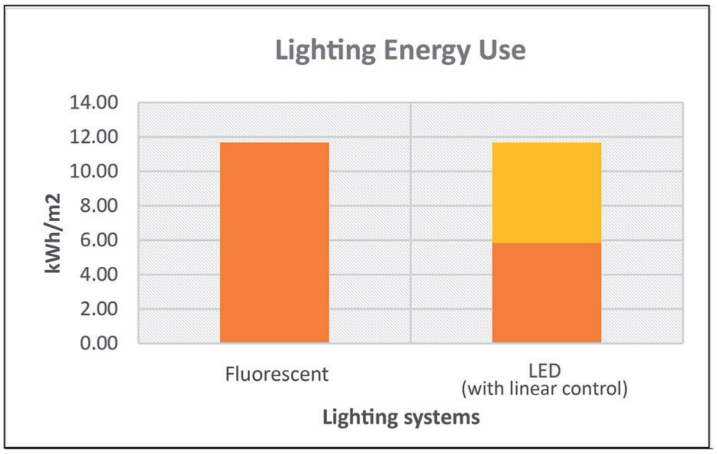

Artificial Lighting:
LED With Linear Control
Model: AOK(Factory) LED 2017
Life Time: 50000 (Standard;TM21 L70)
Luminous Distribution: 120◦
CRI: 7080/
Efficacy: 130 Lm/W
Power Density w/m2 100lux : 2.5
Daylight Sensor
Model: PIR 150W

Figure 7.
The energy use of reference (fluorescent) VS. optimized lighting system (LED with linear control).

reducing noise, and improving air quality are all direct impacts of sealing the building envelope, resulting in nearly zero energy targets. Often a blower door test can be conducted to evaluate the air leakage during air change per hour. Air change here implies the volume of air that equals the house volume exchanged with the outside air [23]. A blower door can establish a negative 50-pascal house pressure. Existing homes in need of retrofitting can often leak air at the rate of 15 air changes per hour (15 ACH50). Sealing the external and internal surfaces of a building can aid in bringing this level of leakage down between a range of 2ACH50 (airtightness standard for a cost-effective zero energy home)—0.7 ACH50 (airtightness standard for a passive house). Setting an airtightness goal for retrofitting projects can thus prove to be a wise decision for cutting down on energy consumption by optimizing the building envelope.

Building insulation should be considered as a fundamental component of any retrofit project. Different surfaces, such as walls, floors, and ceilings, require different types and thicknesses of insulating materials that are contextually derived based on climatic conditions and solar exposure. The R-value, or in other words, the ability of a material to resist the flow of heat, is important while choosing adequate insulation and is highly dependent on the kind of material used for insulation rather than the thickness of the material used. The climatic context of the region within which the retrofitting needs to be undertaken thus plays a significant role in determining the requisite R-value of the chosen insulation type and thickness. The Zero Energy Project report [24] outlines practical ways in which high-performance walls (exterior rigid insulation; single plate, double stud walls; double plate walls), high-insulated ceilings (blow insulation onto flat ceilings; insulating cathedral ceilings; exterior rigid insulation), and high insulated-floors (insulated slabs; insulated basements; crawl space), can aid in reducing energy loads by means of the application of appropriate insulation.

Similarly, window replacement and door replacements can play an essential role in transitioning to a nearly zero energy building. Organizations such as the National Fenestration Rating Council have contributed heavily toward establishing rating systems of window and door performance measurements in the form of labels affixed to off-the-shelf window and door units [25]. This process aids in the simplification of retrofitting wherein the everyday citizen can make informed decisions pertaining to the efficiency of these quintessential components of a building. Like the R-value of insulation, a U factor is of prime importance as it indicates the efficiency of a window

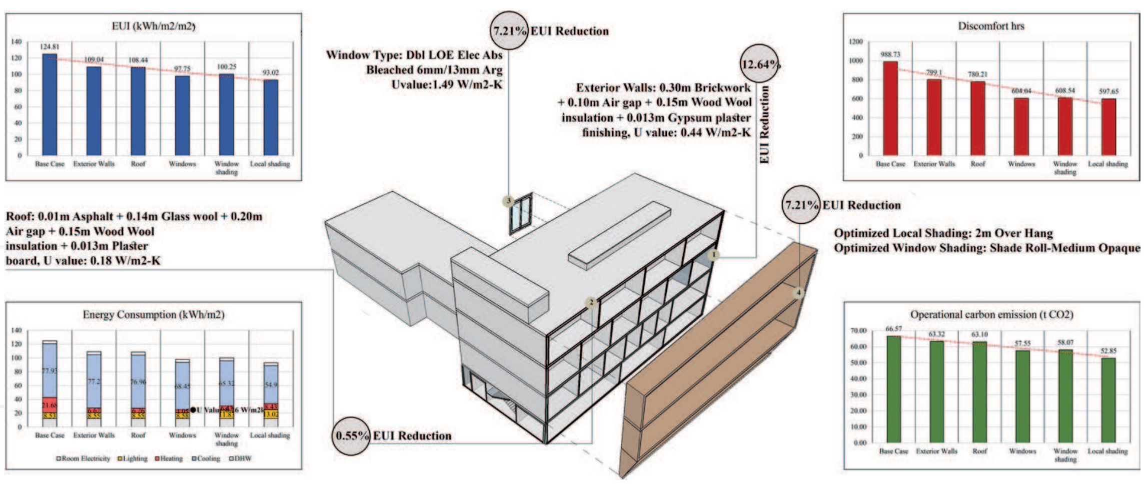

Figure 8.
Construction material optimization.

as regards heat escaping from the interior of a building. For visual comfort purposes, the visible transmittance value is also associated with window ratings. It is responsible for measuring the effectiveness of a window to light the interiors of space with daylight. For doors, the solar heat gain coefficient value that demarcates the door's resistance toward unwanted heat gain and the air leakage value that indicates the entry of external air through the door are vital measures specified by such councils.

For the case of the studied educational building, to establish a lower heat transfer threshold, the application of interior insulation (0.10 m air gap +0.15 m wood wool), replacement of windows with highly sealed windows with a low U value and coated with efficiency-enhancing coatings (Dbl LOE Elec Abs Bleached 6 mm/13 mm Arg), provision of interior window shading (shade roll-medium opaque) and exterior—localized shading elements (2 meters overhang), were explicitly deployed for enhancing the efficiency of south facing spaces (**Figure 8**).

The energy consumption component for a building retrofit process involves active strategies. HVAC systems are omnipresent in the majority of homes globally and how to reduce the energy required for heating or cooling purposes is of particular importance here. The strategies—visual and thermal comfort enhancements, already contribute to reducing conventional HVAC systems' load. However, apart from these passive measures, selecting appropriate HVAC systems conducive to the climatic context and the proportion of spaces to be conditioned are essential criteria to consider. For instance, for residential properties, air-source heat pumps are highly efficient and can take up the form of mini-split heat pumps for individual rooms or multi-zone installations. Variable speed operation by means of sensing temperature conditions inside a building and accordingly increasing or decreasing heating or cooling speeds results in air-source heat pumps in achieving energy savings.

Other strategies such as working with combinations of different heating and cooling systems per the degree of solar exposure and desired comfort levels could also be experimented with. For the case of the educational building, four different systems of radiator + evaporative cooling (the most common system used in the location), VAV, fan coil, and heat pump were simulated and optimized to establish the most efficient option. Accordingly, the optimum system of unitary heat pump can reduce heating, cooling, and the total energy use intensity (EUI) by 69.03%, 38.21%, and 28.81%, respectively. The final results indicated that the proposed method could reduce the annual energy consumption (EUI) by almost half while doubling the comfortable

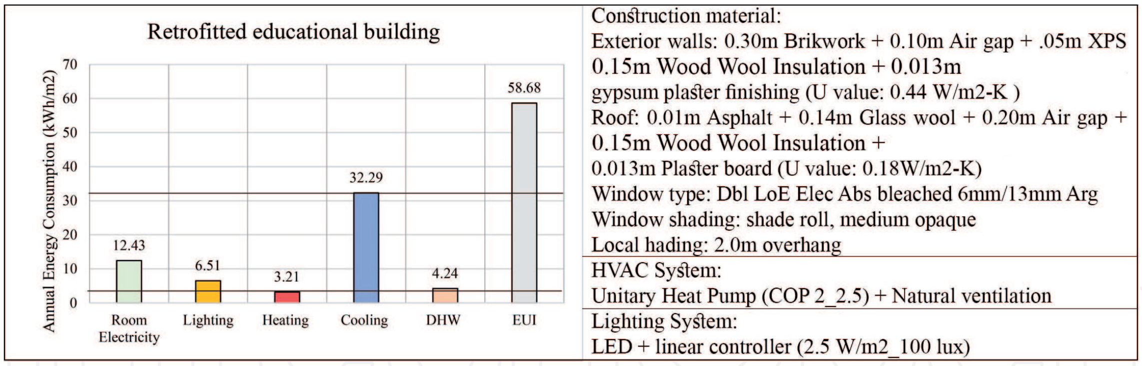

Figure 9.
Energy use and physical features (construction material, HVAC, and lighting systems) of the retrofitted case study.

hours indoors. **Figure 9** represents the energy consumed by different energy-consuming components of the retrofitted case study and the suggested replacement of physical features of the building. Such informed and analytically validated suggestions can inform property owners and make them aware of the retrofitting process's impact in transitioning to a nearly zero energy future.

Another active mode of energy generation is the renewable energy sector. Harnessing the sun's power by means of solar photovoltaic (PV) panels is one of the most cost-effective modes of harvesting renewable energy. The efficiency of solar panels is typically dependent on the amount of unobstructed solar radiation captured by the panels over a period throughout the day. After calculating the amount of energy conserved by applying the aforementioned passive and active strategies, a well-thought-out plan for solar energy capture must be developed. This is also due to the limitations of existing homes regarding the amount of open and exposed roof surface square meters available for the installation of PVs. A well-developed plan can aid in calculating the exact number of panels needed to manage and balance out the amount of energy required to reach a near-zero energy target. The inclusion of microinverters rather than centralized inverters should become the norm to encourage capturing optimal performance per panel while future-proofing the ability to add more panels in the future. Governments globally are now encouraging the installation of panels by providing subsidies and encouraging schemes that make solar leasing affordable and easily accessible.

For instance, in the case of the educational building understudy, PVs were suggested to make the most from renewable energy sources, such as solar radiation, to transfuse an annual amount of 10.7 mWh of electricity to the grid supply a part of the projects' total energy consumption. Hence, 24 panels are suggested to be placed on the roof to bring it closer to an nZEB design. Accordingly, the final design incurs less than 55 kWh/m^2 energy consumption, from which 9.32% is supplied by harvesting solar energy. The associated carbon emission (operational) was also reduced by 17.96% (**Figure 10**).

As a proof of concept for the propositions made in this chapter, jointly—both passive and active strategies proposed for the retrofitting of the educational building exhibited the potential to reduce the energy consumed for heating, cooling, and lighting purposes up to 85.19%, 58.57%, and 23.68%, respectively, compared to the base case (**Figure 11**).

Furthermore, the annual EUI could effectively be reduced by 52.98%, while the associated carbon emissions (t CO_2) and annual comfort hours also exhibit

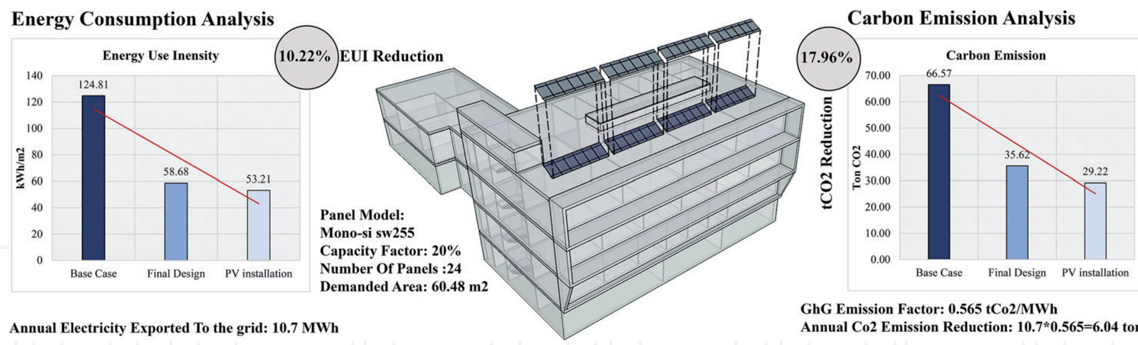

Figure 10.
Energy savings and CO_2 emissions reduction by PV installation.

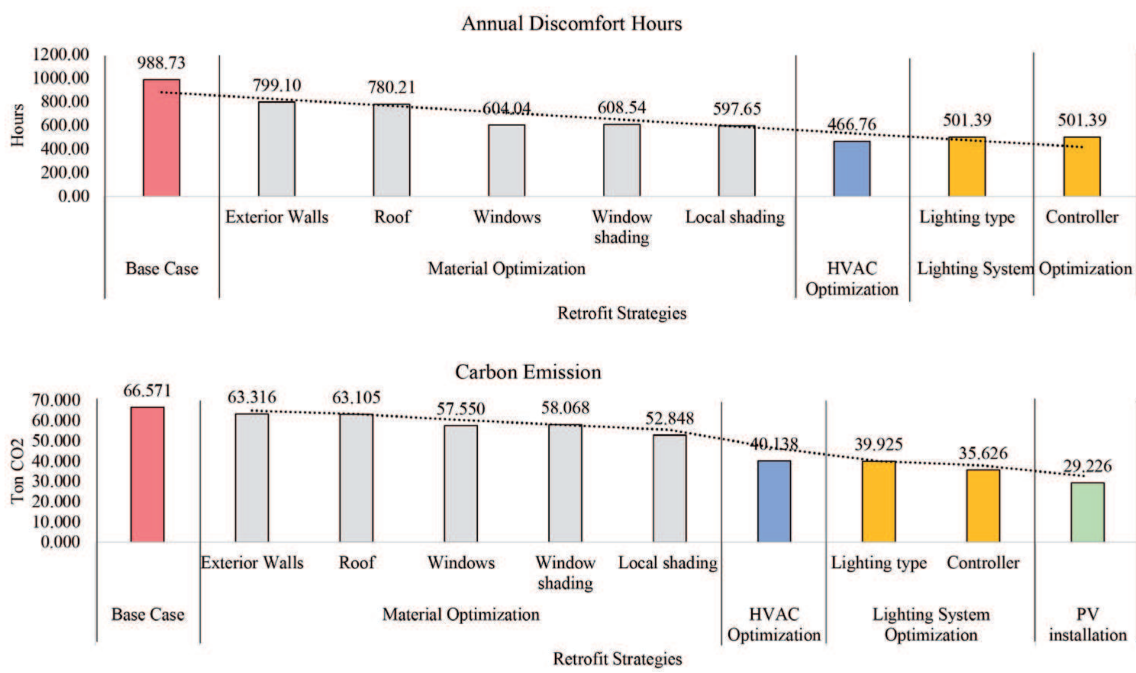

Figure 11.
The impact of the proposed retrofit strategies on the annual discomfort hours and CO_2 emissions.

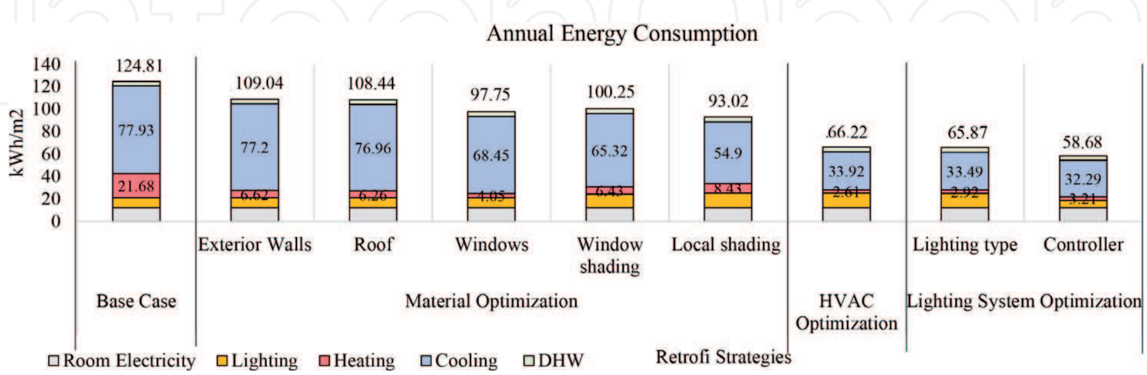

Figure 12.
The impact of retrofit strategies on annual energy use.

improvement by 46.48% and 49.28%. Replacing existing windows with highly efficient windows proved to have the highest impact (22.58%) on the comfort experienced indoors, followed by using an optimum HVAC system and applying interior insulations, each with an effective percentage of 21.90% and 19.18%. The inclusion of an efficient HVAC system also aided in reducing operational carbon emission to a great extent (24.05%). Installing PV panels also exhibited a substantial reduction in carbon emissions (19.18%) (**Figure 12**).

5. Conclusion

The chapter attempts to rationalize and strategize the retrofitting of existing buildings as a valuable means for transitioning toward a nearly zero energy future. The perspective presented in this chapter revolves around three fundamental components:

a. Visual comfort (daylight-based zoning, shadings)

b. Thermal comfort and ventilation (solar radiation-based zoning, openings, insulation, and window replacement)

c. Energy consumption (efficient lighting system and controllers, building material and HVAC system optimization, PV panels as the renewable energy sources)

An actual case study of an existing educational building has been conducted to present the tangible benefits of applying passive and active measures within these three components to reduce energy usage and carbon emissions. The results of this study have been presented in parallel to the theoretical discourse on methods to achieve a nearly zero energy building goal as a proof of concept for the advocated practices. Besides the case study conducted by the authors to reassure the readers about the benefits of retrofitting, Harvey (2013) further outlines various building typologies that have achieved energy reductions by adopting retrofitting practices—detached and single-family homes (50–75%); apartments (80–90% reduction in heating); building envelope retrofitting (1/2 to 1/3rd reduction in cooling, and 2/3rd reduction in cooling); HVAC optimization-based energy saving in commercial buildings (25–50%); lightning-based retrofitting in commercial buildings (30–60%) [9].

Retrofitting is a viable option to consider despite high upfront costs since the annual cost savings on the energy present an economically attractive scenario. However, critical mediation stages during the lifespan of a building must be identified since these can serve as potential stages to upgrade energy provisions. Such stage-wise upgradation can be streamlined to minimize disruptions to owners and organizations while keeping abreast of the latest technologies and techniques for energy conservation. Policy interventions that are participatory development-driven—between government, local councils, and owners/organizations, can further aid in contextually sensitive retrofitting processes. Bottom-up policy initiatives that subsidize and acknowledge geo-location, climatic and socioeconomic conditions, major renovation cycles, capital improvement cycles, and resiliency upgrades should undoubtedly become the norm in the near future. The strategies suggested in this chapter can further aid in systematically fusing passive and active approaches toward nearly zero energy buildings. Such strategies will also benefit substantially by interfacing them with qualitative research conducted on-ground that predominantly deals with the assessment of human behavior and the drive to adopt retrofitting strategies. Community concerns, economic limitations, fear of disruption of everyday life, etc., could become critical insights from such qualitative explorations. These can further aid in tailoring policies while being sensitive toward the concerns of the everyday citizen. Retrofitting processes can benefit building typologies, such as aging building stock (houses and apartments alike), large-scale institutional buildings, offices with older energy-intensive energy systems, and heritage buildings. Additionally, buildings located in zones that face severe weather conditions (extreme heat or cold) or are undergoing post-disaster reconstruction can also benefit through undertaking the nearly zero energy transition.

The need to address climate change to shape a sustainable present and a thriving future is of utmost importance now more than ever. Retrofitting existing building stock in conjunction with sensitizing citizens and corporations alike and the participatory development of building policies and programs could undoubtedly hold the key to reducing emissions. Let us never forget that we have only one Earth, and it is our collective responsibility to protect this beautiful planet and our future, which are intrinsically linked.

Author details

Nimish Biloria[1,2]* and Nastaran Abdollahzadeh[1]

1 Faculty of Design, Architecture and Building, University of Technology Sydney, Sydney, Australia

2 Faculty of Engineering and the Built Environment, University of Johannesburg, Johannesburg, South Africa

*Address all correspondence to: Nimish.biloria@uts.edu.au

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