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Towards Achieving Sustainable Development Goal-2030 Agenda-Thirteen: A Review of Technological Advances from the Built Environment Professionals

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ABSTRACT

Natural resources are increasingly under pressures to cater for the growing human population and their corresponding, often conflicting needs. However, the need to conservatively utilize these resources without deteriorating the environment to the disadvantage of the future generations has prompted some actionable steps at the global level, the prominent of which is the promulgation of the United Nation's Sustainable Development Goal 2030 (SDG-2030) Agenda, having seventeen (17) inter-related actionable areas of human endeavours (i.e., Agenda). Of particular interest within this context is the Agenda Thirteen (Agenda-13) which encompasses the need for urgent action to combat Climate Change and its impacts across various areas of human engagements. This is necessary as Climate Change impacts are characterized with anthropogenic carbon emissions resulting in global temperature rise, sea level rise, flooding, desertification, droughts, and other related disasters. Within the precinct of Built Environment, it is established that building construction and operation alone account for about 40% of the global emissions. This calls for concerns and requires urgent collaborative actions to curtail the trend. This submission, which is review based therefore, highlights various joint efforts particularly, integration of technological advancements by the relevant building professionals, towards attaining the goal of Agenda-13. This is with a view to limiting climate change enablers for reduced environmental impacts. These collaborative efforts are categorized into *pre-construction* and *post-construction* activities from the relevant professionals in the built environment. While the former includes Indoor Thermal Comfort Simulation, Integration of Daylighting Technologies, and adoption of Computational Fluid Dynamics integrated architectural design process, the latter consists of design of Double Skin Facades, development of Building Integrated Photovoltaics façade, integration of Evacuated Tube Solar Air Collector System, adoption of Phase Change Material on Building façade, and implementation of Life Cycle Energy Analysis Policy, among others. These endeavours aim at reducing carbon emissions at the building micro level for overall clean, safe and sustainable global environment.

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1. Introduction

Rapid growth in population, economic activities and general urbanization during the last decades have had several environmental, economic, and social consequences, as governments across the globe attempt to improve the wellbeing of the teeming population Anukwonke et al., 2022; Koukelli, Hoces, and Asut, 2021). In effect, natural resources are transformed to build more houses, schools, hospitals, roads, railways, bridges, public libraries, and other public facilities, to accommodate the needs of the growing population. Thus, increase in industrial production gave rise to consumerism, with its attendant massive pressure on natural resources and the environment, leading to the undermining of the nature balance (Blewitt, 2014). This has raised concerns on depletion of local natural resources over the years, and signaled negative impacts capable of harming the well-being of the future generations on a global scale. Consequently, future severity of the problem has necessitated the need to embark on ecological and environmental preservation, for Sustainable Development of the natural resources (Stanujkic et al., 2020).

Thus, Sustainable Development within this context defines the process of transformation of natural resources without degradation for further utilization by future generations (Cohen, 2017). It connotes the use of natural resources without depleting them beyond replenishment, and without deteriorating the environment where they are situated (Yu et al., 2020). The term Sustainability which was initially introduced to represent a connection between development and environment, has become broader to include all aspects of development, inclusive of economic, social, and environmental dimensions, as the goals of sustainable development are now expanded, relative to those initially conceived in the 1990s (Rogers, Jalal and Boyd, 2012).

Arising from the foregoing, the need for Sustainable Development led to series of efforts at the international level which informed convergence of the maiden global conference in Brazil, the Earth Summit in 1992 (i.e., Rio-de-Janeiro-92), and a follow-up conference twenty years later (2012) in the same country (i.e., Rio+20), among others. These were followed with the declaration of Millennium Development Goals (i.e., MDG-2015) by the United Nations in 2015 (United Nations, 2015). Having observed unrealizable nature of the MDG-2015 Agenda, it was replaced with a more robust framework tagged, Sustainable Development Goals (SDG) with its main focus in 2030 (i.e., SDG-2030) (Stanujkic and Karabaševic, 2018; Attoye and Hassan, 2017; Nejat et al, 2015). This new concept is composed of seventeen (17) comprehensive objectives, 169 targets, separate ways of executions, and follow up actions. The seventeen (17) objectives are serially tagged Goals 1 to 17, having 'Poverty Elimination' and 'Partnership for goals' as Goals 1 and 17 respectively. Of primary interest for the purpose of this submission is Goal 13 (i.e., Agenda 13) with the focus on 'the need for urgent action to combat Climate Change and its impacts'. This is to be considered within the confine of the Built Environment (as against Natural Environment).

Built Environment constitutes the human-made surroundings that provide the setting for human activities, ranging in scale from buildings and parks or green space to neighborhoods and cities, often inclusive of their supporting infrastructure (Kaklauskas and Gudauskas, 2016). It encompasses the places where we live and work and the ways we travel (Thompson, and Kent, 2017). Buildings account for approximately 40% of global energy consumption (Attoye and Hassan, 2017; Nejat et al, 2015) as the built environment contributes significantly to global greenhouse gas emissions. Over 15% of carbon emissions result from energy consumption by buildings in many industrialised nations (Nejat et al, 2015; Gillott, and Spataru, 2010). Despite the level of emissions, the global building stock is expected to increase and double by 2060 because of new constructions, particularly in developing countries, due to the rapid growth in population, economic activities and fast urbanization, with an attendant increase in CO_2 emissions (Lotfabadi, 2013). Climate change, caused by the escalating levels of greenhouse gases in the atmosphere is therefore posing threats to human progress and well-being. Global climate disruption poses the most significant defiance to the environmental security of the earth and the heritage for future generations (Jafari, 2013; World Bank, 2016). Thus, there is the need for sustainable utilization of the available limited resources to guarantee safety of the future generations (Anukwonke et al., 2022). In line with the Agenda Thirteen of the United Nation's Sustainable Development Goal (SDG Agenda-2030), this paper therefore contributes to the existing body of knowledge by examining some of the efforts to combat Climate Change and its impacts, within the precinct of the Built Environment. This is with a view to reducing global carbon emissions and minimizing building construction impacts, for overall clean, safe and sustainable global environment.

2. Literature Review

Climate change is considered one of the severe issues that threaten sustainable development with regard to the environment, human health, food security, economic activities, natural resources and infrastructure (Karimi et al., 2022). It refers to climate fluctuations, directly and indirectly, related to human activities and change in the atmospheric composition (Amos et al. 2015). Recent scientific evidence shows impacts of climate change in form of the frequency, intensity and duration of extreme weather events, such as changing rainfall patterns, rising temperatures, droughts, among others (Table 1). These would remain unabated unless practical measures are taken to reduce greenhouse gas emissions, and mitigate climate change risks (Majedul Islam, 2022; Bell et al. 2018; Aphunu and Nwabeze 2012). Average global surface temperature has been rising in the last century as Intergovernmental Panel on Climate Change (IPCC) observed that the average of 0.87 °C (0.75–0.99 °C) for the 2006–2015 decade was over the second half of the nineteenth-century average (Laurini 2019; Capellán-Pérez et al. 2016). A future projection indicates that an average temperature increase of 1.5 °C may be realised as soon as 2026, and the global average temperature rise of between 2.7 and 5.2 °C above pre-industrial levels by 2100 (IPCC 2018; Foster et al. 2017; Capellán-Pérez et al. 2016; United Nations, 2015).

Table 1 Impact of climate change and extreme events on humanity

Climatic factors	Exposure pathways	Impact on humanity
• **Increasing temperatures Extreme heat events**	• Extreme heat, worsened air quality	• Increase in heat-related illness and death Elevated risk of cardiovascular and respiratory illnesses and death
• **Rising sea-level Frequent and intense extreme precipitation, cyclones, hurricanes and storm surges and associated flooding**	• Contaminated water; salinity intrusion; disruption of houses and other infrastructures	• Increased waterborne diseases; Reduced agricultural production; Injuries; Drowning; Preterm birth and low birth weight Infrastructure disruptions and post-event disease spread; Negative impact of mental health and well-being
• **Change in temperature extremes and seasonal weather pattern**	• Change in infectious agents	• Increased vector-borne diseases
• **Change in precipitation pattern and run-off**	• Recreational water and shellfish contaminated with waterborne pathogens	• Increased water and foodborne diseases
• **Droughts**	• Reduced water quantity Reduced air quality	• Reduced agricultural production; Respiratory impacts related to reduced air quality; Mental health impacts
• **Wildfires**	• Rising temperatures and hotter, drier summers increase the frequency and intensity of wildfires	• Smoke inhalation; Burns and other traumatic injuries Asthma exacerbations Mental health impacts

(Source: Majedul Islam, 2022)

Climate Change is considered as the alteration in the climatic arrangements over long periods arising from the natural processes like variability in sun radiations, volcanic eruptions, modifications in the climate system or because of the activities by humans' pollution, industrialization and land use changes (Hughes et al. 2018). However, extensive scientific analysis, most climate science and the Fourth Assessment Report of the IPCC agree that anthropogenic activities have had an increasingly dominant impact on the observed global warming since the mid-twentieth century (Malla et al., 2022; IPCC 2018). Human activities are observed to be the primary sources of excessive greenhouse gases (GHGs). Increasing emission of these GHGs inclusive of CFCs (chlorofluorocarbons), HCFCs (hydrochlorofluorocarbons), HFCs (hydrofluorocarbons), PFCs (perfluorocarbons), and SF6 (Sulphur hexafluoride) results in heat-trapping phenomenon which reduces heat loss into outer space, thereby making the universe hotter than expected, a scenario referred to as 'the greenhouse effect' (Farooqi et al., 2022; Anukwonke et al., 2022).

The built environment has a strong impact on both human and environmental health as development of buildings and other infrastructure within, consume great quantities of materials and energy during construction, operations, and eventual deconstruction at the end of their life cycles (Bardage, 2017). With increasing global population, urbanization and general economic activities during the last decades, there has been a corresponding increase in the pressure exerted on the available resources. These have raised concerns over depletion of local natural resources and supply difficulties as the building sector constitutes one of the major end users of energy (Koukelli, Hoces, and Asut, 2021; Kwong, Adam, and Sahari, 2014). Buildings account for about 15 % of carbon emissions, with transport and industry being responsible for 14 % and 21 %, respectively, and the remainder is due to other activities (Karyono and Bachtiar, 2017). Thus, efficient and sustainable utilization of energy is essential in conserving the fast-depleting resources, and protecting the environment from avoidable carbon emissions.

From the foregoing, needs to address climate change has featured in the policy frameworks of many countries (Valizadeh et al. 2020; Karimi et al. 2018). The threat of climate change has become a problem of the global commons which has brought the international community together, to devise mechanisms for addressing it particularly, to keep the global warming below 2 °C (Indukuri, 2022). The United Nations serves as an umbrella organisation with its key institutions at the forefront of propelling climate action from the 1970s. With the Stockholm Conference of 1972 to address global environmental issues, formation of the United Nations Environment Programme (UNEP) was achieved. Vienna Convention of 1985 brought attention to the protection of the ozone layer and made way for the Montreal Protocol of 1987 that set limits on the use and production of ozone depleting substances. With emerging consciousness and awareness on climate change, IPCC was established in 1988, to provide scientific information on the impacts, hazards and risks of climate change, with indications for the possible responses to deal with it. With the Earth Summit of 1992, a framework convention (United Nations Framework Convention on Climate Change i.e., UNFCC) was adopted to formulate principles, general goals and actions that countries should take as precautionary measures to limit GHG emissions. So far, not fewer than 197 member countries have ratified the UNFCCC, and are party to it. Hence, a Conference of Parties (COP) is held every year, and since inception, a total of twenty five (25) had been held (as at 2019) (Indukuri, 2022; Attoye and Hassan, 2017). The Earth Summit of 1992 was followed with series of other conventions: in Johannesburg (2002), the provisions of Earth Summit of 1992 were renewed; in Rio de Janeiro (2012), the idea of sustainable development in the context of economic and sociocultural settings, in addition to the environmental dimension was promoted; earlier, in the year 2000, an eight-point agenda, 'Millennium Development Goals' (MDGs-2015 Agenda) was promoted. Having measured its success for a period of fifteen (15) years, MDGs-2015 Agenda was replaced by another fifteen-year Programme, Sustainable Development Goals (SDG – 2030 Agenda) in Paris, 2015. The main agenda of SDGs-2030 are poverty elimination, provision of favourable and decent living conditions for people all over the globe by ensuring world peace, and sustainable economic and social development. The new Agenda is composed of 17 comprehensive objectives (known as SDGs), 169 targets, separate ways of executions, and follow up actions. Of the seventeen (17) goals, the first one, Goal 1, addresses 'Poverty eradication' as the last one, Goal 17, emphasises 'Partnership for goals' (Yu et al., 2020). Within the context of Built Environment, the focus of this submission is the Goal 13, which encompasses the need for urgent action to combat Climate Change and its impacts on the tropical design. The tropical climate is mainly characterized by an elevated temperature, the basis of which indoor thermal discomfort is usually experienced. To achieve comfortable indoor thermal environment, adoption of active measures such as installation of air-conditioners is usually integrated with the consequential increase in the resulting carbon emissions. As a departure from the old approach, this submission reviews some of the advances from the professionals in the Built Environment (i.e., Architects, Planners, Engineers, etc.) in their approach to combat Climate Change through reduced carbon emissions. Thus, subsequent sections of this submission dwell on the individual/joint efforts being made by the relevant professionals in the built environment (i.e., Architects, Planners, Engineers, etc.) towards achieving this important Goal-13 of the SDG-2030 Agenda.

3. Methodology

This submission adopts a literature review approach with focus on attainment of indoor thermal comfort particularly, in the tropical design through multi-disciplinary deployment of technological advancements from related professionals in the built environment inclusive of Architects, Planners, Engineers, etc. The approach is categorized into pre-construction and post-construction technological advancements, as highlighted in the following sections.

3.1 Pre-Construction Technological Advancements

In an attempt to reduce carbon emissions from building design and construction, evaluations of building performance are done by determining its potential carbon emissions at its design stage, ahead of actual construction. This is done through exploration of possible design options with a view to determining and adopting most efficient, and economical building design, for reduced carbon emission upon its construction, and subsequent usage. These pre-design evaluations usually involve building simulations that cover diverse areas of building performance for an overall efficient building energy consumption.

Building simulation involves subjecting virtual building models into performance analysis using appropriate software. It is a powerful tool that architects, planners, engineers, and other relevant professionals use to analyze how the form, size, orientation, and type of building systems affect energy performance of the building. Considering building input parameters, it is used to optimise building energy efficiency for informed design decisions (to improve building energy performance) with regard to the buildng envelope, glazing, lighting, HVAC, etc. (Olaniyan, Soyebo and Oyadokun, 2018). As a modern design tool, this analysis is particularly useful to attain best design solutions in the early phases of a project design in diverse areas of building performance inclusive of Indoor Thermal Comfort, Daylighting, Computational Fluid Dynamics, and Life Cycle Analysis, among others (Energy Design Resources, 2021). Each of these diverse areas is considered in turn, with specific applications by previous researchers, to demonstrate their practical influence on overall reduced carbon emissions:

3.1.1 Indoor Thermal Comfort Simulation

In order to respond to the climate change challenges, in an attempt to achieve sustainable design solutions, thermal simulation programs are employed to analyse thermal and energy behaviours of a building. This to arrive at specific thermal targets especially indoor thermal environment, through reduction of energy consumption with attendant environmental impacts (Olaniyan et al, 2018; Wang, Yan and Yi, 2011). Thermal comfort defines the state of mind that expresses mental satisfaction with the surrounding thermal environment (Shastrya, Mania and Tenoriob, 2016). It is regulated by balanced combination of environmental parameters (i.e., ambient temperature, mean radiant temperature, water vapour pressure or relative humidity, and relative air velocity), and personal parameters (i.e., clothing or thermal resistance, and activity or metabolic rate). The primary aim is to ensure adequate thermal capacity is available in the building structure and interior envelope surfaces of habitable rooms for overall thermal comfort of the occupants (Prianto and Depecker, 2003). Ordinarily, this is attained through the use of active measures such as air-conditioning systems with its attendant carbon emissions, arising from fossil fuel that powers the system. However, with deployment of technological advancement through pre-construction numerical simulation of the proposed structure(s), to analyse the influence of design elements and building envelopes on indoor thermal comfort for sustainable building development, best design solutions are easily obatained with pre-determined minimal carbon emissions (Energy Design Resources, 2021). A typical illustration of a virtual building model subjecting to such a simulation environment (i.e. DesignBuilder) is demonstrated in Figure 1, with some thermal comfort data output shown in Figure 2.

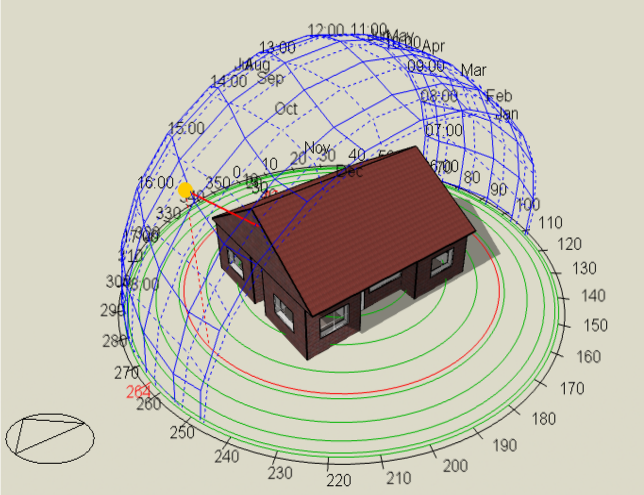


Figure 1 Typical Virtual Model of the Building as displayed on DesignBuilder software Interface (Source: Author's work, 2022)

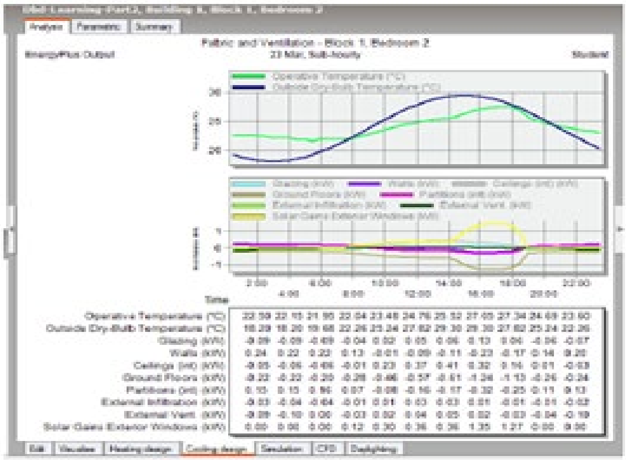


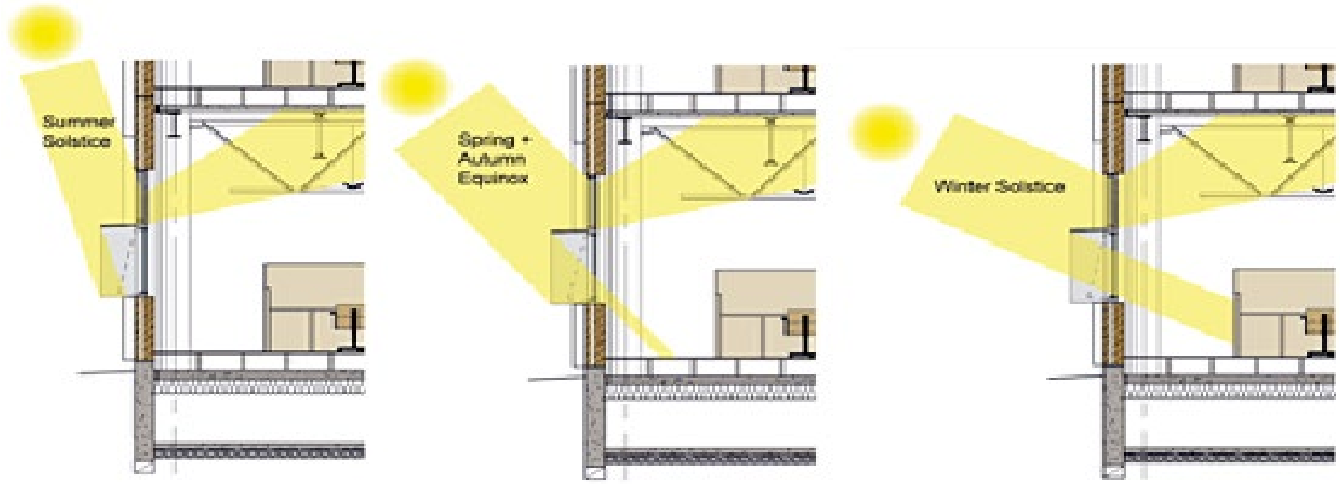
Figure 2 Typical thermal comfort data output for indoor Thermal Comfort for a Residential apartment (Source: Author's work, 2022)

In effect, carbon emissions are reduced with a view to combating climate change impacts, in line with SDG-2030 Agenda 13. Such simulation software may include Anthermc, DesignBuilder, eQUEST, TRACE 700, IES, TAS, TRNSYS, COMFIE, etc., (BEST Directory, 2022; Olaniyan, 2018). Typical illustrations abound in previous research works where significant evidence-based reduction in carbon emissions were achieved to arrive at energy efficient building designs. These include: building's energy performance and indoor thermal comfort for a hot and semi-arid climate by El-Bichri et al (2022): dynamic thermal simulation of five ecological houses located in different cities of France with different climate zones by Kaoula and Bouchair (2020); experimental validation of five house-like cubicles, built at a real scale in a village with a typical Mediterranean climate located in Spain, under summer conditions by Serrano et al. (2016); experimental testing of five earth brick types in a laboratory wall prototypes by Bruno et al. (2020); several studies comparing thermal implications and energy optimisation between various walling materials (Homod et al., 2021; Marincic et al., 2014; Patel & Prasad, 2016; Sghiouri et al., 2020; Taylor et al., 2008), among others. In each of these cases, building thermal performance simulation through application of technological advancement was carried out to optimise energy efficiency of the building, resulting in reduced energy consumption with the overall reduction in carbon emissions

3.1.2 Integration of Daylighting Technologies

Daylighting is a renewable energy solution for illumination and visual comfort in buildings (Yu, Su and Chen, 2014). It is regarded as a basic energy saving design strategy for buildings (Ihm, Nemri and Krarti, 2009). It defines controlled admission of natural light, direct sunlight, and diffused-skylight into a building to reduce electric lighting with a view to saving energy (Ander, 2016). It involves redirection of sunlight into building spaces to maximise sufficiently, usage of natural lighting for reduced electric lighting (Alva & Madamopoulos, 2020). It is an energy-efficient strategy that integrates many technologies with design philosophies. The potential energy saving through daylighting is mainly achieved by applying daylight-linked artificial lighting control system, which regulates artificial lighting output in accordance with the quantity of daylighting that penetrates through the existing windows or other relevant openings, to ensure that the required indoor illuminance level is maintained. In this regard, both High frequency dimming control, and on-off control, are the two commonly adopted lighting control system in day-lit buildings (Li, 2010). Apart from the basic daylight apertures (i.e. windows and passive skylights), advanced daylighting technologies comprises of an integrated daylight-responsive control system involving one or more of: Climate-responsive window-to-wall area ratio; High-performance glazing; Daylighting-optimized fenestration design; Skylights (active); Tubular daylight devices; Daylight redirection devices (Figure 3); Solar shading devices; Daylight-responsive electric lighting controls, etc.

Ordinarily, artificial lighting facilitates heat gain inside the building. However, reduction in the use of artificial lighting through integration of daylighting technologies with proper electric lighting control system, can result into considerable less cooling load and potential for smaller cooling, ventilation and air-conditioning (HVAC) plants, since most of non-domestic buildings are in use during daylight hours (Li, Lam and Wong, 2006). Thus, potential energy savings from artificial lighting through daylighting technologies can be determined using European Standard EN15193, static climate-based Daylight Factor (DF) method, dynamic climate-based Daylight Coefficient (DC) method, among others. Using Computational analysis, daylighting room performance can be obtained through lighting simulation tools such as Raytracing, Energyplus, Relux, Daysim, TAS, etc (Yu, Su and Chen, 2014). From previous studies, energy consumption savings from electric lighting in non-domestic buildings of: 20–30%, and 25-40% in Hong Kong and USA respectively, were recorded (Li and Wong, 2007); 20–40% reduction in another studies by Embrechts and Bellegem (1997); 10.8 to 44% reductions in UK buildings by Ghisi and Tiker (2006); 30 to 77% reductions in field measurements and computer simulation analysis on commercial buildings from studies by Doulos, Tsangrassoulis and Topalis (2008). As part of daylight harvesting strategies, Kontadakis et al. (2018) demonstrate adoption of interior and exterior light shelf, as a component of the building façade; Lee et al. (2018) illustrate light-redirecting performance of an awning system (with a built-in light-shelf) with its energy saving-capability; use of anidolic reflector (i.e. light pipe) in the ceiling plenum was studied by Kennedy and O'Rourke (2015), and; light redirecting system through reflective louvers, Okasolar in-pane louver series was developed by Okalux (Okasolar, 2018), to demonstrate its energy saving capabilities. These daylighting strategies illustrate a global shift towards more efficient energy resource management, with its end-use lower energy consumption and attendant reduced carbon footprint potentialities.



(a) (b) (c)

Figure 3 Seasonal performance of shading, redirection devices for optimised daylighting during: (a) Summer Solstice (b) Spring and Autumn Equinoxes; (c) Winter Solstice (Source: Ander, 2016)

Ordinarily, artificial lighting facilitates heat gain inside the building. However, reduction in the use of artificial lighting through integration of daylighting technologies with proper electric lighting control system, can result into considerable less cooling load and potential for smaller cooling, ventilation and air-conditioning (HVAC) plants, since most of non-domestic buildings are in use during daylight hours (Li, Lam and Wong, 2006). Thus, potential energy savings from artificial lighting through daylighting technologies can be determined using European Standard EN15193, static climate-based Daylight Factor (DF) method, dynamic climate-based Daylight Coefficient (DC) method, among others. Using Computational analysis, daylighting room performance can be obtained through lighting simulation tools such as Raytracing, Energyplus, Relux, Daysim, TAS, etc (Yu, Su and Chen, 2014). From previous studies, energy consumption savings from electric lighting in non-domestic buildings of: 20–30%, and 25-40% in Hong Kong and USA respectively, were recorded (Li and Wong, 2007); 20–40% reduction in another studies by Embrechts and Bellegem (1997); 10.8 to 44% reductions in UK buildings by Ghisi and Tiker (2006); 30 to 77% reductions in field measurements and computer simulation analysis on commercial buildings from studies by Doulos, Tsangrassoulis and Topalis (2008). As part of daylight harvesting strategies, Kontadakis et al. (2018) demonstrate adoption of interior and exterior light shelf, as a component of the building façade; Lee et al. (2018) illustrate light-redirecting performance of an awning system (with a built-in light-shelf) with its energy saving-capability; use of anidolic reflector (i.e. light pipe) in the ceiling plenum was studied by Kennedy and O'Rourke (2015), and; light redirecting system through reflective louvers, Okasolar in-pane louver series was developed by Okalux (Okasolar, 2018), to demonstrate its energy saving capabilities. These daylighting strategies illustrate a global shift towards more efficient energy resource management, with its end-use lower energy consumption and attendant reduced carbon footprint potentialities.

3.1.3 Adoption of CFD-integrated design process for informed decision-making in architectural design

Computational Fluid Dynamics (CFD) is a fast and effective computer-based numerical analysis simulation tool that analyzes complex fluid flows which evaluates ventilation, energy performance, design, and stability in the field of architecture, among others. It is used to model and quantify airflow-related cases (including ventilation, infiltration and dispersion of the contaminants), and test the wind-built environment interactions through numerical analysis. It enables the analysis of various shapes and environmental conditions (Lee et al, 2021; Merin Abbas & Gürsel Dino, 2019). It constitutes an important tool to understand current airflow designs, to reveal present shortcomings for improved ventilation and energy performance in particular (Melendez, Reilly & Duran, 2021). Within the CFD domain, Heating, ventilation and air conditioning (HVAC) systems can be manipulated to determine the optimal configuration for ventilation efficiency and energy performance. A typical illustration is Figure 4 of the CFD study carried out by Moosavi et al. (2014) which predicted air temperature in the naturally ventilated building with windward openings reduced to 0.1 m. The study shows the effects of minimizing windward opening size on indoor temperature distribution using CFD simulation tool.

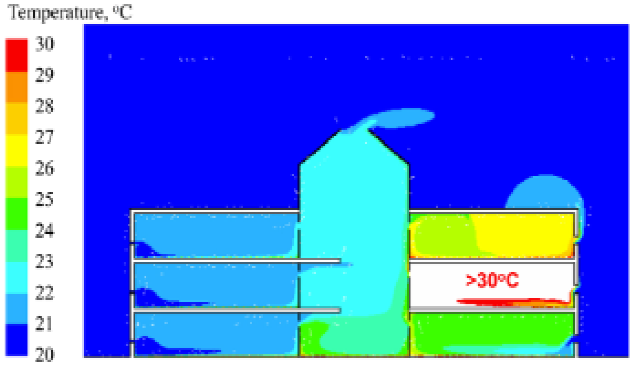


Figure 4 Predicted air temperature in the naturally ventilated building with windward openings reduced to 0.1 m (Source: Moosavi et al, 2014)

In general, numerical analyses involving CFD are often carried out to evaluate building design and energy performances. Such information obtained by CFD assists in investigating the impact of building technologies, quantifying indoor environment quality, and integrating renewable energy systems (Moosavi et al., 2014). CFD modeling approach was used to determine the influence of building morphology on the efficiency of building-integrated wind turbines in Bahrain Trade Centre (Chaudhry, Calautit & Hughes (2015). The study highlighted the potentials of using advanced CFD to factor wind into the design of any architectural environment. Other studies inclusive of Jana, Sarkar & Bardhan (2020), Subhashini & Thirumaran (2020), Mora-Pérez, Guillén-Guillamón & López-Jiménez (2015), Lu and Sun (2014), Chong et al. (2014), Wu, Hung & Lin (2013), Mithraratne (2009), Chen (2004), have also demonstrated application of CFD-integrated design process for informed decision-making to evolve sustainable design solutions with reduced energy needs, to mitigate carbon emissions

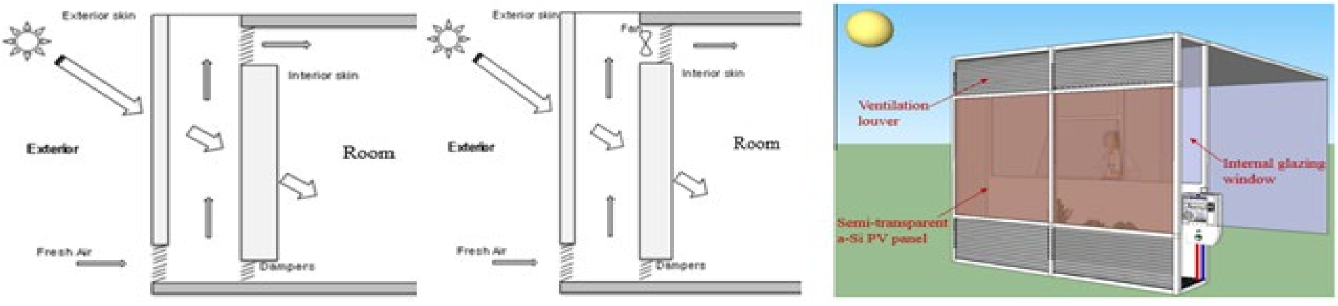
3.2 Post-Construction Technological Advancements

This involves deployment of advanced technologies for building operations, through thermal harvesting, and management in secondary thermal applications, to optimize occupants' comfort and reduce building energy requirements (Cuce and Riffat, 2015). It involves exploration of new building techniques and development of technologies that harvest Infra-Red (i.e., thermal) solar energy which in turn, offsets the energy requirements of electrical systems for mechanical systems for heating/cooling needs. This concept may involve (but not limited to) any of the following approaches:

3.2.1 Design of double skin facades (DSF)

This is a form of construction involving arrangement of separated two layers of façade curtain with an infill air cavity which can in turn be naturally or mechanically ventilated for controlled heat gains or for captured heated air which is used for space and water heating (Alva, Vlachokostas and Madamopoulos, 2020; Su, Li, and Xue, 2017). The need for this is borne out of the increasing costs of energy, necessity for reduction in energy consumption and growing concerns for environmental protection [European Commission, 2022). DSF integrated with photovoltaic modules reduces solar heat gain due to their high absorptivity and low transmittance. Previous work by Peng et al. (2016) shows that only one seventh of the incident solar energy passes through such DSF type as its direct solar heat gain coefficient is as low as 0.15. This is due to its ability to block much solar heat gains from passing through. As illustrated in Figure 5, the arrangement involves combinations of varying thermal masses (may be of Concrete, Sandcrete Block, Glass or Aluminium) (Fallahi et al., 2010).

Over the past decade, DSF has become an increasingly important feature in the architectural building design and operation, as its usage spreads across, to cover provision of: thermal buffer zones; solar preheating of ventilation air; energy saving; protection against wind, sound and pollutants, and; night cooling and space for energy collection devices like Photovoltaics cells. It has become an important feature of renewable thermal source to enhance clean energy utilization as quotient of carbon emissions is significantly reduced (Agathokleous and Kalogirou, 2016). In effect, it is an approach at building micro-level to combat climate change impacts on the environment. Studies carried out by Zhu et al. (2020), Luo et al. (2017), Su, Li and Xue (2017), Han, Lu, and Yang, (2010), Zhou and Chen (2010), De Gracia et al (2013), Gan (2009), Gratia and Herde (2004), Mei et al. (2003), Eicker et al (1999), among others, demonstrate material compositions, heat transfer methodologies, comparative energy performance and quantifications (relative to other renewable energy sources), dynamic thermal model and challenges associated with DSF integration in buildings. Essentially, when DSF is designed for optimal performance, it is capable of reducing energy needs in the building with the resulting positive impact on the global environment.



(a)[1] **(b)**[2] **(c)**[1]

Figure 5 Schematic diagram of ventilation approach in a DSF: (a) naturally ventilated façade (b) mechanically ventilated façade; (c) mechanically ventilated façade (Sources: 1 – (Agathokleous and Kalogirou, 2016); 2 – (Peng et al., 2016)

3.2.2 Development of Building Integrated Photovoltaics (BIPV) façade

This is an advanced application of technologies in which building façade is substantially integrated with photovoltaics panels with a view to harvesting natural solar energy for building operation, with minimal impact on the environment. It is an emerging innovation in which building façade is converted into a clean renewable micro-energy-based generator as it satisfies the fundamental and conventional design objectives of aesthetics and environmental control (Attoye & Hassan, 2017; Peng, Lu and Yang, 2013), as illustrated in Figure 6.

(a) (b) (c) (d)

Figure 6 Application of BIPV facades in architectural design: (a) White PV (b) Coloured PV panels (c) PV-powered media wall of Xicui Entertainment Complex in Beijing (d) Building integrated media energy display (Source: Sun et al, 2021)

If designed for optimal performance, the facades can facilitate significant reduction in heat gains and heat losses in summer and winter respectively, through the entire building envelope (Peng, Lu, & Yang, 2013). In particular, multiple gains such as reduced use of fossil fuels, lower carbon emissions, and decreasing emission of ozone depleting greenhouse gases, among others, are derived from BIPV façade technology (Zhang, Lu and Peng, 2017; Agathokleous and Kalogirou, 2016). Several studies affirm substantial energy saving capability of the technology with its reduced pollution and other environmental challenges associated with the conventional energy sources particularly, the negative impacts on the ecosystem (Elinwa, Radmehr, and Ogbeba, 2017; Bayoumi, 2017; Peng et al, 2016; Chow et al., 2010; Wong et al, 2008). It is a promising way of cutting down the environmental costs of fossil fuel energy generation as it is capable of delivering electrical energy at a lower cost compared with grid electricity, for certain end users (Song et al, 2016; Norton et al, 2011)

3.2.3 Integration of Evacuated Tube Solar Air Collector System

This is a form of solar energy harvesting technology in which heated air is transported through a horizontally placed absorber tubes integrated into glazing unit system, installed on a building facade (Alva, Vlachokostas and Madamopoulos, 2020; Maurer et al., 2012). Different configurations of evacuated tube solar collectors inclusive of U-type, H-type, T-type, heat pipe type, etc., exist (Ataee & Ameri, 2015; Nkwetta, & Smyth, 2012). Essentially, Evacuated U-tube solar collector consists of a heat exchanger which transfers the energy from Sun solar radiation to the working fluid. The system consists of an array of fixed-angled, tilted absorber slats connected to fluid piping and contained within three glass panes. Air is heated by convection through the sun-exposed tubing and returned into the building for potential use in mechanical systems (Maurer et al., 2017). Through radiative heat transfer process, the solar radiation incident on the outer glass surface of the evacuated tube is transferred to the inner glass tube. Then, the heat so generated is absorbed by the U-tube from where it is exchanged to the working fluid (Naik, Bhowmik, and Muthukumar, 2019). A typical illustration of this principle is shown in Figure 7 and Figure 8.

Several research works have been carried out to demonstrate potential energy saving capabilities of this technology by Singh and Vardhan (2021), Yildirim and Yurddas (2021), Naik, Bhowmik and Muthukumar (2019), Maurer et al. (2017), Gao et al. (2014), Maurer et al. (2012), among others. As an applicable technology, it is capable of generating building energy needs through clean and renewable energy source which combats climate change induced carbon emissions from fossil fuels.

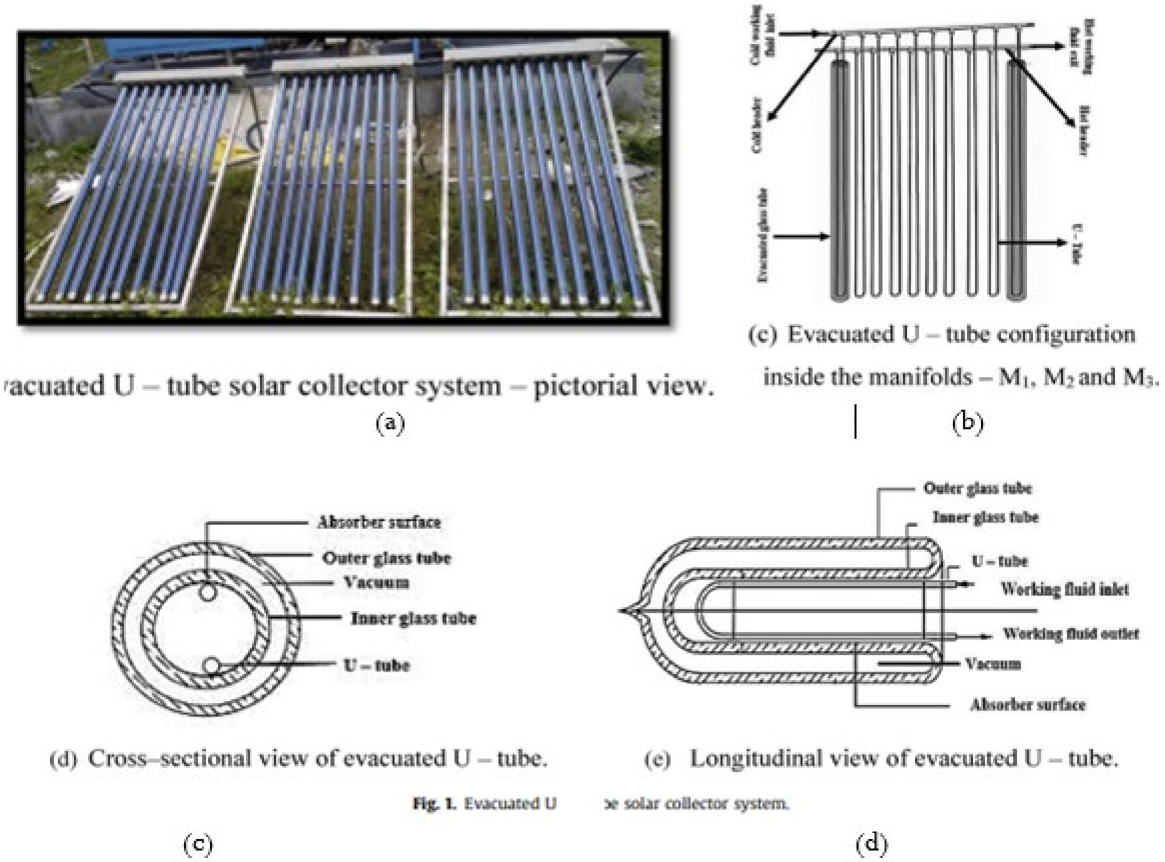


Figure 7 Evacuated U-tube solar collector system: (a) Pictorial View (b) U-tube configuration inside the manifolds (c) Cross-sectional view of Evacuated U-tube (d) Longitudinal view of Evacuated U-tube (Source: Naik, Bhowmik & Muthukumar, 2019)

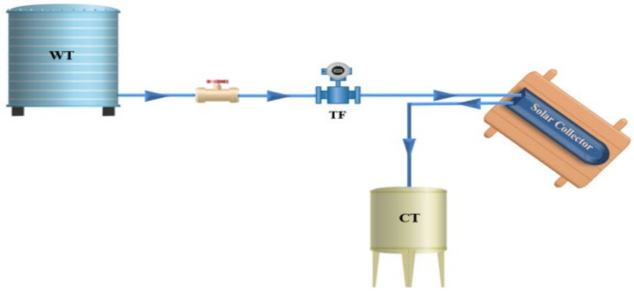
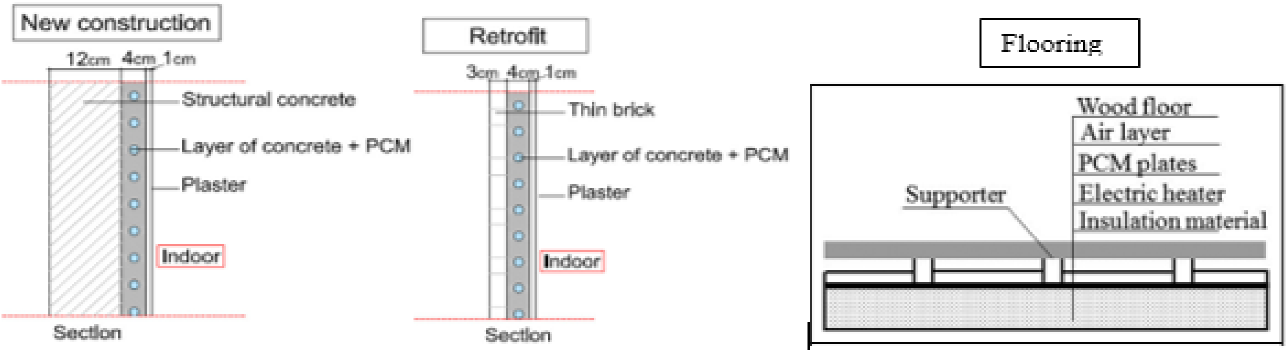


Figure 8 Schematic View of solar collector system application in buildings (CT – Collection tank; TF – Turbine type flow metre; WT – Water tank) (Source: Kiran, Premnath & Muthukumar, 2021)

3.2.4 Adoption of Phase Change Material on Building façade

This represents a joint advanced technological deployment by related building professionals with a view to combating climate change impact at building micro-level. Phase Change Material (PCM) in this context refers to thermal energy storage (TES) material which absorbs heat (cold) from the environment and stores it, and releases same to the immediate environment at a later stage, when needed. This cycle of thermal energy exchange with their environment is completed in their process of phase change, to conserve energy usage, and reduce carbon emissions while regulating the comfort of the surrounding environment (Yichao et al., 2020; Wang et al., 2018). PCM, also known as latent heat storage material is characterized with high energy storage density and stable output temperature that constitute important features for improving its energy structure and utilization. With its high heat of fusion, it absorbs and releases heat at a nearly constant temperature, and has capacity to store 5–14 times more heat per unit volume than conventional sensible storage materials (Sharma, Chen & Buddhi, 2009). Its melting temperature is expected to be close to the human health and comfort temperature levels, according to the indoor thermal comfort conditions (approximately 25 °C). TES technology could be useful for domestic hot water or space heating and cooling purposes as PCM releases latent heat earlier absorbed during the phase change from solid to liquid. Its application in building as a component of building envelope facilitates smoothing of the diurnal temperature fluctuations, with the overall reduction in the building's energy consumption (Navarro et al., 2019; Zalba et al., 2003).

Right use of PCM can minimize the peak heating and cooling loads, thereby downsizing cooling/heating systems, and has the capability to keep the indoor temperature within the comfort range due to smaller temperature fluctuations. Its main advantage is its ability to enhance the thermal storage potential with a minimum change of the existing building design (Harlé et al, 2022; Souayfanea, Fardouna, and Biwole, 2016). It can improve the thermal inertia of buildings, and improve their energy usage, which contributes to reduction of greenhouse gas emissions and therefore global warming (Harlé et al, 2022). In residential buildings, between cooling and heating energy savings of 5 and 30% can be attained with the application of PCM on thermal mass in well insulated structures (Souayfane, Fardoun, and Biwole, 2016; Kosny, 2015). It can be integrated into the building envelope through direct incorporation, immersion, shape-stabilization, micro-encapsulation and macro-encapsulation (Liu et al, 2018; Wahid et al., 2017; Konuklu, Paksoy & Charvat, 2015). They can also be incorporated into finish materials, thermal insulation or structural components (Kosny, 2015). Schematic illustrations (sectional views) of PCM in new construction, retrofit, flooring and ceiling applications are shown in Figure 9 and Figure 10.



(a)[1] **(b)**[1] **(c)**[2]

Figure 9 Schematic Phase Change Material applications in: (a) new construction (b) retrofit, and; (c) flooring (sources: 1 – Navarro et al, 2019; 2 – Cui et al, 2017)

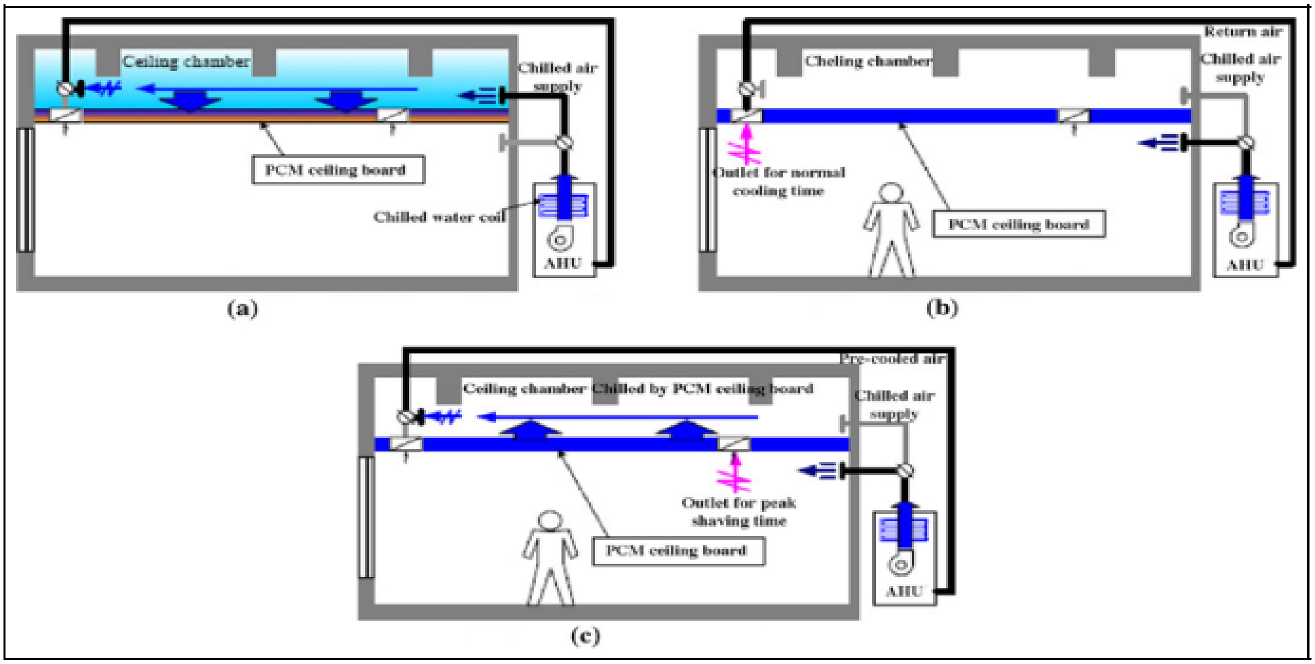


Figure 10 Schematic Phase Change Material applications in ceiling: (a) overnight thermal storage time (b) normal cooling time, and; (c) peak shaving control time (source: Cui et al, 2017)

Apart from the common inorganic and organic PCM, also in existence are the monolithic and binary or multicomponent composite (eutectic mixtures) types (Li et al., 2017). For effective energy saving, building structure, climate, environment, and the purpose of using PCM, have significant role to play. In particular, varieties of PCM applications (such as paraffin, fatty acid, hydrated salt, eutectic), integrated in building envelope in varying climatic regions differ as Figure 11 presents a global survey of different PCMs in use, on a world map with identified varying climatic sub-areas. The figure describes PCMs usage/applications in different cities of the world, to emphasize its global acceptability.

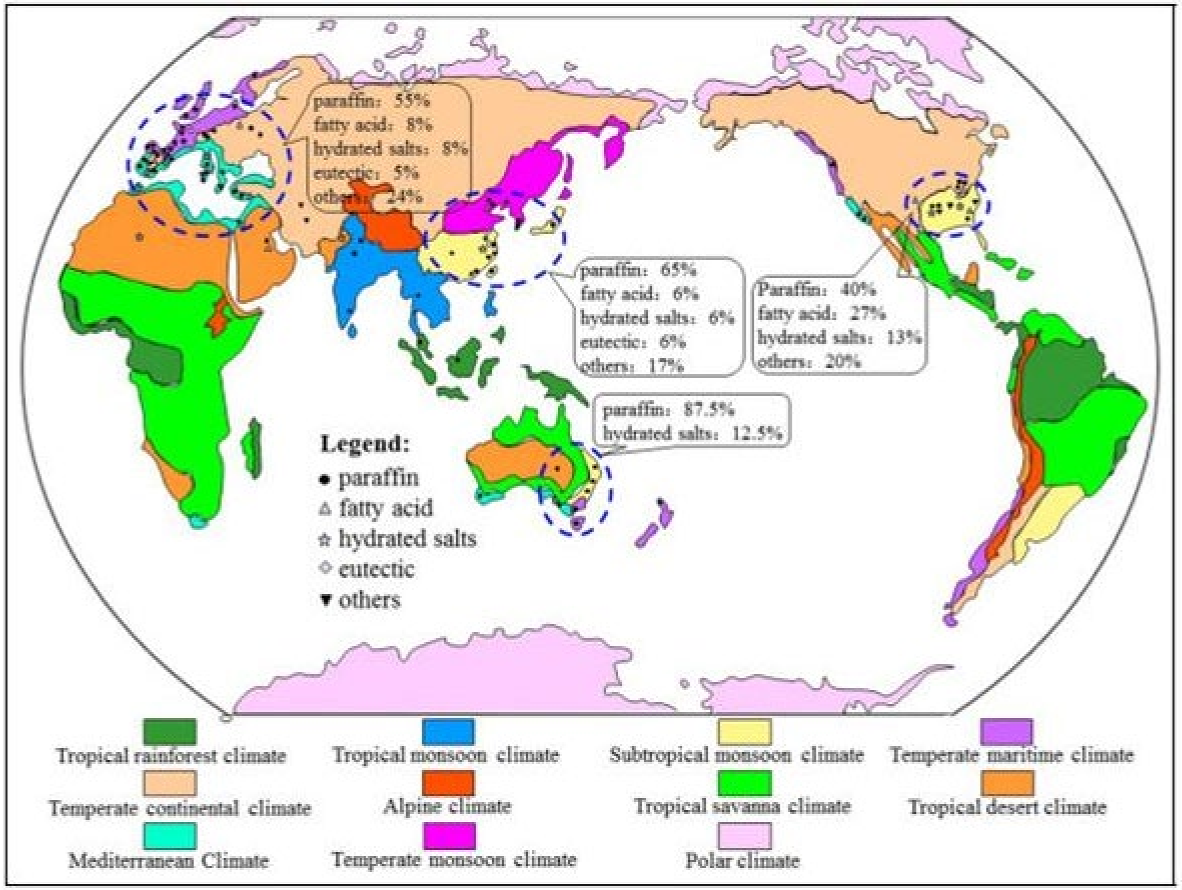


Figure 11 Adoption of varying Phase Change Material applications in different Climatic Regions (source: Cui et al, 2017)

Previous studies inclusive of Shah et al. (2022), Liu et al (2018), Cui et al. (2017), Genc & Karagoz (2017), Kalnæs & Jelle (2015), Memon (2014), Zhou, Zhao and Tian (2012), among others, have been conducted to explore possibilities of integrating PCM into building design as new constructions and retrofits.

3.2.5 Implementation of Life Cycle Energy Analysis Policy on New Construction

Life cycle energy analysis (LCEA) is one of the several tools for analysing and minimizing environmental impacts of building construction as it minimizes the risk of shifting an environmental impact from one part of the life cycle to another (Paulsen & Sposto, 2013). It is an approach through which all energy inputs into a building throughout its life cycle, from 'cradle to grave' are accounted for (IPCC, 2007; Cabeza et al, 2014). Implementation of LCEA policy requires substantial professional and technical expertise especially, on new construction works, to account for the energy use at different phases of the construction cycle, with a view to reducing carbon emissions. These phases include those of manufacturing (i.e., embodied energy), building operation (i.e., operating energy), and final demolition (i.e., demolition energy) (Stephan, Crawford & de Myttenaere, 2013). As graphically illustrated in Figure 12, manufacturing phase includes manufacturing and transportation of building materials as well as technical installations used in building construction, with a typical comparison of Global Warming Potential by Life Cycle Energy Analysis at this Stage (Embodied Effects), as illustrated in Figure 13.

4. Conclusion

Increasing urbanization resulting from the growing population necessitates the need for more infrastructural facilities particularly, housing, among others, with its attendant energy utilization, and consequent negative impacts on the environment. Thus, there is the need for innovative ways to optimize energy use in buildings, to lessen the impact of climate change, due to increasing carbon emissions from building construction and operation. This is emphasized with the promulgation of the seventeen-point United Nation’s Sustainable Development Goal 2030 (SDG-2030) Agenda with particular reference to Agenda Thirteen (Agenda-13) which encompasses the need for urgent action to combat Climate Change. Within this context, this submission has discussed beneficial impact of emerging technologies through collaborative efforts of the relevant professionals within the built environment, to address the pandemic climate change related challenges. In particular, the submission focuses on the application of the emerging technologies at both pre and post construction stages for more optimized energy utilization and reduced carbon footprint particularly, at the building micro level. This is a collaborative effort towards realization of the SDG-2030 Agenda Thirteen (Agenda-13) in particular, for overall sustainable clean and safe global environment..

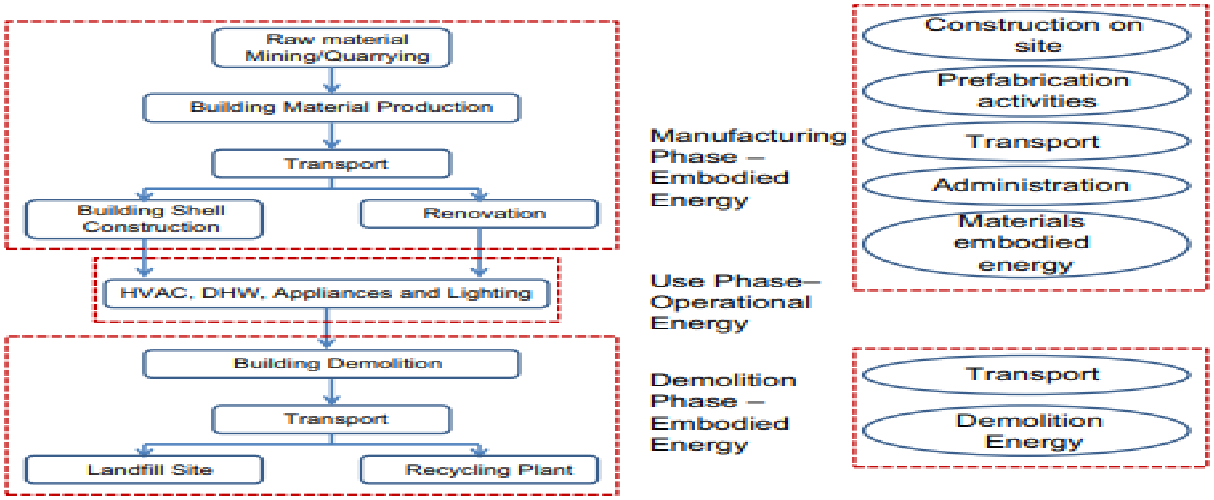


Figure 12 Life Cycle Energy Analysis of a building (source: Cabeza et al., 2013)

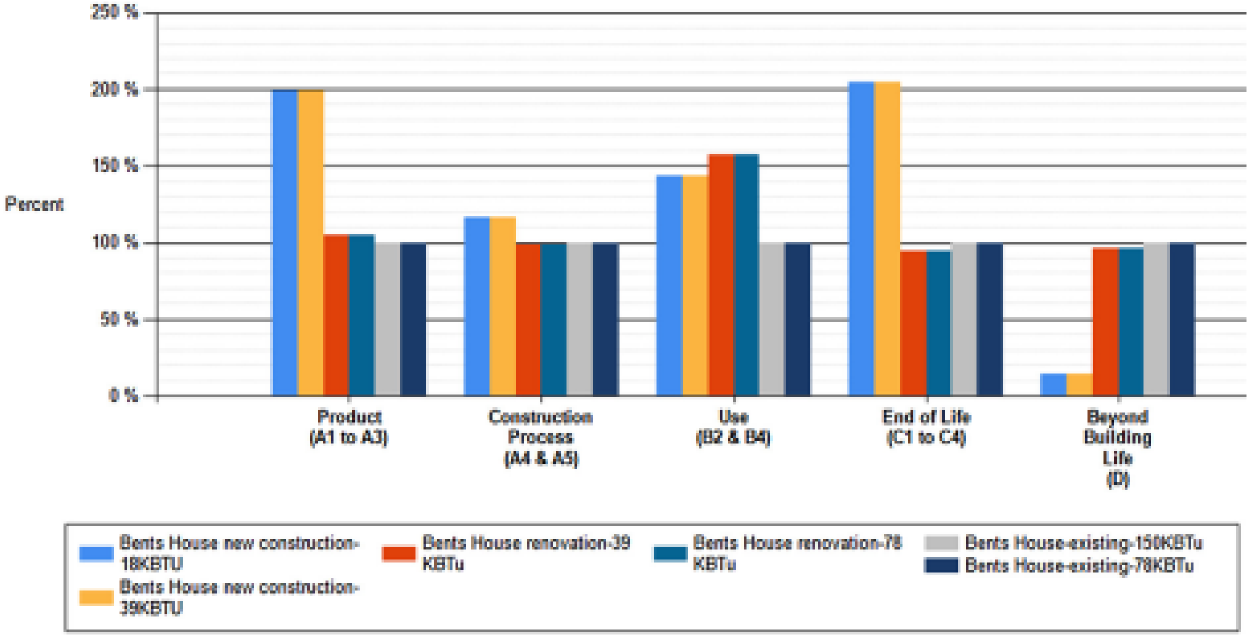


Figure 13 Comparison of Global Warming Potential by Life Cycle Stage (Embodied Effects) (source: Hu, 2017)

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