A quantitative case study to assess the performance of UK supermarket buildings in relation to future climate change and modern construction techniques (MMCs)

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Abstract: This study examines several non-domestic building construction techniques and their impact on a typical UK supermarket's building performance under the worst-case scenarios of the period of climate change in the 2080s. To determine operating energy consumption and carbon emissions, emphasis is placed primarily on the three LIDL-approved construction techniques and the materials used in their construction. The Chartered Institution of Building Services Engineers (CIBSE) provides the current and projected weather files to be tested, and Thermal Analysis Software (TAS), a dynamic building simulation tool, is used to quantify the results and generate reports. The case study is based on a recently constructed single-story supermarket building in Norwich and employs three building models, P1, P2, and P3, each of which uses a particular set of construction materials. The results indicate that the percentage increase in energy consumption and carbon emissions for models P1 and P2 is close to 8.80%. However, P3 model has an increase of less than 8.50% when compared to the building's current condition, making it a marginally better option. It suggests that a precast concrete and glulam beam structure offer the best resistance against the worst climate change scenario. While presenting the findings, this investigation merges the two distinct aspects of the built environment, construction and operation.

Keywords: climate change, construction, operational carbon, TAS, supermarket building performance.

1. Introduction

According to IPCC (The Intergovernmental Panel on Climate Change), climate change is one of the most urgent problems of the 21st century because the global climate is constantly fluctuating It has a significant impact on the environment, particularly the built environment, which influences not just energy use and greenhouse gas (GHG) emissions but also global costs and the economy (Stern & Great Britain. Treasury, 2007).One of the major recognized contributors to climate change is the operational energy (in-use phase) of the buildings (Sharma et al., 2011; Adalberth, 1997). According to The Non-Domestic National Energy Efficiency Data-Framework 2020 or ND-NEED (England and Wales), there are 1,656,000 non-domestic buildings in England and Wales (end of March 2020) and among them, the top three non-domestic building users are Shops (29%), Offices (20%) and Factories (14%) as depicted in Figure 1.

The most recent data also suggests that total non-domestic buildings in England and Wales used 293 TWh and 140 TWh of electricity respectively, and 153 TWh of gas (Steadman et al., 2020). Due to such huge energy consumption in the UK, the built environment and energy intensive buildings are one of the largest sources of emissions and therefore it is necessary to quantify and reduce these emissions.

However, recent developments demonstrate the increasing importance of the impact of construction in proportion to operational energy use as well. During the complete life cycle of the building, the operational energy plays a significant part as it is responsible for the building equipment usage such as the lighting, cooling, heating, use of domestic hot water and other minor appliances (Hasan et al., 2020). However, it is interlinked with other stages as well which include construction, occupation, and end-of-life deconstruction. In recent years, there has been much focus on the overall life cycle of the building which includes embodied (production/construction and end-of-life) and operational (in-use) stages.

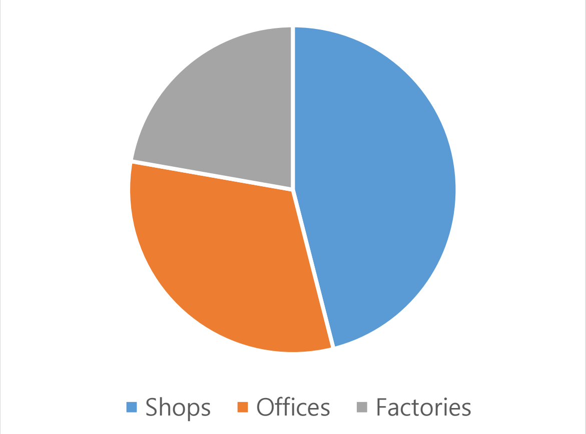

Figure 1. Energy usage division by percentage in the UK non-domestic buildings (Steadman et al., 2020)

2. Relationship Between Modern Construction Materials/Methods and Climate Change

As previously mentioned, much emphasis has been placed on reducing and saving on the costs of the buildings in operation phase as well as their emissions and energy consumption. Nevertheless, adaptation planning for the overall reduction is needed, by considering the building materials utilized in the structure of the building. Different buildings in the UK are constructed to last only for a specific period usually a few decades. For example, the service life of a UK residential house is assumed to be 50 to 60 years for international assessments (Meikle and Connaughton, 1994).

It is important to consider how the building's performance is affected by the link between the materials used in construction and the effects of climate change. Such an approach is necessary, since there is a significant likelihood that future performance issues will appear that may not be existing in the buildings' present state. (Almås et al., 2011). Ultimately, it will lead to shortening of the building service life (El-Dash, 2011). Therefore, it has become a significant challenge in the UK to develop innovative construction methods using different building materials for the newly built supermarket and retail buildings that will not only be able to provide the building with futureproofing by reducing the impact of future climate change but also prolong the service life of the building and keep the carbon emissions and energy consumption of the building in check, especially in the face of changing climate under various representative concentration pathway scenarios (RCPs).

Typically, the selection of building materials is based on providing a high comfort level to the customers by achieving a particular internal environment that would enable the supermarket to function efficiently. There is no regard given to the external climate.

According to one study, there are three important aspects to selecting a specific construction method to ensure good performance of the building (Phillipson, Emmanuel and Baker, 2016). They include:

1. Protecting the building and its contents against climate loads.
2. Maintaining good performance in the face of weathering and other degradation mechanisms.
3. Allowing ventilation to control internal temperatures, moisture levels, and internal air quality.

It is also important to note that historically speaking, some buildings specifically high energy use intensity (EUI) ones, such as supermarkets and retail stores, have been designed and constructed using the historic climatic data as compared to other domestic buildings such as homes/dwellings (Bahadori-Jahromi et al., 2022). The idea behind such construction was to perform a risk evaluation of the excesses that a building might experience from the climate loadings. However, as the recent extreme climate change has proved, this approach to be inadequate and designers are now being encouraged to take i future climate change into consideration instead (Stalker, 2006).

Even though the relationship between the methods of construction and climate change is a complex one, it cannot be ignored. It is currently a critical factor to consider while designing a building. Multiple studies indicate that, during the construction stage of the building, focusing only on the previous climate data or ignoring the future climate change data can have a potentially catastrophic impact on the built environment including the risk of flooding in some cases (Milly, Wetherald, Dunne and Delworth, 2002; Wilson and Piper, 2008).

3. Methodology

The methodology followed for this work, consists of two different aspects of investigation and later combination of the both is used to bring forth the comprehensive results. It includes the use of different construction methods (LIDL-approved ones) and the building services to quantify operational usage and emissions of the supermarket building.

3.1 LIDL-approved construction methods

The first part of the research approach makes sure that the construction methods used in this paper are approved by LIDL, a leading supermarket retail chain in the UK. Each construction method uses a different set of construction materials which is then used to change the building fabric accordingly. For the analysis, a building energy modelling software is required which allows the user to incorporate multiple building construction materials and also accommodate the needs of the operational energy and carbon emissions functionality as well. The software model must also allow the use of climate change scenario data (current and future). Using such a software facilitates the generation of accurate results for the current state of the climate in a particular location and generate results for the supermarket building for the future years.

3.2 Thermal Analysis Software (TAS) v9.5.0-Building Energy Modelling:

TAS offered by EDSL meets all the requirements needed to quantify and report the results in the present study. It is a complete dynamic building simulation package. Some of the important characteristics of TAS are described below:

- *3D Modeller:* Able to generate building models, simulate the models, and perform detailed daylight analysis.
- *Building Simulator:* Capable of editing specific

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aspects prior to simulation of the building such as apertures, internal gains, and constructions along with providing 3D visualisation and multiple databases to use such as calendar, construction, and internal conditions databases. It also assists with overheating analysis, calculating heating, and cooling loads, calculating air flows, etc.

- *Results viewer:* This characteristic helps in viewing and exporting the data (2D, 3D hourly results) in tabular form and generating reports and charts for easy reading

The construction materials are assigned individually to each of the elements used in building construction and are tailored to the specifications of a typical supermarket. The simulation process starts with choosing a specific building and its local climate modelling, the basic components of the building such as floor, walls, windows and doors, it is important to import the Computer Aided Design (CAD) of the building. Next step involves the drawing of the physical walls, assigning building elements and adding any further windows and zones. Final step is to run the simulation and check for errors, if any are found, fix theme and run the final modelling file (Hasan et al., 2022).

3.3 Construction Database – TAS EDSL

The construction database application (TCD) available in TAS consists of multiple construction-related databases which assist the building simulator to model conduction heat transfer and storage through the fabric of the building. The supermarket building fabric is composed of material layers, and the building simulation models the interaction of heat flow through each of these layers individually. The main construction database provided in TAS v9.5.0 uses ASHRAE (The American Society of Heating, Refrigerating and Air-Conditioning Engineers) v90.1 standards (2007, 2010, 2013 and 2016).

3.4 3D Modeller and Building Design

Since the supermarket building needs to be assessed for its operational needs, it is important that initially a 3D model of the building is designed. The 3D design along with the important characteristics of the building such as height, structure/frame, floor area, entrance lobby along with other rooms/offices are simulated with the help of an AutoCAD diagram. The operational hour of the supermarket is calculated using the National Calculation Methodology (NCM) standard calendar. As each room/office is designed according to a typical supermarket in the UK, it is noted that each room is allocated with its respective zone in the software with a specific set of internal conditions adhering to the NCM.

CIBSE (The Chartered Institution of Building Services Engineers) Weather Files (Current and Future)

An important aspect of this investigation is to explore the impact of future climate change on different building fabrics and the building services of the supermarket building for the future time. However, it is necessary to first evaluate the demand (cooling, heating) of the building in the local climate of today so that it can be compared to the future needs of the building. TAS allows the incorporation of the weather files provided by CIBSE and generates hourly dynamic simulations with the current and future weather files.

The weather data used for energy analysis and for compliance with the UK Building Regulations (Part L) is known as Test Reference Year (TRY). It is composed of 12 separate months of data, each representing an ‘average’ month as derived from the collected data (Herrera et al., 2017). CIBSE licenses the historic weather data from the Met (The Meteorological Office) for 16 locations across the UK, three of which are in London.

CIBSE also provides the emission scenarios for the future which are described as:

2050s (2041-2070)
High - 10^{th}, 50^{th}, 90^{th} percentile
Medium - 10^{th}, 50^{th}, 90^{th} percentile

2080s (2071-2100)
High - 10^{th}, 50^{th}, 90^{th} percentile
Medium - 10^{th}, 50^{th}, 90^{th} percentile
Low - 10^{th}, 50^{th}, 90^{th} percentile.

4. Case Study

In the study, three approved construction techniques are taken into consideration for a standard design LIDL supermarket building. Some of the specifics of the LIDL building design, which extends to most of the standard retail buildings in the UK, include a floor area of 2,500 m^2 single story building with multiple offices and rooms each, with their own energy usage and construction methodology.

The three approved methods of construction for the building fabric used mainly in retail and supermarket constructions in the UK (P1 – P3) are given below:

Model P1: Steel columns and beam structural frame, cladding panel external walls, and a concrete slab foundation.
Model P2: Steel columns and beam structural frame, Proton block, and cladding panel external walls with a concrete slab foundation.
Model P3: Precast concrete column and glulam beam structural frame, precast concrete, and cladding panel external walls with a concrete slab foundation.

Other important parameters regarding the building fabric and aesthetics include the internal walls finish for each model to have the paint to plasterboard. The floor should be covered in ceramic tiles, vinyl, and paint. There is a curtain walling on one side of the building with aluminum frames with steel external doors. Some of the details of the models are given in Table 1 which explains the models with the construction details such as the building fabric (construction materials) together with the pictorial description of the models designed in the Autodesk Revit software.

4.1 Selection of city

For the present study, the city of Norwich, the largest city in East Anglia, is selected which is situated in the climatic region of Eastern England. Norwich has long, extremely cold, and windy winters while the summers are short, comfortable, and partly cloudy. The research work that provides an insight on the effect of climatic changes on retail buildings located in Norwich, UK is very limited.

CIBSE provides weather data for 16 locations in the UK for the current and future time periods. This research at Norwich is necessary in order to stay ahead of the climate change curve because it is extremely unlikely that the rise in the mean summer temperature for the South and East of England will be below 1.4 °C by the 2080s in the United Kingdom. (Gupta and Gregg, 2012).

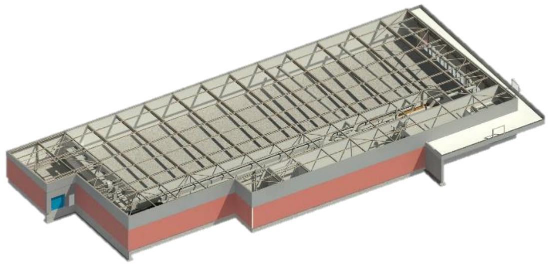
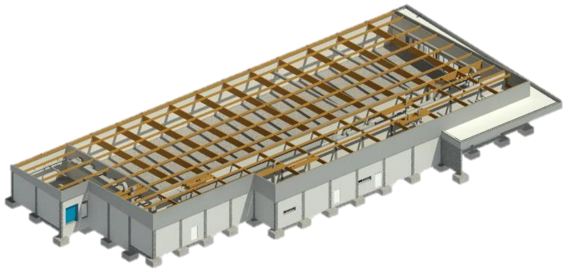
4.2 Building Modelling and Simulation

All the data used for modelling purposes is collected by conducting site visits of the LIDL stores and undertaking buildings' architectural design files and the data is verified thoroughly for the accuracy. Some of the important information collected includes the building's construction such as construction material with their thermal transmittance or U-values, thermal zones, and building services with their fuel types for the heating, cooling, ventilation, hot water, and lighting, based on the EPBD (Energy performance of buildings directive) requirements.

For the three approved modern construction methods (MMCs), a model of the standard or P1 supermarket was designed in the 3D modeler of TAS with a focus on accuracy and using the AutoCAD drawings. All the necessary structures of the supermarket building such as floor, roof, walls, windows, doors, and other building features are added.

As for the location and weather datasets, TAS has the incorporated features of CIBSE weather files including the selected city of Norwich with the flexibility of running the simulations with current and future weather files of varying emissions including the low, medium, and high percentile as described.

Table 1. Approved design models of different construction methods

Model	Construction Details (Building Fabric)	Illustrated Description
P1	• Cladding panel • external walls • Steel columns • Steel beams • Slab foundation	
P2	• Poroton block + Cladding panel external walls • Steel columns • Steel beams • Slab foundation	
P3	• Precast concrete + Cladding panel external walls • Precast concrete columns • Glulam beams • Slab foundation	

5. Results and Discussion:

The first part of the results include the annual energy

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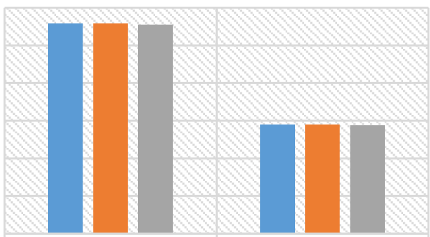
consumption and the annual carbon emissions for a typical UK supermarket building for all three approved methods of construction under the current scenario of the local climate of Norwich.

Current Scenario

Under the current scenario, which is the 2020s timeline in CIBSE weather datasets, the results of each model P1, P2, and P3 are summarized in Figure 2.

For P1 and P2, the total annual energy consumption is found to be 111.75 kWh/m^2 and the carbon emissions value is 58.0 kgCO_2/m^2. For model P3, the total annual energy consumption is 110.94 kWh/m^2 and the carbon emissions is 57.6 kgCO_2/m^2. According to survey data and real-time annual energy measurements recorded over five consecutive years, a consumption range of 137.31 kWh/m^2 to 150.53 kWh/m^2 was observed. These values are slightly higher compared to the 111.75 kWh/m^2 calculated using TAS. However, these differences are affected by various factors such as the exact location of the building, weather database difference and historical climate change, dissimilar HVAC systems, air infiltration systems, as well as use of TAS instead of Simplified Building Energy Model (SBEM) methodology carried out by independent commercial assessors.

The models P1 and P2 present almost identical results for both the annual energy consumption and the carbon emissions whereas P3 has a slight decrease in both attributes. It is understandable as glulam laminated timber beams would produce lesser emissions as compared to their counterparts.



	Annual Energy Consumption (kWh/m²)	Annual CO_2 Emission (kgCO_2/m²)
Model 1	111.75	58
Model 2	111.75	58
Model 3	110.94	57.6

Figure 2. Model P1, P2 and P3 - Operational Energy/Carbon emissions under current scenario

Future Worst-Case Scenario

The building service life is the time during which the building is in use and multiple studies have indicated that the average service life of a commercial building varies from anywhere to 50 to 75 years (Junnila and Horvath, 2003; Scheuer, Keoleian and Reppe, 2003). All the future calculations are performed using the CIBSE weather files of 2080s with the emissions scenarios of 'High' 10th, 50th and 90th percentile considered.

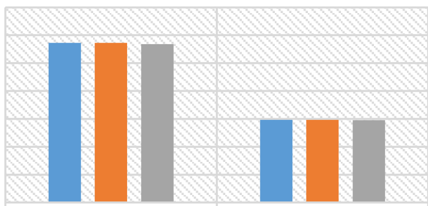
High 2080s (2071-2100 years)

The year 2080s will cover a thirty-year period from 2071 to 2100 years. CIBSE offers three emission scenarios for the 2080s which are Low, Medium, and High. Since this investigation is to test the supermarket building under the future worst-case scenario, the focus will be only on the High emission scenario of 10th, 50th, and 90th percentile for each of the three approved methods of construction.

High 10th Percentile

The 10th percentile of the High emission scenario gives an idea of the likely minimum change (unlikely to be less than) with current theories and models (Eames, Kershaw and Coley, 2010).

The annual energy consumption and carbon emission of each of the three models are summarized in Figure 3 where Model P1 and P2 have almost identical values of 114.47 KWh/m^2 and 114.46 KWh/m^2 for annual energy consumption and the same value of 59.40 KgCO_2/m^2 for carbon emission. Model P3 has slight reduction in both the parameters with 113.74 KWh/m^2 and 59 KgCO_2/m^2 respectively.



	Annual Energy Consumption (kWh/m²)	Annual CO_2 Emission (kgCO_2/m²)
Model 1	114.47	59.4
Model 2	114.46	59.4
Model 3	113.74	59

Figure 3. Model P1, P2 and P3 - Operational Energy/Carbon emissions under High 10th percentile

High 50th Percentile:

The High 50th percentile is the central estimate in between 10th and 90th percentile of the emissions scenario and the results are compiled in Figure 4. The two parameter values for Model P1 and P2 are almost identical with 117.38 KWh/m^2 and 117.37 KWh/m^2 for annual energy consumption respectively and 60.90 KgCO_2/m^2 for carbon emissions. As expected, Model P3 has performed slightly better with 116.81 KWh/m^2 and 60.60 KgCO_2/m^2 respectively.

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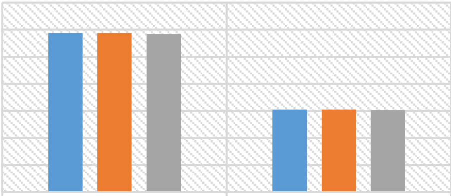


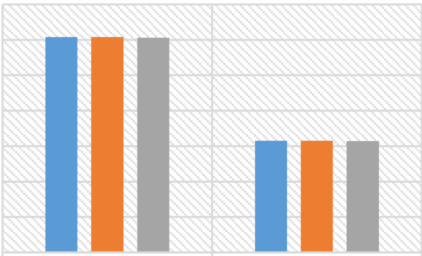
	Annual Energy Consumption (kWh/m²)	Annual CO_2 Emission ($kgCO_2/m^2$)
Model 1	117.38	60.9
Model 2	117.38	60.9
Model 3	116.81	60.6

Figure 4. Model P1, P2 and P3 - Operational nergy/Carbon emissions under High 50th

High 90th Percentile:

Using a high percentile TRY such as the 90th gives an indication of the extent of likely future warming (UKCP09 defined the 90th percentile as unlikely to be greater than).

Under the worst-case scenario and 90th high percentile, annual energy consumption of Models P1 and P2 reached to 121.59 KWh/m^2 and 121.58 KWh/m^2 and carbon emissions for both reached 63.10 $KgCO_2/m^2$. Figure 5 illustrates how Model P3 performs considerably better with 121.23 KWh/m^2 and 62.90 $KgCO_2/m^2$, respectively.



	Annual Energy Consumption (kWh/m²)	Annual CO_2 Emission ($kgCO_2/m^2$)
Model 1	121.59	63.1
Model 2	121.59	63.1
Model 3	121.23	62.9

Figure 5. Model P1, P2 and P3 - Operational Energy/Carbon emissions under High 90th scenario

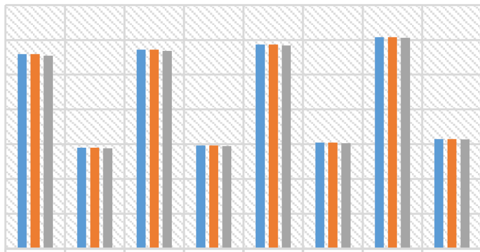
The figure 6 represents all the possible scenarios with the present (2020s) against the future high emission scenarios (10th, 50th and 90th). Under the worst-case scenario of High 90th percentile emission scenario, the annual energy consumption and carbon emission for the three models increases by following:

Model P1: Annual energy increase 8.81%, annual carbon emission increase 8.79%

Model P2: Annual energy increase 8.80%, annual carbon emission increase 8.79%

Model P3: Annual energy increase 8.48%, annual carbon emission increase 8.44%

It is clear for both the annual energy consumption and annual carbon emissions, the High 90th percentile scenario is catastrophic. Among the three approved methods of construction, Model P1 is the poorest design especially under future climate change followed by model P2. Model P3 presents the best option among the three as it produces the least amount of carbon emissions. Under the other emission scenarios of the 10th and 50th percentile, a similar pattern can be observed, with P3 performing marginally better than the other two construction techniques. It is important to keep in mind that the resultant values are produced over the 60-year period with the CIBSE based emission scenarios based on the original IPCC scenarios.



	Present (2020s) kWh/m²	Present (2020s) $kgCO_2/m^2$	High 10th percentile kWh/m²	High 10th percentile $kgCO_2/m^2$	High 50th percentile kWh/m²	High 50th percentile $kgCO_2/m^2$	High 90th percentile kWh/m²	High 90th percentile $kgCO_2/m^2$
Model 1	111.75	58	114.47	59.4	117.38	60.9	121.59	63.1
Model 2	111.75	58	114.46	59.4	117.38	60.9	121.59	63.1
Model 3	110.94	57.6	113.74	59	116.81	60.6	121.23	62.9

Figure 6. Model P1, P2 and P3 - Operational Energy (KWh/m^2)/Carbon emissions ($KgCO_2/m^2$) under all possible scenarios

6. Conclusions and Future Scope

The aim of this investigation was to design and quantify the impact of the future climate change relative to present day on three different approved methods of construction for a typical UK supermarket.

Since the major share of the carbon emissions from a building is during its operational phase, the study focused mainly on the in-use phase of the supermarket by focusing on the energy consumption of the building services especially cooling, DHW (domestic hot water), lighting, HVAC (Heating, ventilation, and air conditioning) and AHU (Air handing units) equipment.

A case study of a typical supermarket store having floor area of 2,500 m^2 was chosen in the city of Norwich and the building was designed using two different software, Autodesk Revit software and TAS – EDSL, helping to design the different modern methods of construction and simulate the operation of building services under different future climatic scenarios respectively.

The overall investigation presents a thorough comparison of design options with each approved list of methods including the associated energy consumption and emission scenarios from an operational point of view. This paper gives an important insight into the importance of choosing the right materials as it can substantially reduce the GHG (greenhouse gas) emissions, by carefully considering the method of construction in the future.

The results of models P1 and P2 present to be almost identical due to the similar U-values of the materials used in their respective construction materials. As the climate keeps on changing, the U-value representing the rate of transfer of heat through the structure keeps constant which subsequently produce the identical results. However, the model P3 presents results different from other two models signifying that the associated carbon emissions and energy usage of the construction materials considered are better for environment and it can be concluded that it is the best model out of the three models.

Furthermore, an understanding of how anthropogenic activities can further worsen the environment and their lasting effect on the built environment can be observed with the provided tables and numbers in the study.

The outcomes of this research can influence the policy and decision makers as the EUI buildings such as supermarkets are an ever-growing industry in the retail sector. In recent years, the UK along with the EU (Europe Union) has taken bold steps toward decarbonization and net-zero emissions. This study provides exact figures and statistics to assist the constructors, developers, and institutions in their effort to lower carbon emissions associated with the new building stock.

Development of the proper design and bold decisions for new buildings would result in a comprehensive carbon emissions reduction strategy that will provide the much-needed futureproofing of the buildings, making them resilient against the inevitable climate change of the future. Further, the study can be extended using the four RCP climate change scenarios and other building construction models. It would give a better understanding if all types of buildings apart from supermarket buildings in a particular locality are considered for the analysis.

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