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Comparing building performance of supermarkets under future climate change: UK case study

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Abstract. Focus on climate change and extreme weather conditions has received considerable attention in recent years. Civil engineers are now focusing on designing buildings that are more eco-friendly in the face of climate change. This paper describes the research conducted to assess the impact of future climate change on energy usage and carbon emissions in a typical supermarket at multiple locations across the UK. Locations that were included in the study were London, Manchester, and Southampton. These three cities were compared against their building performance based on their respective climatic conditions. Based on the UK Climatic Projections (UKCP09), a series of energy modelling simulations which were provided by the Chartered Institute of Building Service Engineers (CIBSE) were conducted on future weather years for this investigation. This investigation ascertains and quantifies the annual energy consumption, carbon emissions, cooling, and heating demand of the selected supermarkets at the three locations under various climatic projections and emission scenarios, which further validates annual temperature rise as a result of climatic variation. The data showed a trend of increasing variations across the UK as one moves southwards, with London and Southampton at the higher side of the spectrum followed by Manchester which has the least variability amongst these three cities. This is the first study which investigates impact of the climate change on the UK supermarkets across different regions by using the real case scenarios.

Keywords: building simulation; climate change; energy performance; future weather; sustainability

1. Introduction

While the earth is experiencing a rapid climate change, the Intergovernmental Panel on Climate Change (IPCC) puts the human factor as the center of its reasoning, "there is a very high confidence that the globally averaged net effect of human activities since 1750 has been one of warming" (IPCC 2007). As a part of the research, this paper is going to focus on the global effort

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to combat climate change relying on improving the energy efficiency of buildings in the coming decades (IEA 2006). This study investigates the impact of future climate change on the annual energy usage and carbon emissions of a typical supermarket across multiple different UK cities and will consider a standard baseline model of LIDL supermarket situated in London. An identical model is designed in Manchester and Southampton with their respective regional climates. A series of simulations were performed using building modelling software package (Thermal Analysis Software, TAS) by the CIBSE provided current and UKCP09 based future weather files. Also, dynamic hourly simulations of the building were performed in each location.

Commercial, retail, office and other building spaces like these are modelled using the TAS software and have been constructed and thoroughly validated by several researchers (Amoako-Attah and B-Jahromi 2013, 2014, Lykartsis *et al.* 2017, Bahadori-Jahromi *et al.* 2018). The local weather surrounding any building dictates the energy needs of the building (Ciancio *et al*. 2018). It can thus be inferred that the regional and local weather patterns will dictate the energy usage and subsequently, the carbon emissions for the existing buildings in the area (Andrić *et al*. 2017). These buildings, due to their local weather conditions will also dictate the change in their local civil building sector to keep the energy demand low (Zhai and Helman 2019). Fig. 1 shows how climate change not only affects, but also influences a buildings indoor weather condition which needs to be kept at an ambient range to ensure the optimum comfort of the occupants.

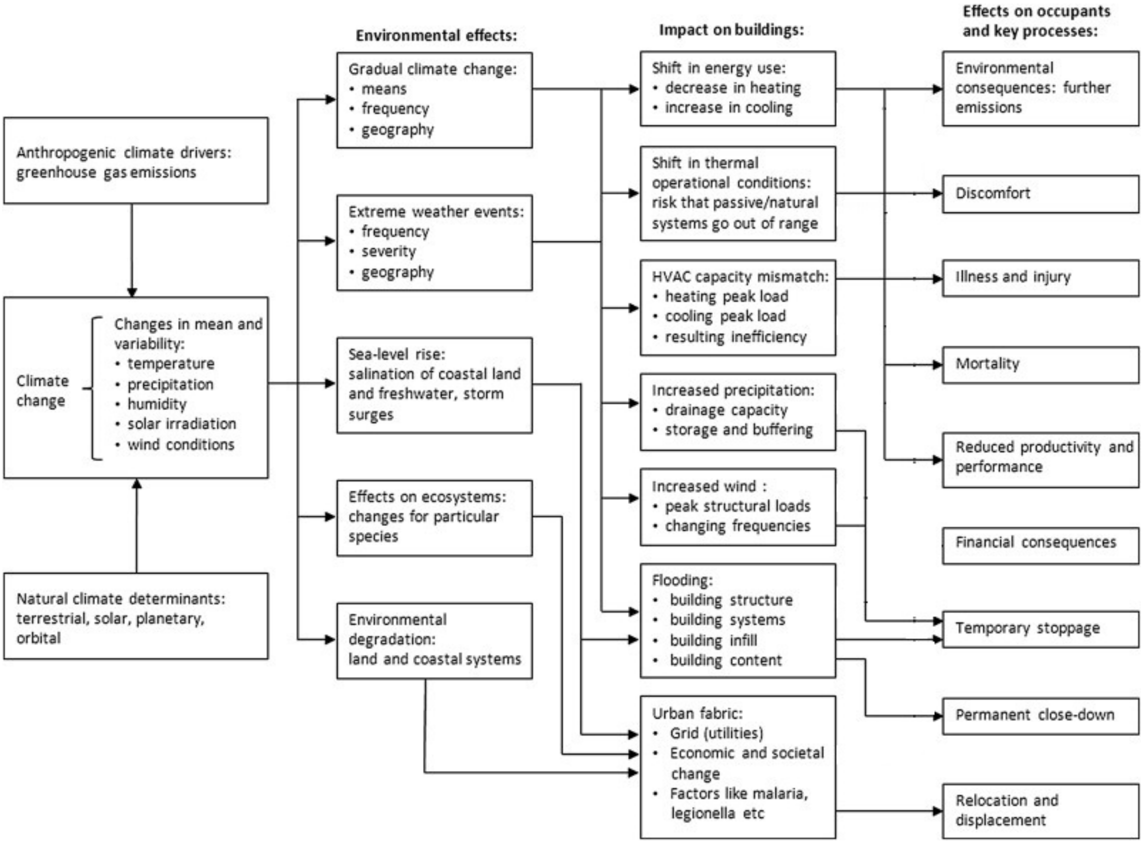


Fig. 1 Schematic summary of climate change effect on built environmental (McMichael *et al.* 2006)

According to one report, UK has over 87,000 supermarkets currently operational across the country (Retail foods, USDA 2019). The UK building sector accounts for approximately 3% of total electricity use and the UK supermarkets and similar organizations are responsible for 1% of the entire UK GHG emissions (Tassou *et al.* 2011). These are described as high energy use intensity (EUI) buildings due to their increased refrigeration and lighting needs.

Several researchers have investigated the effect of regional geographical climate on the energy consumption and carbon emissions on the supermarkets in the area. A considerable proportion of the buildings in the UK already perform quite poorly during the hot weather waves, reinforcing the need of an appropriate climate change future weather files to study the buildings performance assessment at regular time intervals (Nicol and Humphreys 2007).

In the UK, an example of a probabilistic approach of climate file for the future weather conditions was created by Kershaw *et al*. (2011) which was then validated for Plymouth (UK) known as 'PROMETHEUS' weather files based on the UKCP09 projections.

Fig. 2 gives a geographical view of the various research carried throughout the globe by academics to quantify and mitigate the effect of climate change. It includes places such as Europe, South Europe, Lithuania, Netherlands, Northern China, Hong Kong, Middle East. (Cellura *et al*. 2018, Pathan *et al*. 2017, Sabunas and Kanapickas 2017, Kočí *et al*. 2019, Hamdy *et al*. 2017, Dodoo and Gustavsson 2016, Shibuya and Croxford 2016, Wan *et al*. 2012, Farah *et al*. 2019, Roshan *et al.* 2019, Petri and Caldeira 2015). The world map is shown with the same colour representing that research regarding climate change is being carried out in these particular countries and how to mitigate its effects.

Despite all the studies available regarding the energy and carbon emissions of buildings worldwide, not enough data is available for UK after the creation of the UK Climate Projections (UKCP09). Although the effect of climate change on energy and carbon emissions in different building types has been investigated for various locations in the UK and around the world, no such investigation has been performed for supermarkets located in the climatic regions in Great Britain (Braun *et al*. 2016).

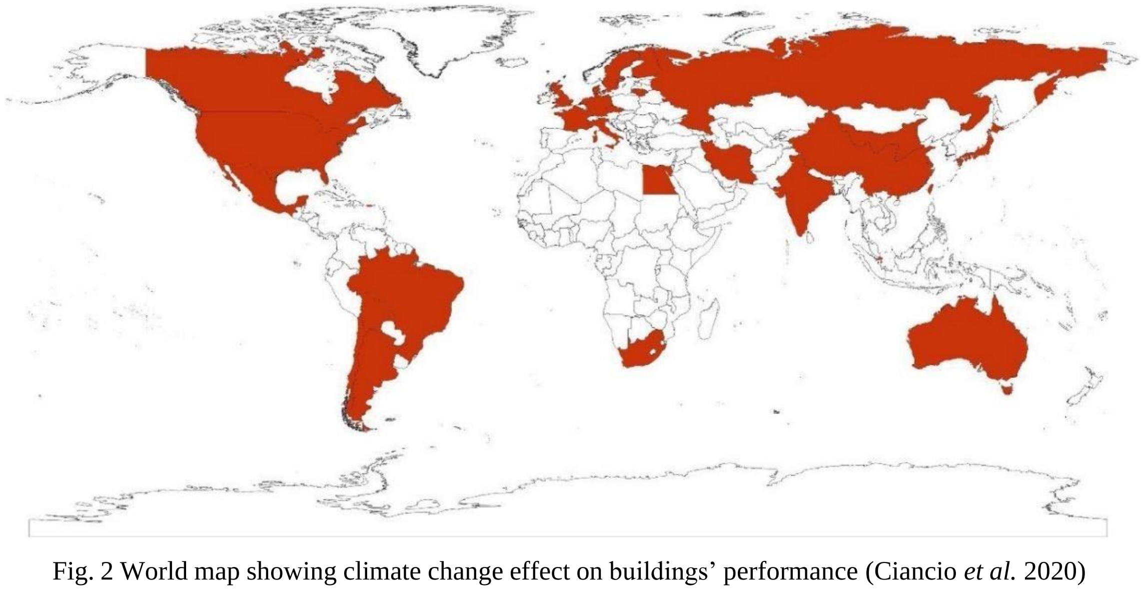


Fig. 2 World map showing climate change effect on buildings' performance (Ciancio *et al.* 2020)

2. Methodology

2.1 Thermal Analysis Simulation (TAS-EDSL) 3D modelling

One of the most critical steps in the methodology was to choose a simulation platform that can produce a dynamic model and can use the weather files. TAS- EDSL use individual calculations with several underlying software products and data exporting capability (Crawley *et al*. 2008). It is also in compliance checking for the building regulations guidance 2010: Part L2 for England and Wales (Pan and Garmston 2012) and comes integrated with the Building Research Establishment (BRE) software tool 'Simplified Building Energy Model' (SBEM) for analysis of building energy consumption (SBEM BRE 2020). TAS also provides the opportunity to combine the dynamic thermal simulation of the building with control functions over natural and mixed-mode ventilation (Bahadori-Jahromi *et al*. 2017).

2.2 Weather files used in simulation packages

A common feature present in all the software packages is the use of weather files used in building performance simulations are based on specific locations. Conventionally, the weather files used are in the form of hourly datasets and available in various formats depending on their geographical location.

CIBSE has taken an approach of producing two different simulation weather data sets, Test Reference Year (TRY) files for energy assessments and Design Summer Year (DSY) files for overheating analysis (CIBSE 2002). Since 2006, TRY and DSY are available for 14 sites throughout the UK using improved selection algorithms (Levermore and Parkinson 2006). The current TRY and DSY were morphed to incorporate the UKCP09 climate change scenarios of the time periods and the emission scenarios to limit any uncertainties that could affect the weather data (Eames *et al.* 2010). The future weather files are representative of the carbon emission scenarios of a low, medium, and high with varying levels of probabilities of 10th, 50th, and 90th percentiles and for three future timelines 2020s, 2050s and 2080s (Virk *et al*. 2015).

2.3 City selection criteria

The cities were selected after careful consideration, keeping in mind the regional climates in the UK. The chosen cities were in different regional climates to have a valid comparative view of the changing climate. UK has eleven regional climates based on different climatic characteristics such as temperature, sunshine, rainfall, snowfall, and wind (UK regional climates, 2021). These regions are:

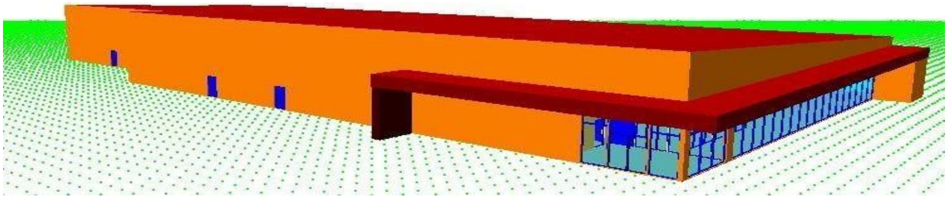
- Scotland (Northern, Eastern, Western)
- Northern Ireland
- Wales
- Midlands
- England (North West & Isle of Man, North East, Eastern, Southern, South West

Out of these regional climates, a cross over table was made with CIBSE provided 'current' and 'future' weather files which are presented in Table 1.

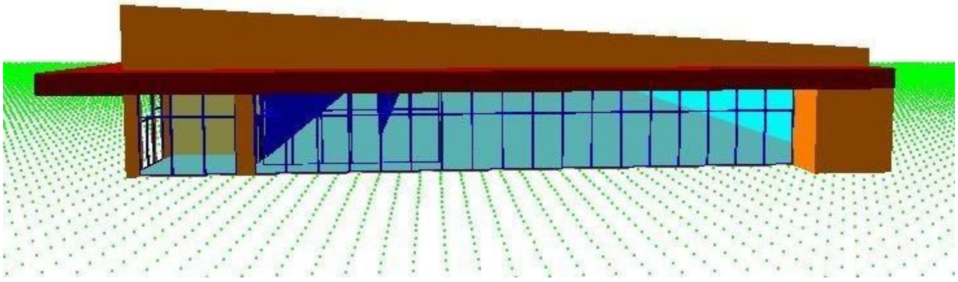
A variety of selected cities gives an invaluable insight into the future and direct effect of climate change as they have significantly different climatic characteristics and in turn shows how drastically the key performance indicators can change in the coming years due to climate change.

Table 1 England regional climates and selected cities

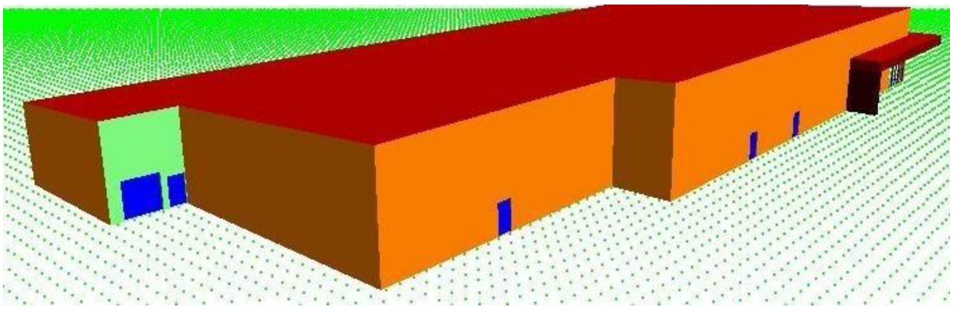
UK regional climate	**City selected**
North-West England & Isle of Man	Manchester
Southern England	Southampton
England South-East & Central South	London



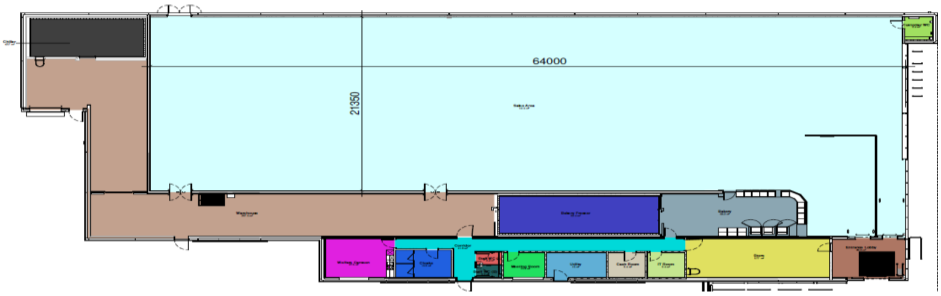
(a) Front view



(b) Side view



(c) 3D view



(d) Floor plan

Fig. 3 3D Supermarket

2.4 3D modelling

This is a real case purpose-built UK supermarket, and all the building data has been obtained by surveying and reviewing the building design documents to make sure the model represents the true scenario.

Figs. 3(a)-(d) show the 3-D drawings and the floor plan of the building along with its dimensions. The peak height of the supermarket store is 7.02 meter with a declining angle of 3.30° finishing at 5.104 meter. The entrance door is 5-meter-wide and 2.9-meter-tall in total. The rear elevation has a height of 4.635 meter tall. The curtain walling has double glazed units and is divided into upper and lower windows.

3. Modelling process

The architecture of building design in the software provides detailed measurements for the height and size of various compartments and sections of a typical UK supermarket with a floor area of 2,500 m^2

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 internal conditions are also explicitly applied according to the individual zones and to be certain that these conditions adhere to the National Calculation Methodology (NCM). TRY files are used to predict average energy consumption and compliance with the UK building regulations (Eames *et al.* 2015).

3.1 Simulation process

The simulation process starts with choosing with specific building and its local climate. After

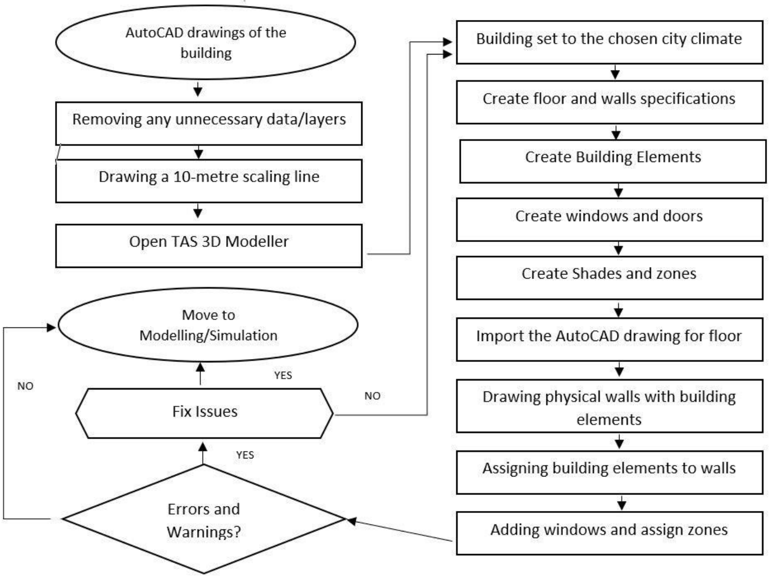


Fig. 4 Research flow plan: preparation to pre-modelling stage

Table 2 Simulation assumptions: building specification

Building element	**Calculated area-weighted average U-values (W/m^{2}K)**
Wall	0.24
Floor	0.21
Roof	0.13
Windows	3.08
Personnel doors	1.32
Vehicle access doors	1.78
High usage entrance doors	3.34

Table 3 Simulation assumptions: building summary specification

Calendar	**NCM standard**
Air permeability	5.0 m^3/h.m^2 @ 50Pa
Infiltration	0.125 (ACH)
Fuel source	Grid supplied electricity
CO_2 factor	0.519 kg/kWh

modelling the basics of the building such as floor, walls, windows and doors, it is important to import the computer aided design of the building. Next step is to draw the physical walls, assigning building elements and adding any further windows and zones. Final step is to run the simulation and check for any error, if there are any issues fix those and run the final modelling file. To eliminate any errors, the TAS modeler undergoes a range of performance parameters and assumptions including the building summary, calendar year, weather database, building elements, zones, internal conditions, and schedules to simulate the building properly. Fig. 4 shows a flowchart representing the multiple stages in the supermarket building model from the AutoCAD drawings. The Tables 2-4 shows information relating to the supermarket building which is same in all three locations. However, due to their different geographical locations, their local weather data is supplied separately by The Chartered Institution of Building Services Engineers (CIBSE).

Table 2 shows a summary of simulation assumptions regarding the fabric specification modelled in the software. Similarly, Table 3 shows the building summary specification whereas Table 4 shows the thermophysical characteristics of the building materials.

3.2 UK Climate Projections (UKCP) Projections

For the UK-based buildings, a very accurate climate projection is provided by UK Climate Projections (UKCP). These were used to produce the future test reference years (TRY) that are available in three emission scenarios including high, medium, and low, with more details referred to in the paper (Hasan *et al*. 2020).

3.3 Current weather files

The current climate weather data includes the data of a specific geographical location resulting

Table 4 Construction details: specifications of thermophysical characteristics

Type		**Conductance (W/m^2. °C)**	**Solar absorptance**	**Emissivity**	**Construction type**
			External/Internal	External/Internal	
Wall	Cast concrete wall	0.974	0.700	0.900	Opaque
	Cavity wall	0.25	0.700	0.900	Opaque
	Curtain wall	5.227	0.700	0.900	Opaque
	Metal cladding wall	0.235	0.700	0.900	Opaque
	Steel frame wall	0.379	0.700	0.900	Opaque
Frame	Uncoated glass, air-filled	5.545	0.101 0.078	0.840	Transparent
	Metal, thermal break & spacer	59.116	0.00	0.850	Transparent
	Wood, thermal spacer	7.89	0.00	0.850	Transparent
Floor	Ground floor	0.218	0.700	0.900	Opaque
Door	Insulated personal door	0.94	0.700	0.900	Opaque
	Vehicle door	2.0	0.700	0.900	Opaque

from hourly Met Office observation as a meteorological service usually in areas adjacent to the location. It is described as consisting of months selected from individual years and concatenated to form a complete year (Renné 2016).

3.4 Future weather files

The CIBSE institute produced climate change weather files for 2020s, 2050s and 2080s for 14 locations in UK.

The Future weather files are created using a "morphing" procedure as explained earlier in the paper (Mavrogianni *et al*. 2011).

3.5 Data collection

As a part of data collection, the following information was gathered:

- EPC certificates
- Annual energy usage by calculating the grid-supplied electricity (kWh)
- Annual GHG emissions

Since the baseline supermarket model is designed as the ‘standardized’ LIDL supermarket building, it is assumed that the baseline model in all the chosen cities is identical. A data collection phase is shown below as a part of the flowchart in Fig. 5.

The subheadings 3.2 to 3.5 shows the UKCP, current and future weather files and data collection for each of the three locations. The simulation methodology is the same for all the locations. However, the weather data and the data collection depend on the geographical locations of the supermarket stores.

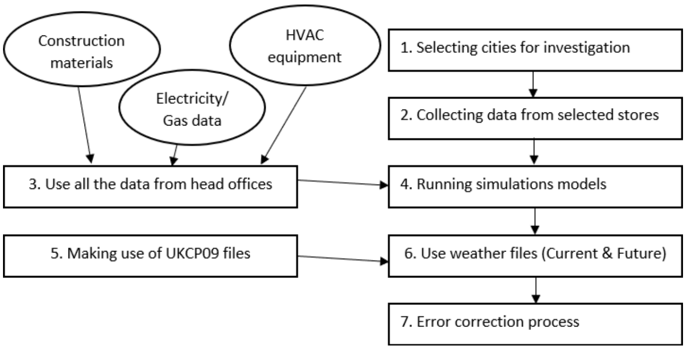


Fig. 5 Research flow plan: supermarkets investigation

4. Results

4.1 London model

As a common practice with all 3-D modelling, a baseline model was created, tested, and validated against the actual building of LIDL in London under the current conditions. The readings from TAS software provided a detailed account of heating, cooling, Domestic Hot Water (DHW), lighting, equipment, and auxiliary energy consumption.

4.1.1 Current weather scenario

Annual energy consumption in kWh/m^2 and CO$_2$ emissions breakdown in kg/m^2 of the baseline building modelled in London is shown in Fig. 6. This scenario is under the current weather conditions.

Lighting uses up the most energy due to the huge retail space including a warehouse, sales floor area and the use of lights in every office, changing room, canteen and toilets with cooling being the second highest energy consumption area as it includes the refrigeration, cooling cabinets and freezers and chillers. Similarly, the associated annual CO$_2$ emissions represent the biggest emissions sector to be lighting with cooling being the second one. The total annual energy is112.33 kWh/m^2, out of which lighting consumes 54.68% and cooling consumes 30.05% of the

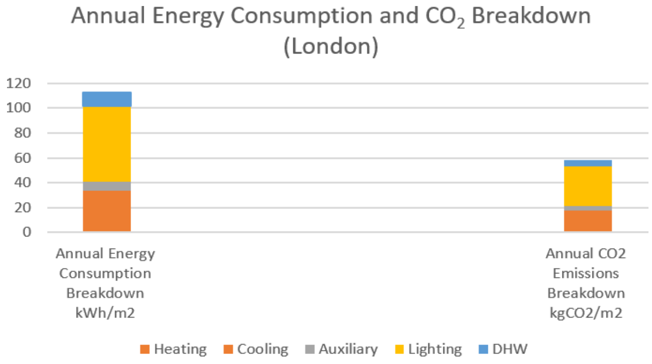


Fig. 6 Annual Energy Consumption and CO$_2$ breakdown

total energy consumption whereas the annual carbon emissions are 58.30 $kgCO_2/m^2$. For comparison purposes, a four-bedroom detached house located in Berkshire, England with poor insulation and a high demand of space heating/cooling demand can have an annual energy consumption of 135 kWh/m^2 and an annual carbon emission of 51.73 $kgCO_2/m^2$ (Bahadori-Jahromi *et al*. 2018). Similarly, a four-story hotel in Watford, Hertfordshire with 10,000 m^2 floor area have an annual energy consumption of 260 kWh/m^2 and an annual carbon emission of 89.27 $kgCO_2/m^2$ (Amirkhani *et al*. 2020). By these standards, depending on the floor area, when it comes to total energy consumption in the UK, the industrial area leads in energy consumption followed by residential areas and then the commercial industry.

4.1.2 Future weather scenarios and Energy & CO_2 emissions

Multiple simulations were run with six and nine different emissions scenarios of low, medium, and high emission percentile under the periods 2050s and 2080s. Fig. 7 shows the annual energy and carbon dioxide consumption for future climatic projections for all the 2050s and 2080s scenarios. All the predicted scenarios show that there is a constant gradual increase in energy.

For energy consumption, there is a peak increase of 3.66% in the 2050s medium (90th) percentile scenario and a 9.58% increase in the 2080s high (90th) percentile scenario, respectively.

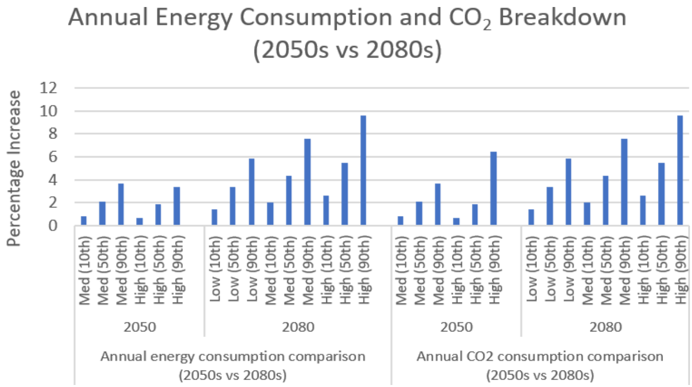


Fig. 7 Annual energy and CO_2 consumption comparison (2050s vs 2080s)

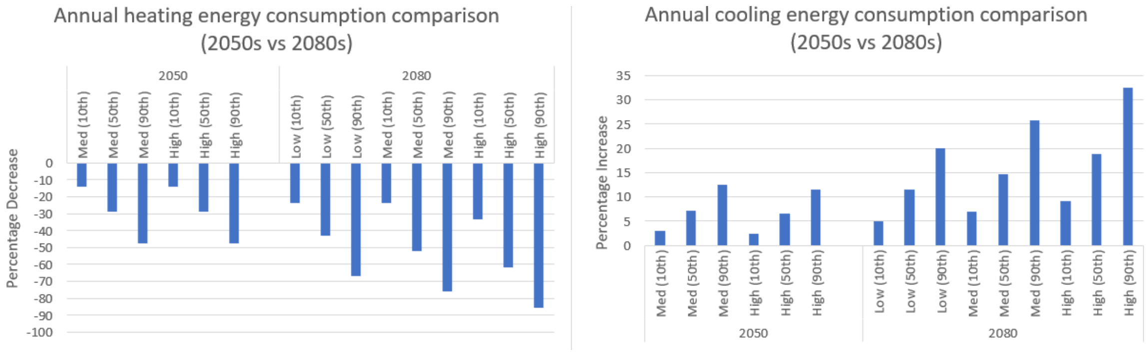


Fig. 8 (a) Annual heating energy consumption (2050s vs 2080s); (b) Annual cooling energy consumption (2050s vs 2080s)

For carbon emissions, there is a peak increase of 3.65% in the 2050s medium (90th) percentile scenario and a 9.59% increase in the 2080s high (90th) percentile scenario, respectively.

The increased consumption over the years is attributed to the increased cooling demand in the face of increasing temperatures.

4.1.3 Heating & Cooling comparison

Figs. 8(a)-(b) shows the annual heating and cooling energy comparison for future climate projections for all the 2050s and 2080s scenarios. All the predicted heating energy scenarios show a constant gradual decrease in heating energy over the years, irrespective of any scenario or percentile chosen, whereas the cooling energy increases regardless of any scenario chosen.

For heating energy, there is a peak reduction of 47.62% in the 2050s medium (90th) percentile/high (90th) percentile scenario and an 85.72% reduction in the 2080s high (90th) percentile scenario, respectively. It confirms a gradual increase in the temperature over time. Over the years, the reduced heating consumption is attributed to the increase in temperature influencing the heating demand to be reduced.

For cooling energy, there is a peak increase of 12.47% in the 2050s medium (90th) percentile scenario and a 32.41% increase in the 2080s high (90th) percentile scenario, respectively. This rise in the annual cooling energy consumption confirms a gradual increase in the temperature over time. Over the years, the increased cooling consumption is attributed to the increasing external temperature, thus increasing the need for cooling in the supermarket building.

4.3 Manchester Model

4.3.1 Current weather scenario

Annual energy consumption and CO_2 emissions breakdown of the baseline building modelled in Manchester is presented in Fig. 9.

The total annual energy for the current weather scenario for a typical supermarket building in Manchester comes up to be 109.45 kWh/m^2. The emissions are 56.81 kgCO$_2$/m^2 with heating and cooling at 0.14 and 15.99 kWh/m^2 respectively.

4.2.2 Future weather scenario and Energy & CO_2 emissions

There are six and nine different emissions scenarios under the years the 2050s and 2080s

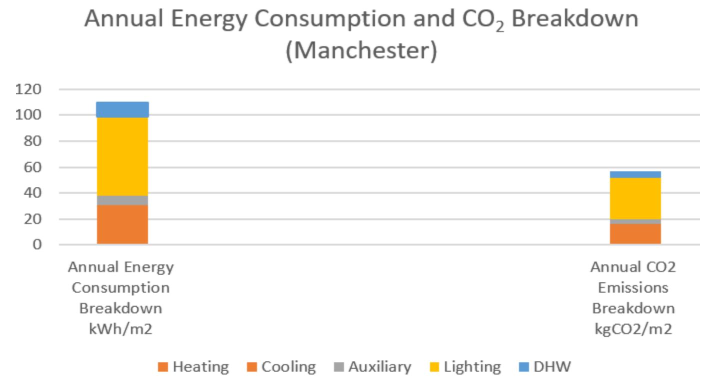


Fig. 9 Annual energy consumption and CO_2 breakdown

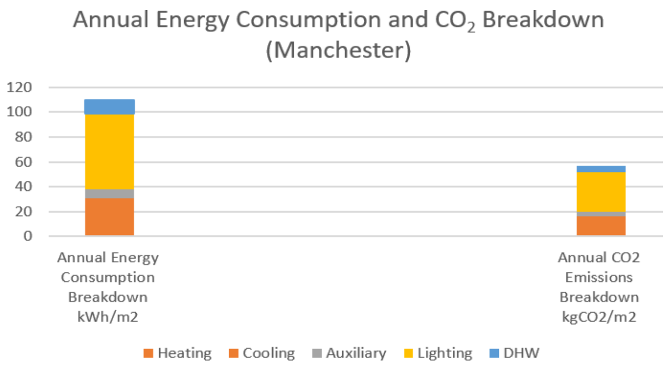


Fig. 9 Annual energy consumption and CO_2 breakdown

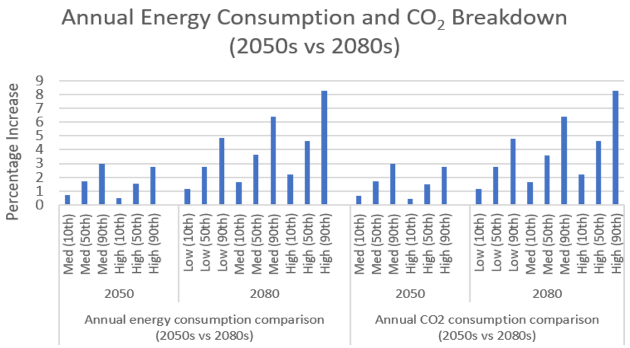


Fig. 10 Annual energy and CO_2 consumption comparison (2050s vs 2080s)

respectively. A total of 130 simulations were run and validated against the actual data and then further mathematical calculations were made to determine the percentage increase/decrease for the key performance indicators. Fig. 10 shows the annual energy and carbon dioxide consumption for future climatic projections for all the 2050s and 2080s scenarios. All the predicted scenarios show a constant gradual increase in energy consumption over the years, irrespective of any scenario or percentile chosen.

For energy consumption, there is a peak increase of 3.00% in the 2050s medium (90th) percentile scenario and an 8.30% increase in the 2080s high (90th) percentile scenario, respectively.

For carbon emissions, there is a peak increase of 2.99% in the 2050s medium (90th) percentile scenario and an 8.29% increase in the 2080s high (90th) percentile scenario, respectively. The increased consumption over the years is attributed to the increased cooling demand in the face of increasing climatic temperature.

4.2.3 Heating & Cooling comparison

Figs. 11(a)-(b) shows the annual heating and cooling energy comparison for future climatic projections for all the 2050s and 2080s scenarios.

All the predicted scenarios of heating energy show that there is a constant gradual decrease in heating energy over the years, irrespective of any scenario or percentile chosen whereas, the

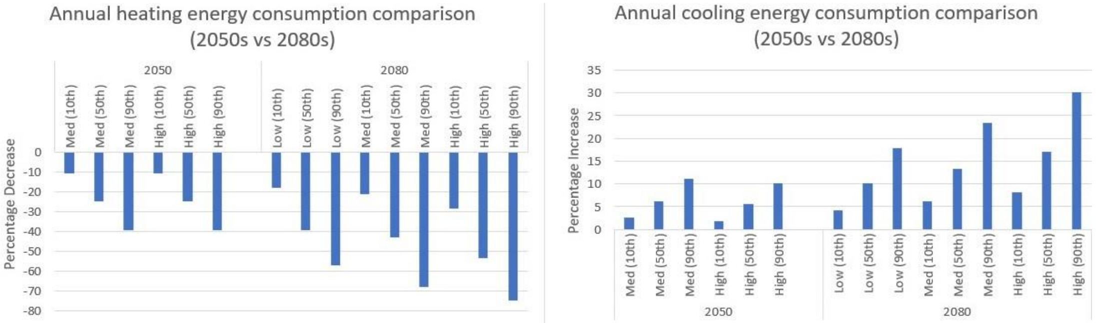


Fig. 11 (a) Annual heating energy consumption (2050s vs 2080s); (b) Annual cooling energy consumption (2050s vs 2080s)

cooling energy increases irrespective of any scenario chose.

For heating energy, there is a peak reduction of 39.29% in the 2050s medium (90th) percentile/high (90th) percentile scenario and a 39.29% reduction in the 2080s high (90th) percentile scenario, respectively. Over the years, the reduced heating consumption is attributed to the increase in climatic temperature influencing the heating demand to be minimized.

For cooling energy, there is a peak increase of 11.00 % in the 2050s medium (90th) percentile scenario and a 30.11% increase in the 2080s high (90th) percentile scenario, respectively. Over the years, the increased cooling consumption is attributed to the increasing external temperature, thus increasing the need for cooling in the supermarket building.

4.3 Southampton model

4.3.1 Current weather scenario

Annual energy consumption and CO_2 emissions breakdown of the baseline building modelled in Southampton is presented in Fig. 12.

The total annual energy for the current weather scenario for a typical supermarket building in Southampton comes up to be 111.63 kWh/m^2 whereas, the emissions are 57.94 kgCO_2/m^2 with heating and cooling at 0.12 and 17.15 kWh/m^2 respectively.

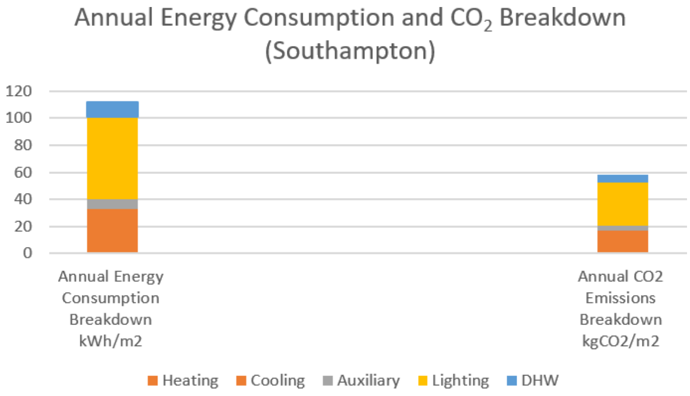


Fig. 12 Annual energy consumption and CO_2 breakdown

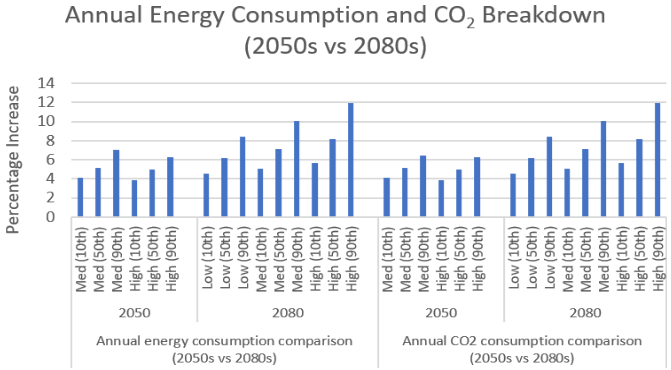


Fig. 13 Annual energy and CO_2 consumption comparison (2050s vs 2080s)

4.3.2 Future weather scenarios

Under the years 2050 and 2080s, there is an array of different emission scenarios. Six emission scenarios from 2050s and then nine from 2080s help to find out the percentage increase/decrease for the key performance indicators.

4.3.3 Energy & CO_2 emissions

Fig. 13 shows the annual energy and CO_2 consumption for future climatic projections for all the 2050s and 2080s scenarios. A constant increase in the energy consumption is documented in every scenario of any year.

For energy consumption, there is a peak increase of 3.73% in the 2050s medium (90th) percentile scenario and a 10.04% increase in the 2080s high (90th) percentile scenario, respectively. For carbon emissions, there is a peak increase of 3.72% in the 2050s medium (90th) percentile scenario and a 10.02% increase in the 2080s high (90th) percentile scenario, respectively. The increased consumption over the years is attributed to the increased cooling demand in the face of increasing climatic temperature.

4.3.4 Heating & Cooling comparison

All the predicted scenarios of heating energy show that there is a constant gradual decrease in

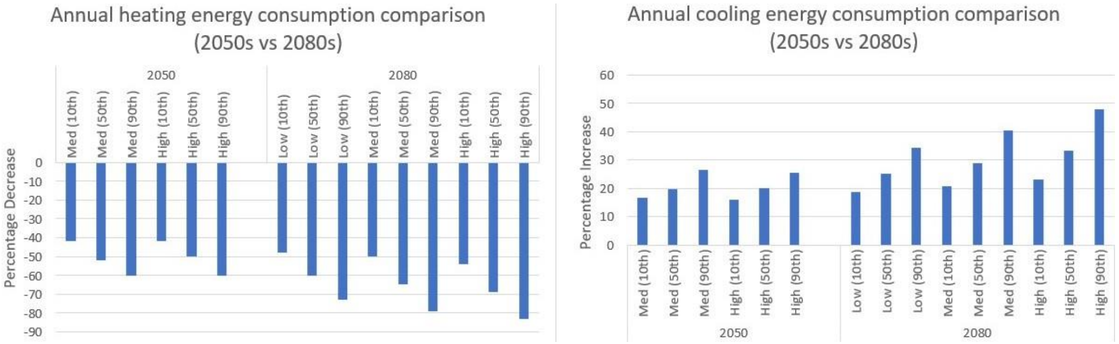


Fig. 14 (a) Annual heating energy consumption (2050s vs 2080s); (b) Annual cooling energy consumption (2050s vs 2080s) heating energy over the years, irrespective of any scenario or percentile chosen whereas, the cooling energy increases regardless of any scenario chosen. Figs. 14(a)-(b) shows the annual heating and cooling energy comparison for future climatic projections for all the 2050s and 2080s scenarios.

For heating energy, there is a peak reduction of 40.91% in the 2050s medium (90th) percentile/high (90th) percentile scenario and a 72.72% reduction in the 2080s high (90th) percentile scenario, respectively. Over the years, the reduced heating consumption is attributed to the increase in climatic temperature, influencing the heating demand to be minimized.

For cooling energy, there is a peak increase of 12.91% in the 2050s medium (90th) percentile scenario and a 34.43% increase in the 2080s high (90th) percentile scenario, respectively. This rise in the annual cooling energy consumption shows a gradual increase in the temperature over time.

4.4 Full multi-city comparative analysis

Tables 5(a)-(d) presents all the data of key performance indicators of a typical supermarket building for London, Manchester, and Southampton.

Those includes the annual energy consumption, annual carbon emissions, heating, and cooling energy consumption for the future years of the 2050s and 2080s for the emission scenarios of low, medium, high and of 10th, 50th and 90th percentile, respectively between various cities. It also helps distinguishes the best- and worst-case scenario among all possible outcomes.

All the predicted scenarios show that there is a constant decrease in heating consumption over the years and all the predicted scenarios show a constant increase in cooling consumption over

Table 5(a) Multi-city annual heating and cooling consumption (all emissions scenarios)

Annual heating consumption	London	Manchester	Southampton
	2050s		
Med 10	-14.29	-10.71	-9.09
Med 50	-28.57	-25.00	-27.27
Med 90	-47.62	-39.29	-40.91
High 10	-14.29	-10.71	-9.09
High 50	-28.57	-25.00	-27.27
High 90	-47.62	-39.29	-40.91
	2080s		
Low 10	-23.81	-17.86	-18.18
Low 50	-42.86	-39.29	-40.91
Low 90	-66.67	-57.14	-59.09
Med 10	-23.81	-21.43	-22.72
Med 50	-52.38	-42.86	-45.45
Med 90	-76.19	-67.86	-68.18
High 10	-33.33	-28.57	-31.81
High 50	-61.90	-53.57	-54.54
High 90	-85.71	-75.00	-72.72

Table 5(a) Continued

Annual heating consumption	London	Manchester	Southampton
	2050s		
Med 10	2.93	2.5	3.14
Med 50	7.14	6.23	7.35
Med 90	12.47	11.00	12.91
High 10	2.31	1.72	2.32
High 50	6.58	5.58	6.53
High 90	11.46	10.16	11.61
	2080s		
Low 10	4.98	4.15	5.44
Low 50	11.52	10.03	11.95
Low 90	20.02	17.85	20.93
Med 10	6.93	6.07	7.59
Med 50	14.75	13.21	15.73
Med 90	25.65	23.36	27.08
High 10	9.06	8.05	10.16
High 50	18.72	16.97	20.09
High 90	32.41	30.11	34.43

the years (Table 5(a)), irrespective of any scenario or percentile chosen.

This increase in cooling requirements can be attributed to the long summers and extreme summer heat waves, which can be due to increasing annual average temperature whereas the large decline in heating requirement points out to a rapid increase in temperatures in the future across the UK.

Table 5(b) shows all the predicted scenarios show a constant increase over the years. This increase in energy demand can be attributed to the due to the burden on cooling requirements.

Table 5(b) Multi-city annual total energy consumption (all emissions scenarios)

Annual total energy consumption	London	Manchester	Southampton
	2050s		
Med 10	0.85	0.69	0.9
Med 50	2.08	1.7	2.12
Med 90	3.66	3.00	3.73
High 10	0.67	0.47	0.67
High 50	1.92	1.52	1.88
High 90	3.36	2.77	3.36

Table 5(b) Continued

Annual total energy consumption	London	Manchester	Southampton
2080s			
Low 10	1.45	1.13	1.56
Low 50	3.37	2.73	3.45
Low 90	5.89	4.88	6.08
Med 10	2.04	1.66	2.19
Med 50	4.34	3.62	4.57
Med 90	7.57	6.41	7.88
High 10	2.67	2.20	2.94
High 50	5.51	4.65	5.84
High 90	9.58	8.30	10.04

Table 5(c) Multi-city annual CO_2 emissions (all emissions scenarios)

Annual carbon dioxide emissions	London	Manchester	Southampton
2050s			
Med 10	0.86	0.67	0.89
Med 50	2.09	1.69	2.12
Med 90	3.65	2.99	3.72
High 10	0.67	0.46	0.65
High 50	1.92	1.50	1.88
High 90	6.45	2.76	3.35
2080s			
Low 10	1.46	1.13	1.55
Low 50	3.38	2.73	3.45
Low 90	5.88	4.80	6.07
Med 10	2.04	1.65	2.19
Med 50	4.34	3.61	4.55
Med 90	7.56	6.41	7.87
High 10	2.66	2.20	2.93
High 50	5.51	4.63	5.83
High 90	9.59	8.29	10.02

5. Discussion

The study investigated the variability of future climatic conditions on a typical UK supermarket across three different cities – London, Manchester, and Southampton. The statistical analysis of simulation results concludes that the worst-case scenario (High 90) of 2080s would cause the most damage to the supermarket industry where the Med 10 scenario of 2050s would cause a non-significant change. Similarly, the Low scenarios of 2080s help built a regression line value to understand the gradual to drastic increase in the energy and emissions and a declining trend in heating demand.

In terms of total energy consumption difference between current and future data sets, the peak percentage changes for the 2080s high (90th) percentile were 9.58%, 8.30% and 10.04% respectively for the three cities. The peak differences in emissions were found to be 9.59%, 8.29% and 10.02% for the 2080s high (90th) percentile for the three urban settlements, respectively. For cooling, these values were 32.41%, 30.11% and 34.43% for 2080s high (90th) percentile respectively. The differences in heating parameters for the 2080s high (90th) percentile turned out to be 85.71%, 75.00% and 72.72%.

The results clearly proclaim that the annual energy and carbon emissions increase drastically over the coming years specifically under the worst-case scenario and for the southern areas of UK. It requires attention to the supermarket's prioritized approach so that a pre-emptive action can counter these effects. In terms of operational carbon emissions, the most important design change of the building includes curbing the use of lighting as it is the biggest source of carbon emissions. A good recommendation would be increasing the use of passive lighting in stores, installation of the same and automation wherever possible. Additionally, lighting control and smart lighting can ensure that the energy consumption and associated emissions are reduced. Other energy efficiency measures include usage of efficient heating, cooling, ventilation and using equipment with higher coefficients of performance, usage of renewable and microgeneration technologies plus on-site low and zero (LZC) technologies. By making these changes in the most affected areas in UK, the supermarket buildings can tailor their needs and can reduce the impact of future climate change.

Such retrofit customizations must also keep in mind the utility of commercial infrastructure, like hotels where cooling and heating demands will occupy the primary considerations in energy consumption (Rotimi *et al*. 2018, Salem *et al*. 2019, Amirkhani *et al*. 2020).

6. Conclusions

This research enables the existing scientific inputs to amplify further the predictability and the implications of any construction-based endeavors undertaken in the future and promote effective, efficient, and responsive eco-friendly policies. It also enables the engineering community to understand the requirements for future-proof supermarket buildings. It would allow the decision-makers to adopt mitigation strategies to slow down the effects of climate change by tackling it beforehand, therefore building a more safe, resilient, and secure world for us all. Emerging renewable and microgeneration technologies can be utilized to adapt to climate change by infusing energy efficiency measures through enhanced effective planning and design options to generate a robust construction blueprint. HVAC systems, passive design technologies to mitigate mechanical ventilation, and better refrigerant usage with low environmental impact and excellent thermodynamic performance can be absorbed and integrated into supermarket architecture and energy designs to reduce the future energy demands in the supermarkets.

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