

Impact of future climate change on UK building performance

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Abstract. Global demand for dwelling energy and implications of changing climatic conditions on buildings confront the built environment to build sustainable dwellings. This study investigates the variability of future climatic conditions on newly built detached dwellings in the UK. Series of energy modelling and simulations are performed on ten detached houses to evaluate and predict the impact of varying future climatic patterns on five building performance indicators. The study identifies and quantifies a consistent declining trend of building performance which is in consonance with current scientific knowledge of annual temperature change prediction in relations to long term climatic variation. The average percentage decrease for the annual energy consumption was predicted to be 2.80, 6.60 and 10.56 for 2020s, 2050s and 2080s time lines respectively. A similar declining trend in the case of annual natural gas consumption was 4.24, 9.98 and 16.1, and that for building emission rate and heating demand were 2.27, 5.49 and 8.72 and 7.82, 18.43 and 29.46 respectively. The study further analyse future heating and cooling demands of the three warmest months of the year and ascertain future variance in relative humidity and indoor temperature which might necessitate the use of room cooling systems to provide thermal comfort.

Keywords: buildings; energy; performance; future weather; sustainability

1. Introduction

Judicious making of inform long term strategic infrastructure investments decisions involve cost and sustainable environmental consideration in relation to building performance and occupancy comfort. Over the years, based on the knowledge to design and build with the view to reduce carbon dioxide emissions, professionals in the building industry have adapted two main approaches. Whilst one approach has been related to the reduction in the building energy demand through the appropriate selection of building elements and design, a converse approach has been the adaptation of renewable systems (Palme *et al.* 2013). Although, these two approaches have led to the enhancement and improvements of building performance predictability, yet the future accuracy in real building performance cannot be ascertained due to the variability of climatic conditions (Palme *et al.* 2013).

In general, the variability and impact of climate change to buildings and its components have been largely ignored (Crawley 2008). Moreover, investigations ought to be pursued in the area of primary energy consumption and carbon emissions in relation to energy demands (Palme *et al.*

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2013).

The impact of global warming resulting to changes in the world's climatic conditions is widely acknowledged (Palme *et al.* 2013, Du *et al.* 2011, De Wilde and Coley 2012, UKCP 2010) and the evidence requires little justification to point to the impact of climate change on building. The Inter-government Panel on Climate Change (IPCC) fourth assessment report indicated that the rise of world temperature as a result of possible anthropogenic emissions of greenhouse gases in our century would vary between the range of 1.1 to 6.4°C (IPCC 2007). Since there is a direct bearing of changes in climatic conditions on buildings, it is imperative for the building industry to research on the impact of climate change on building performance.

There exists valuable technical information to help in the assessment and analysis of how climatic condition varies on buildings. For a little over the past decade, the International scientific community have developed atmospheric-ocean general circulation models (GCM) to predict climatic variations at a relatively high level of spatial resolution (Crawley 2008). The four main GCM are the United Kingdom HadCM3, the Australia CSIRO2, the Canada CGCM2 and the United States PCM (IPCC 2001). The Fig. 1 indicates the range of annual average temperature change predicted by the GCM based on the IPCC scenarios (IPCC 2001).

In the United Kingdom, the UK Climate Projections 2009 (UKCP09); a fifth generation climate change data based on the Met Office Hadley Centre climate model (HADCM3) provides a state-of-the-art information of future climatic condition predictions (UKCP 2010) which serves as a platform for the analysis of the impact and vulnerability of climate change on buildings have been developed. The projections which are in consonance with the current scientific knowledge has been deemed appropriately for analysis of long term climate variations (UKCP09). The projections are presented in three future greenhouse emission scenarios of high, medium and low (William *et al.* 2011) for both Test Reference Years (TRY) and Design Summer Years (DRY) (UKCP 2010). This is done for annual, seasonal and monthly climate averages based on seven 30 year time periods (UKCP 2010). Fig. 2 is the summary of total global emissions for the three scenarios.

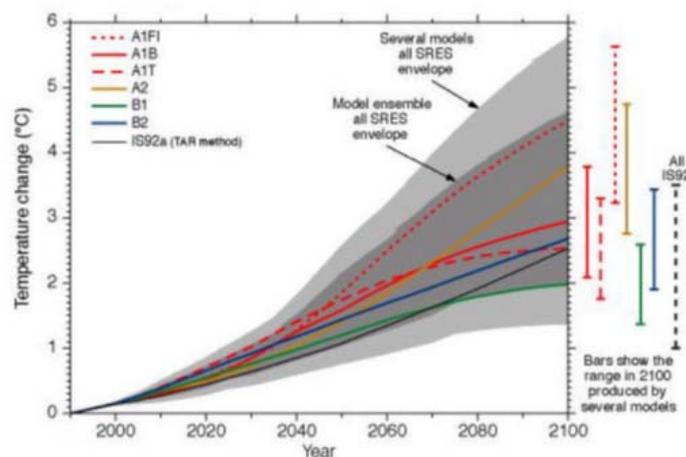


Fig. 1 Range of Annual Average Temperature Change Predicted by the GCM using IPCC Scenarios (IPCC 2001)

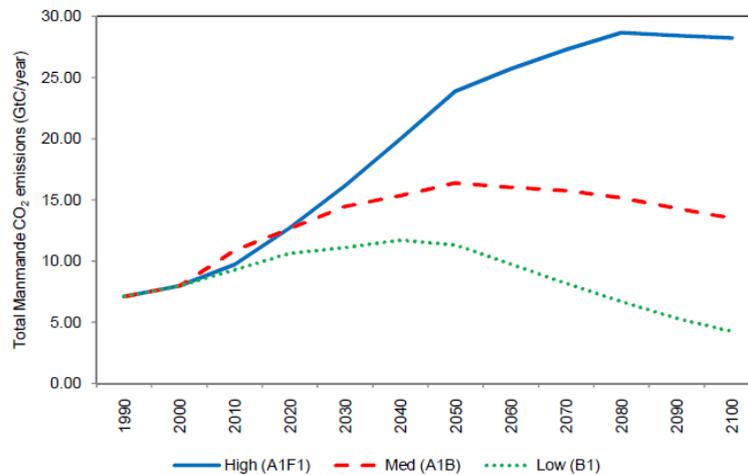


Fig. 2 Global Carbon Dioxide Emissions Scenarios derived from (Nakicenovic and Swart 2000)

Studies related to the analysis of the future climatic patterns show increases in the number of days with high temperatures in the United Kingdom (UKCP 2010). The mean daily maximum temperatures were observed to have an increase range between 2.2 and 9.5°C (UKCP 2010). Whilst the mean daily minimum observable trends in winter temperatures show a range of increase between 0.6 and 5.95°C with reference to specific locations (UKCP 2010). These findings present vivid evidence that the climatic projections point to a long term warming climate which will result in the reduction of winter heating demand and an increase in summer cooling demand (Palme *et al.* 2013). Thus, changes in weather condition may impact building performance (William *et al.* 2011).

Furthermore, United Kingdom building regulation with its continuous emphases on improvement of building requirements is influencing the building industry toward the achievement of the set UK climate change act target of reducing greenhouse emissions by 80% in relation to 1990 emission levels by the year 2050 (Climate Change Act 2008). It is noted however, that current practise in the building industry rarely takes cognisance of the need to account for the influence of varying future climatic impact on buildings in its design consideration (William *et al.* 2011).

Despite the findings noted above, there is a global limited research on the impact of current climatic variability on buildings in areas such as heating and cooling demand, energy usage, equipment life and occupant comfort (Crawley 2008). Buildings life time spans tallies with the projected trends of climatic variation (De Wilde and Coley 2012), an indication that the built environment should take cognisance of climatic variability in its design and build consideration with the aim of improving building performance indicators and contribute to the overall global effort of greenhouse emission reduction.

Studies of the impact and vulnerability of buildings which ultimately affect building behaviour and performance due to changes in climatic conditions have been documented (De Wilde and Coley 2012). For instance in 2005 Gaterell and McEvoy presented a study on the impact of climate change uncertainties in relation to detached dwellings energy efficiency in the UK (Gaterell and McEvoy 2005). In 2005 and 2008, Hacker *et al.* (2008, 2009) published their

findings of climate change on indoor environment and carbon dioxide emissions and thermal mass respectively (Hacker *et al.* 2005, 2008), whilst in 2010, Collins *et al.* (2010) presented their work on the bearing of climate change on future energy consumption in the United Kingdom (UK) (Collins *et al.* 2010). In 2009 Lomas and Ji presented work on natural ventilated in hospital wards using alternative weather projections (Lomas and Ji 2009) and in 2012, Barclays *et al.* (2012) also carried out work on specific building system of natural ventilation focusing on wind prediction using information from the UKCP09 (Barclays *et al.* 2012). Other studies have also been conducted in countries other than the United Kingdom in relation to the impact of climate change on buildings (Frank 2005, Crawley 2008, Chan 2011).

As noted above, it is evidence that some work has been undertaken by professionals in the building industry to relate the variability of future climatic conditions to building performance. Whilst future weather information has been used in these studies, almost all of these studies were published prior to the advent of the UK Climate Projection 2009. The UK Climate Projection 2009 present the most advanced comprehensive future weather information for our century, thus resulting in a more accurate and reliable predictive building performance indicators using building simulation methods (Du *et al.* 2011). In addition, although currently extensive research have been done on the output of the UKCP09 in relation to building performance, the various analysis were based on the weather variables rather than varying building performance indicators (William *et al.* 2011).

The Chartered Institution of Building Services Engineers (CIBSE) future weather data set on 14 locations in the United Kingdom is a derivation from downscaling of longitude and latitude grid from the UKCP09. This has been the result of collaboration work between CIBSE and the UK Climate Impacts Program (UKCIP) to assist in the provision of weather data set for building simulation (Shamash *et al.* 2012b). The CIBSE future probabilistic weather data files are presented in the form of Test Reference Years (TRYs) and Design Summer Years (DSY) of carbon emission scenarios of low, medium low, medium high and high for time slices of 2020s, 2050s and 2080s. These outcomes are as the result of morphing historical weather data based on UKCP09 projections of three time periods, three emission scenarios (of low, medium and high) and three probabilistic levels (Shamash *et al.* 2012a). The future weather data set not only serve to “enable designers to assess the impact of climate change on their designs using building energy and thermal simulation models” but also to “enable designers to develop strategies through which buildings can be adapted to cope with the impacts of future climate change” (Hacker *et al.* 2009).

Building energy modelling and simulation programs had been used to evaluate building performances and assessments in the areas of building design and regulatory compliance, evaluation of changing weather data for an overheating analysis, assessment of building internal conditions (infiltration, ventilation, lightning gain, occupancy sensible and latent, equipment sensible and latent, and pollution generation), evaluation and enhancement of building thermal mass, evaluation and selection of renewable energy sources, building automation systems and moisture phenomena. Moreover, modelling and simulation of buildings of selected building range could be extended to represent the entire building stock (Crawley 2003).

This work therefore employs an approved thermal analysis building simulator as a tool to perform series of simulations and thereby evaluate and predict the extent of the impact of varying future climatic patterns, based on the current CIBSE weather data set morphed from the UK Climate Projection 2009 weather information, on newly built detached dwellings in the UK based on five (5) key building performance of total annual energy consumption, annual gas consumption, annual electricity grid consumption, building emissions rate and heating demand.

2. Methodology

2.1 Background

The goal is to verify through a series of simulation using the latest UK Chartered Institution of Building Services Engineers CIBSE TRY of current and future weather data which incorporates the UKCIP09 Projections to evaluate and predict the impact and vulnerability of future climate change on a detached dwelling stock in the United Kingdom.

TAS software version 9.2.1.4 (build) is used as a dynamic simulation modeller to model and simulate the thermal mass of the prototype buildings. TAS has the capability to overcome the

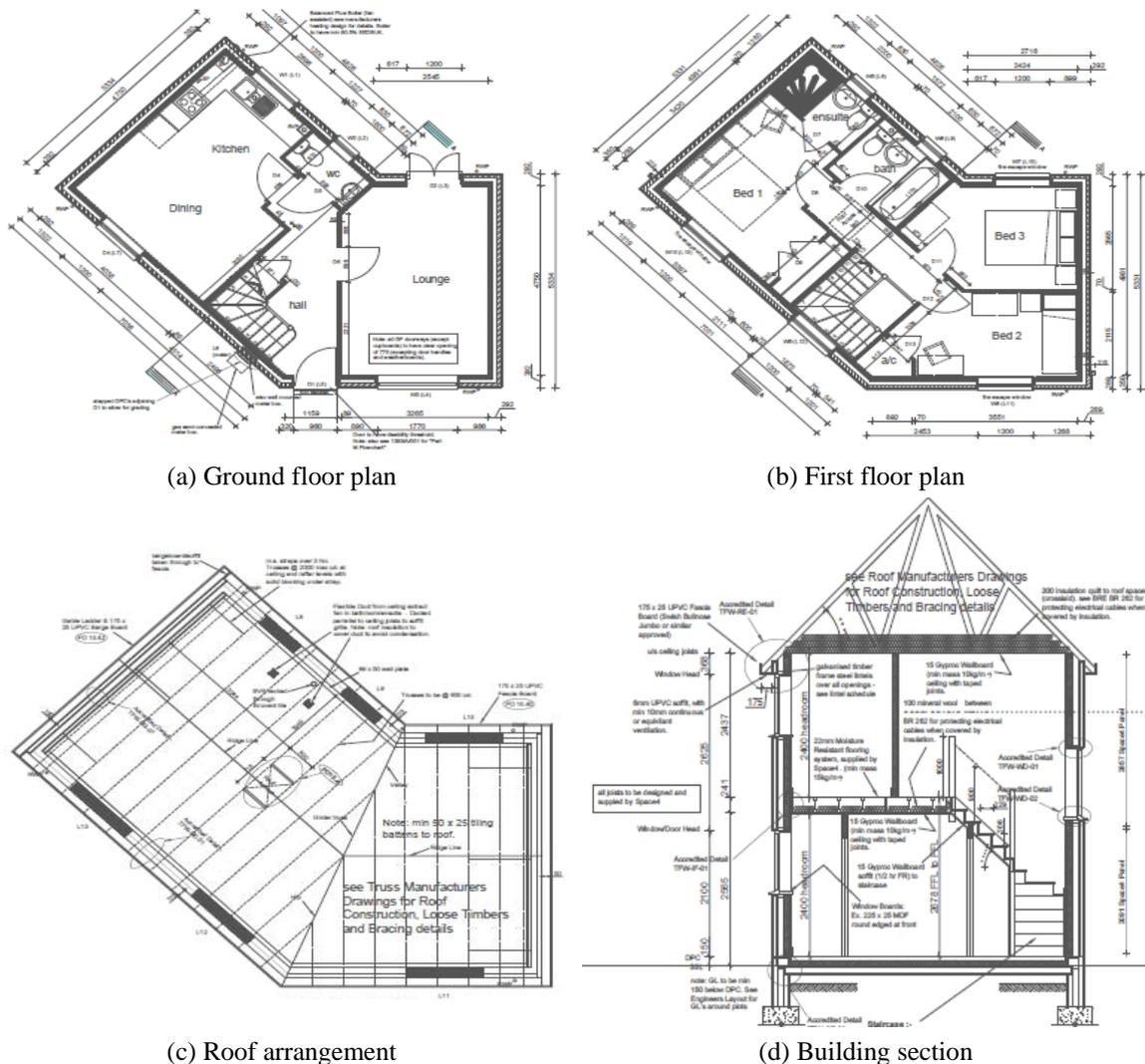


Fig. 3 Architectural plan

challenge of applying the ‘vast quantity of data to assess the probabilistic performance of buildings in the future’ (William *et al.* 2011). Moreover, it offers complete solution as a powerful modelling and simulation in the optimisation of building environment, energy performance and occupant comfort.

Ten residential dwellings of Persimmon South East Ltd Sheppey General Hospital dwelling are selected as building prototypes. Sheppey, Sheerness is 59.4 km from London, the closest weather station. Hence the current and future CIBSE London TRY are chosen for the analysis

2.2 Thermal analysis simulation (TAS) 3D modelling

The data used, are the AutoCAD two-storey residential detached buildings drawings of Persimmon South East Ltd Sheppey General Hospital. The building drawings consisted of the front elevation, rear and side elevation, a section through the elevation, ground floor plan, first floor plan and the roof arrangement plan. The Fig. 3(a)-(d) below indicate the architectural plan of one of the selected houses, the drawing data for 0712 House Type G Pri used in this work.

2.3 Modelling process

Measurements of floors, doors and windows dimensions were taken from the AutoCAD elevations drawings. The floor level was measured from the ground plane at datum 0.0 m. The default wall heights dimensions were measured from the floor finish to directly below the floor finishing of the upper floor. The respective zones on the ground floor and first floor plans were noted and further grouped into Bedrooms, Circulation, Toilet and Miscellaneous.

To aid in the shadow calculations in the 3D Modeller, the orientation of the north angle was changed to 135 degrees clockwise to the North and the latitude, longitude and time zone changed to 51.5 degrees North, - 0.4 degree East and UTC + 0.0 respectively to reflect the geographical and time parameters of London. Sheppey, Sheerness is 59.4 km from London, the closest weather station. The flow charts in Figs. 4-6 below illustrate the drawing files preparation for the 3D modelling process and the modelling of the ground floor, first floor and the roof arrangement respectively.

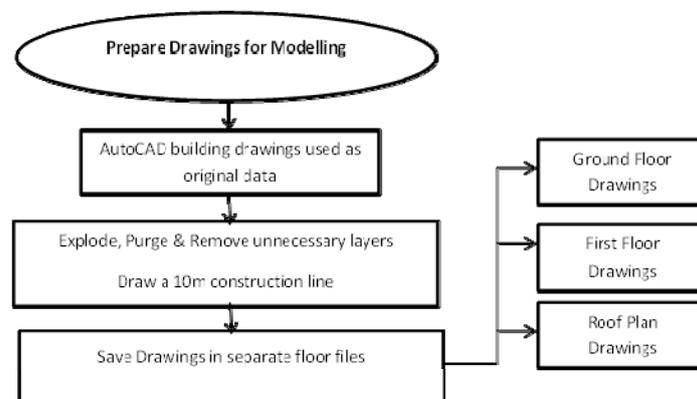


Fig. 4 Prepare drawings for modelling

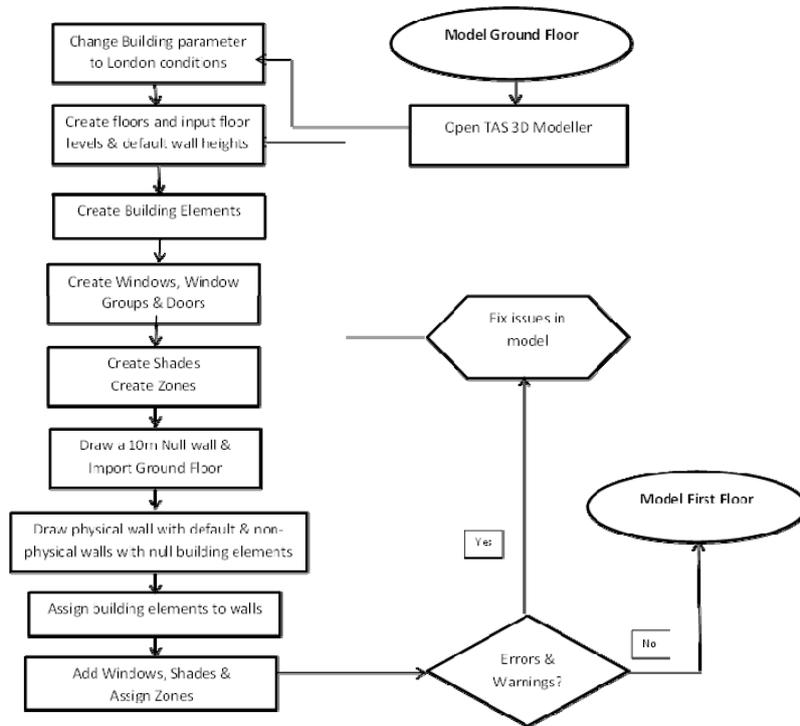


Fig. 5 Ground floor modelling process

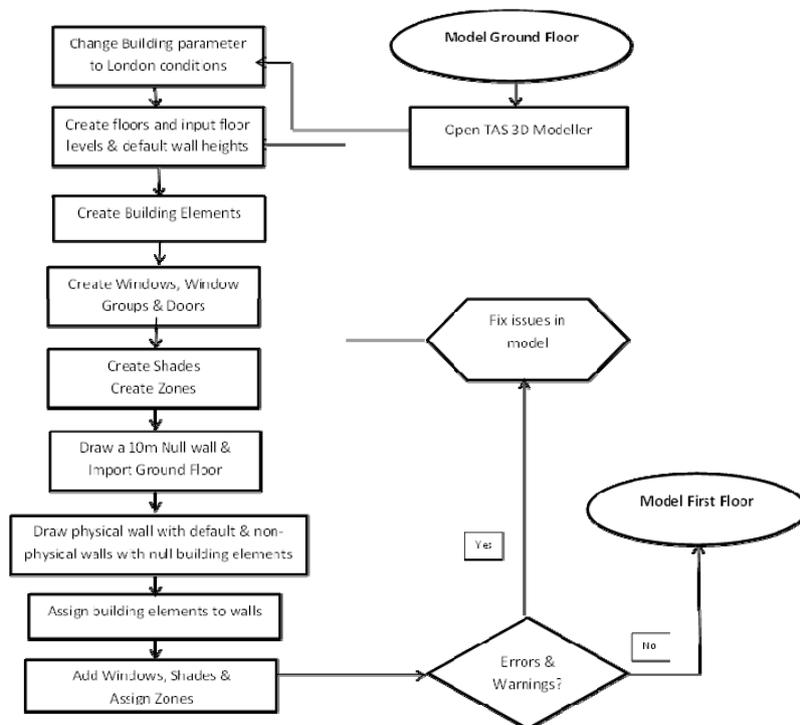


Fig. 6 First floor/roof modelling process

2.4 Simulation process

TAS as a dynamic simulation modeller models the thermal mass of a building. Building performance simulation requires the appropriate selection of modelling parameters and assumptions. The various simulation parameters of Building Summary, Calendar, Weather, Building Elements, Zones, Internal conditions, Schedule, and Aperture Types were populated to simulate the building. Fig. 7 is a flow chart which shows the thermal simulation process with its associated modelling and simulation parameters in Tables 1 and 2.

Table 1 Modelling and simulation parameters and assumptions

<i>Building fabric</i>		
Calculated area weighted average U-values	Wall	0.24 W/m ² K
	Floor	0.21 W/m ² K
	Roof	0.13 W/m ² K
	Windows	2.30 W/m ² K
	Door	2.05 W/m ² K
Average U-value		0.41 W/m ² K
<i>Calendar</i>		
<i>Air permeability</i>	NCM standard	
<i>Infiltration</i>	5 m ³ /hm ² @50Pa	
<i>Lighting efficiency</i>	0.250 ACH	
<i>Average conductance</i>	5.2 W/m ² per 100 lux	
<i>Alpha value</i>	78 W/K	
	22.85%	

Table 2 Modelling and simulation parameters and assumptions

<i>Construction data base</i>	NCM Construction - v4.1.tcd	
Occupancy levels	Bath	0.01873684 pers/m ² . 150 Lux
People density	Bed	0.01873684 pers/m ² . 100 Lux
	Circulation areas	0.02293877 pers/m ² . 100 Lux
	Dining	0.0169163 pers/m ² . 150 Lux
	Kitchen	0.0237037 pers/m ² . 300 Lux
	Lounge	0.0187563 pers/m ² . 150 Lux
	Toilet	0.02431718 pers/m ² . 100 Lux
<i>Fuel source</i>	Natural gas	CO ₂ Factor - 0.198 Kg/kWh
	Grid electricity	CO ₂ Factor - 0.517 Kg/kWh

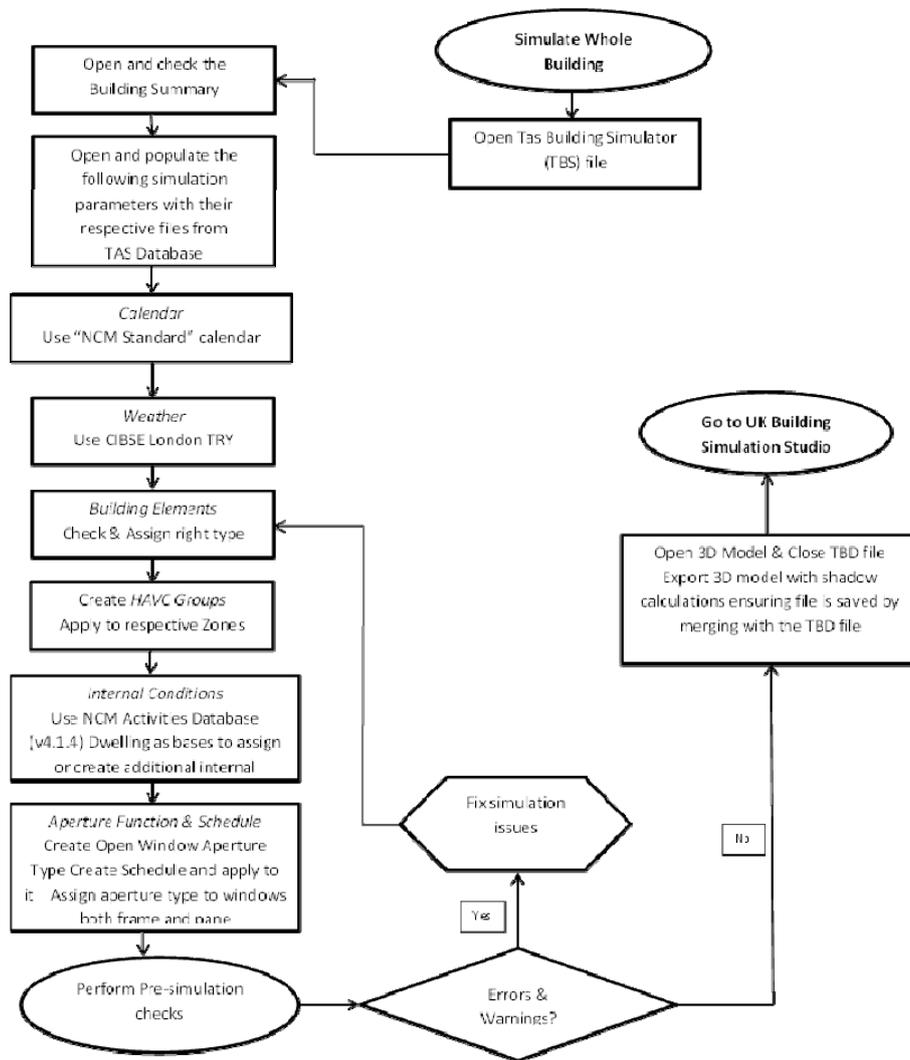


Fig. 7 Thermal simulation process

2.5 UK building regulation studio

The UK Building Regulations Studio used by the TAS EDSL 9.2.1.4 software is based on 2010 regulations. It adheres to the National Calculation for Methodology (NCM) for the Energy Performance of Building Directive (DCLG). The UK Building Regulations Studio is systematically worked through by appropriately selecting various parameters and circuit configuration leading to the generation of series of building reports of which data based on the five (5) key building performance indicators of total annual energy consumption, annual gas consumption, annual electricity grid consumption, building emissions rate and heating demand of for the study are extracted for analysis. The Fig. 8 illustrates the flow chart of simulation processes in the UK Building Regulation Studio.

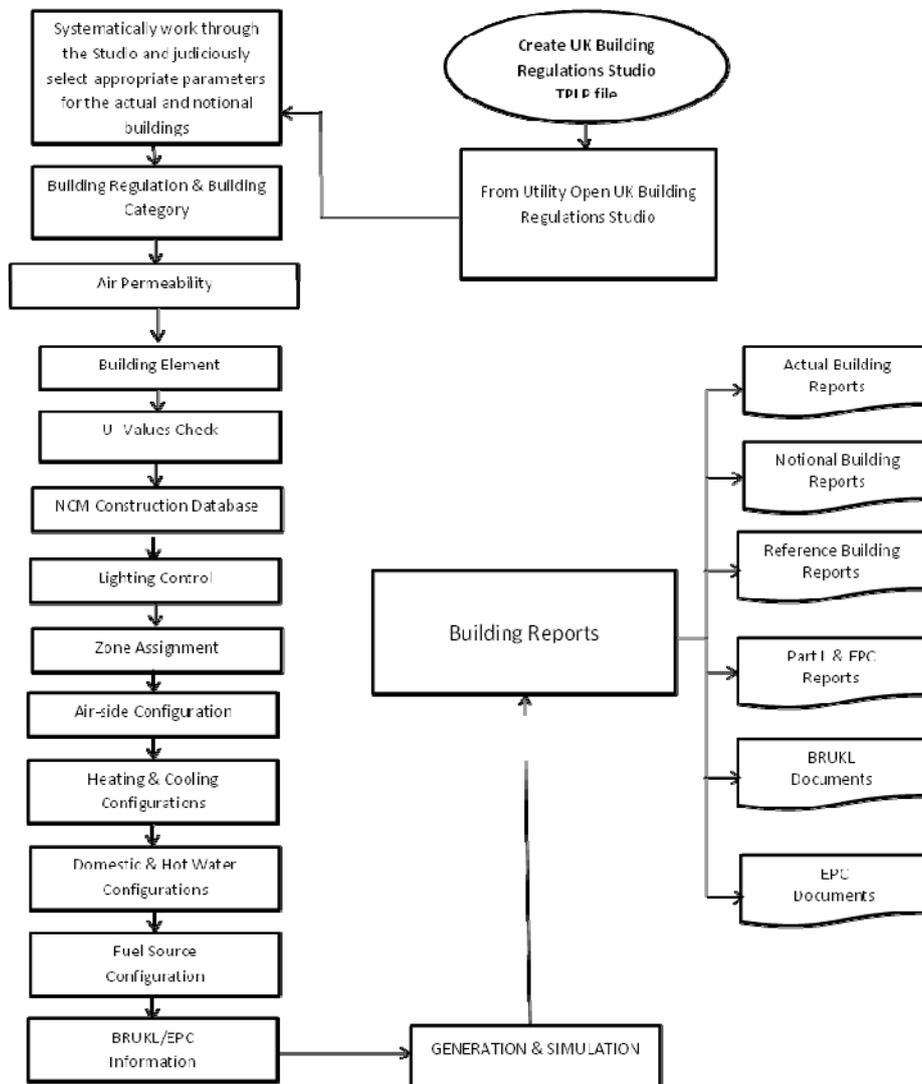


Fig. 8 UK building regulation studio simulation

2.6 Future weather data simulation process

The various modelling and simulation parameters of Building Summary, Calendar, Building Elements, Zones, Internal conditions (which include thermostat set up, infiltration and ventilation, occupancy, lighting and equipment details), Schedule, and Aperture Types which were used to populated and simulate each building are maintained with the only variant being the weather data.

A series of scenarios based on the current and the future climate variables at different time lines of 2020s, 2050s and 2080s with their respective four carbon scenarios of high, medium-high, medium-low and low are simulated. The modelling and simulation processes were followed through for the rest of the nine (9) detached dwellings.

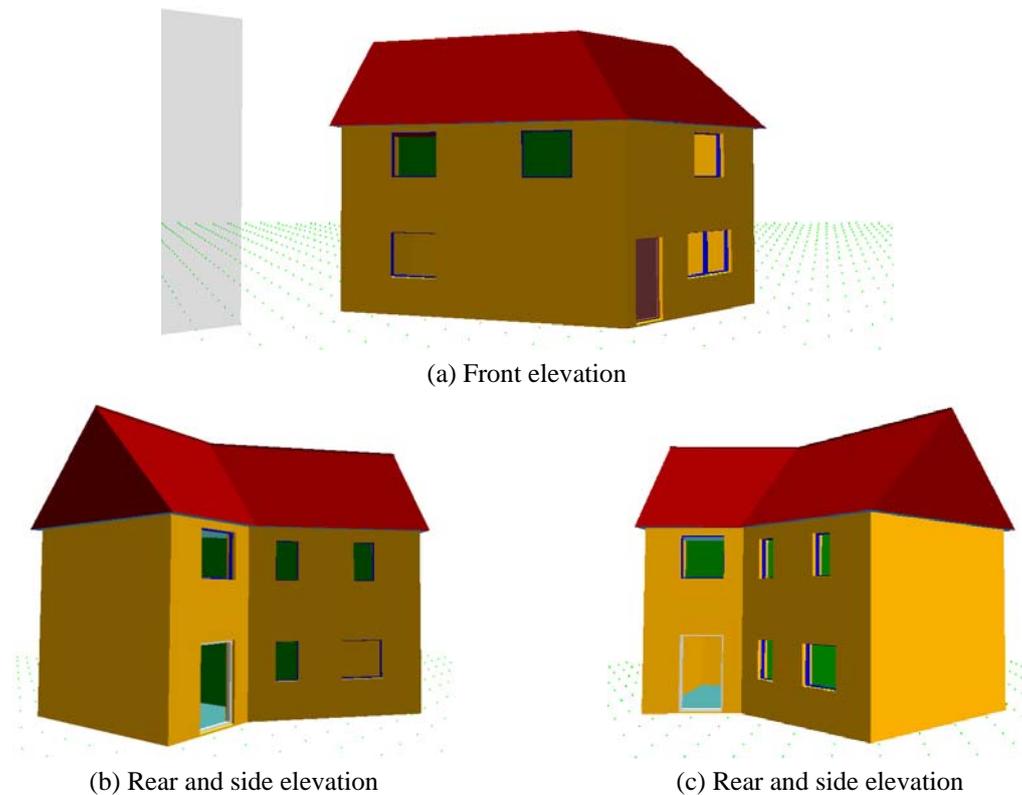


Fig. 9 Modelling results

3. Results and discussion

The analysis of one building prototype - Persimmon South East Ltd Sheppey General Hospital dwelling 0712 House Type G Private - two-storey residential detached building is presented below. Figs. 9(a)-(c) represent the outcome of the modelling process.

Figs. 10-12 show typical TAS results of a simulation information using the UK building Studio 2010 of the building performance indicators earmarked for the study.

Fig. 10 shows the Part L (of the Building Regulations for England and Wales) and Energy Performance Certificate (EPC) reports of total annual energy consumption comparison of actual, notional and reference buildings simulations of the Persimmon building type G, of which information is extracted for statistical analysis. The total annual energy consumption encompasses heating, auxiliary, lighting, domestic hot water (DHW) and equipment energy usage.

From Fig. 10, the auxiliary energy is the additional electric energy consumed by fans and pumps of the heat ventilation air-conditioning (HVAC) systems. The domestic hot water (DHW) is basically the hot water consumption rates in relations to each zone activity. The equipment energy is the consumption due to household appliances, whilst the displaced electricity is the renewable energy configuration, for example the use of solar photovoltaic panels to displace the utility power.

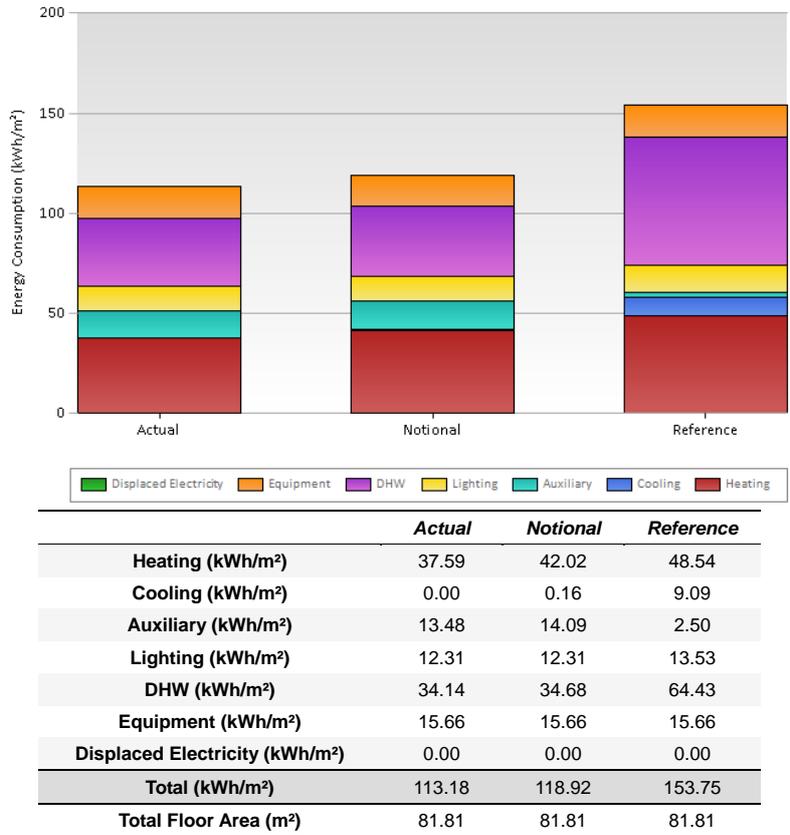


Fig. 10 Annual energy consumption comparison

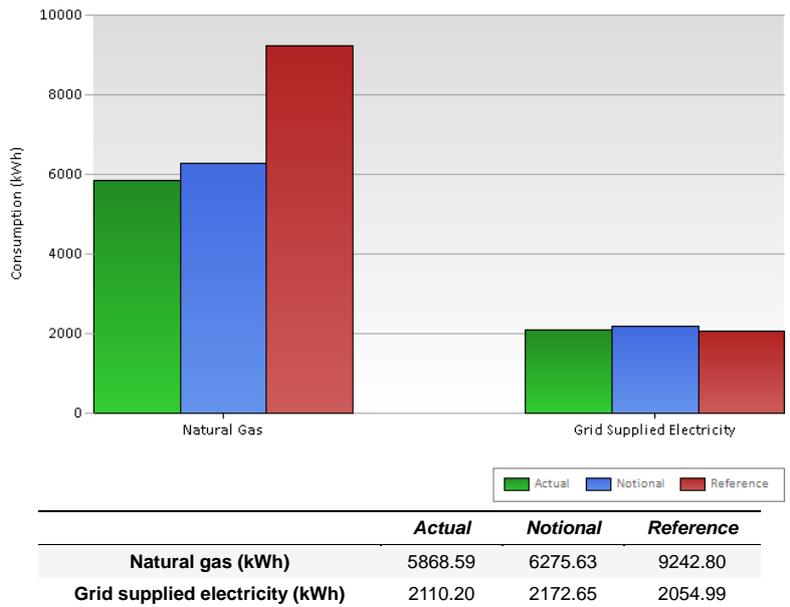


Fig. 11 Annual fuel consumption comparison

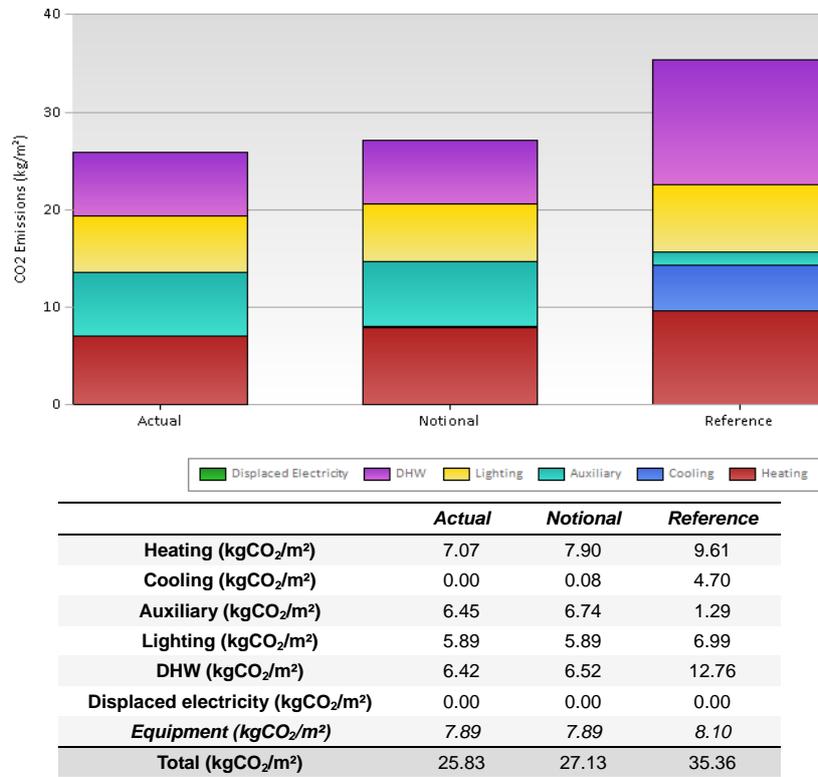
Fig. 12 Annual CO₂ emissions comparison

Fig. 11 shows the Part L and EPC report on annual fuel (natural gas and grid supplied electricity) consumption comparison of actual, notional and reference buildings simulations of which information is extracted for statistical analysis.

Fig. 12 shows the Part L and EPC report on carbon dioxide emission comparison of actual, notional and reference buildings simulations of which information is extracted for statistical analysis.

Table 3 shows an extract of the Building Regulations United Kingdom part L (BRUKL) output document showing the energy and emission summary of which information is extracted for statistical analysis.

Table 3 Energy and CO₂ emissions summary

	Actual	Indicative target
Heating + Cooling demand [MJ/m ²]	113.76	121.9
Total consumption [kWh/m ²]	97.52	103.26
Total emissions [kg/m ²]	25.8	27.1

3.1 Statistical analysis of the key performance indicators

The results of the variations of the key performance indicators of the 13 different sets of simulation of the current and the future weather data of the ten detached dwellings are extracted and tabulated below in Table 4. The table shows the percentage variations of the building performance indicators using the future weather data timelines scenarios when compared to the current weather data.

Table 4 Timeline variance of the key performance indicators

Table 4a Timeline variance of annual energy, natural gas and electricity

House type	Total annual energy consumption (kWh/m ²)			Annual natural gas comparison (kWh)			Annual electricity grid comparison (kWh)		
	% Dec 2020s	% Dec 2050s	% Dec 2080s	% Dec 2020s	% Dec 2050s	% Dec 2080s	% Inc 2020s	% Inc 2050s	% Inc 2080s
	A	2.73	6.44	10.30	4.40	10.38	16.63	0.00	0.01
F	2.72	6.46	10.43	4.17	9.94	16.09	0.00	0.08	0.24
E	2.71	6.49	10.47	4.31	10.33	16.70	0.00	0.02	0.20
G	2.75	6.32	10.19	4.35	10.00	16.14	0.00	0.02	0.16
H1	2.84	6.65	10.74	4.31	10.12	16.35	0.00	0.00	0.06
N	2.90	6.85	11.14	4.25	10.03	16.36	0.00	0.00	0.15
H2	2.76	6.60	10.64	4.18	9.98	16.14	0.00	0.00	0.14
K	2.67	6.20	9.88	4.19	9.75	15.63	0.00	0.02	0.20
M	3.08	7.17	10.74	4.46	10.40	15.62	0.00	0.06	0.24
P	2.89	6.85	11.07	3.75	8.90	14.42	0.00	0.04	0.18
Average	2.80	6.60	10.56	4.24	9.98	16.01	0.00	0.02	0.17

Table 4a Timeline variance of annual energy, natural gas and electricity

House type	Building emission rate (KgCO ₂ /m ²)			Heating demand (MJ/m ²)		
	% Dec 2020s	% Dec 2050s	% Dec 2080s	% Dec 2020s	% Dec 2050s	% Dec 2080s
A	1.97	5.41	8.60	8.20	19.28	30.58
F	1.98	5.40	8.70	7.77	18.31	29.36
E	2.25	5.39	8.65	8.00	19.11	30.49
G	2.27	5.22	8.36	8.18	18.73	29.87
H1	2.31	5.39	8.38	7.59	17.80	28.41
N	2.45	5.80	9.42	7.90	18.66	30.10
H2	2.23	5.37	8.62	6.82	17.17	27.79
K	2.11	4.89	7.76	8.43	19.48	30.66
M	2.68	6.22	9.30	7.68	17.80	28.48
P	2.46	5.82	9.38	7.60	17.99	28.88
Average	2.27	5.49	8.72	7.82	18.43	29.46

Figs 13-17 give the detailed statistical results of the key performance building indicators of total annual energy consumption, annual natural gas comparison, annual electricity grid comparison, building emission rate and building heating demand of Persimmon South East Ltd Sheppey General Hospital dwelling 0712 House Type G Private.

3.1.1 Percentage of total annual energy consumption reduction

The annual energy consumption for current and the future climate variables at different time lines of 2020s, 2050s and 2080s with their respective four carbon scenarios of high, medium-high, medium-low and low all show a progressive decrease variability. This declining trend is observed in all the ten building prototypes with an average percentage decrease of 2.80, 6.60 and 10.56 for 2020s, 2050s and 2080s time lines respectively. This decline is in consonance with the range of annual average temperature change predicted by the GCM based on the IPCC scenarios (IPCC 2001) which generally shows an increase in temperature over stipulated time lines.

3.1.2 Percentage of Annual Natural Gas Consumption Reduction

The annual natural gas consumption for current and the future climate variables at different time lines of 2020s, 2050s and 2080s with their respective four carbon scenarios of high, medium-high, medium-low and low all also show a progressive decrease variability. This declining trend is also observed in all the ten building prototypes with an average percentage decrease of 4.24, 9.98 and 16.1 for 2020s, 2050s and 2080s time lines respectively. This decline is also seen to be in consonance with the range of annual average temperature change predicted by

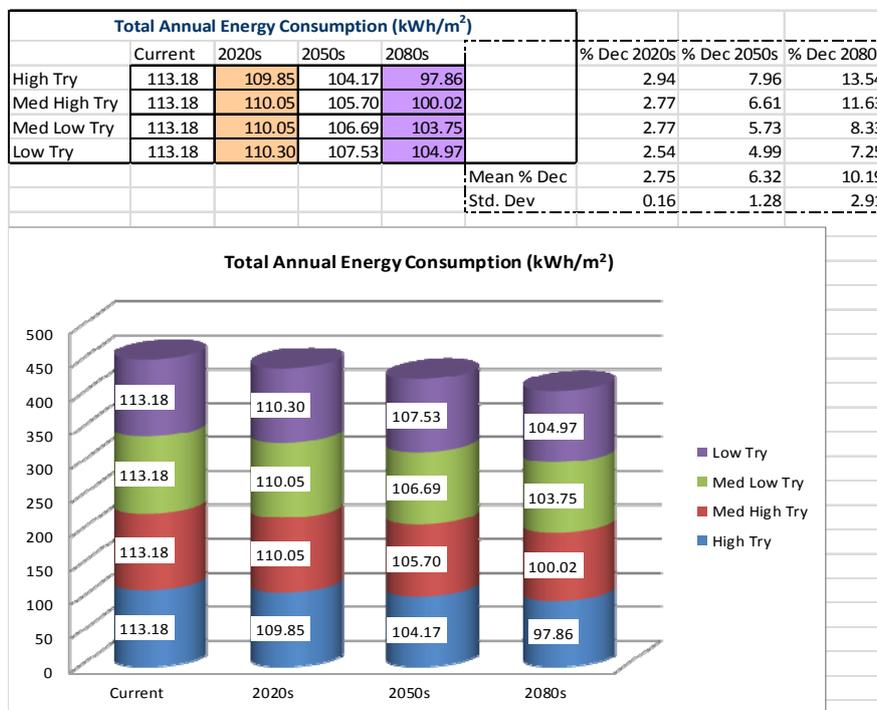


Fig. 13 Total annual energy consumption analysis

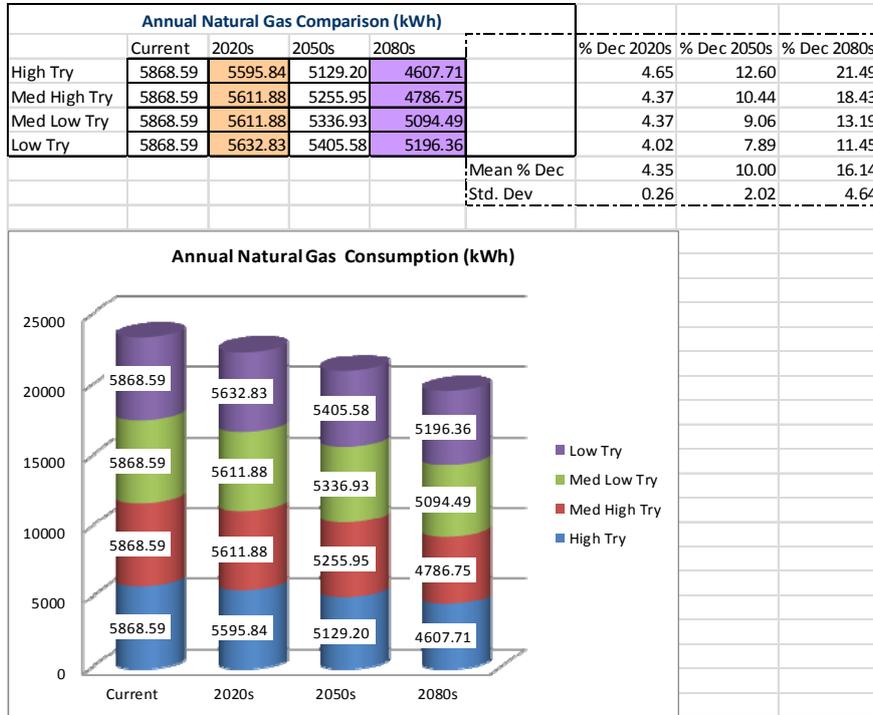


Fig. 14 Annual natural gas comparison analysis

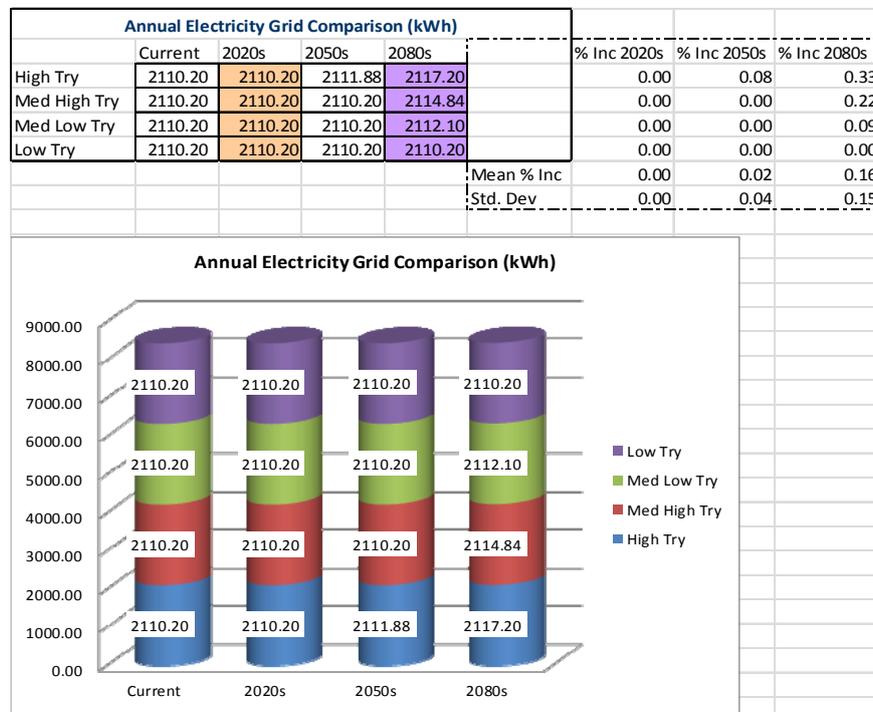


Fig. 15 Annual electricity grid comparison analysis

the GCM based on the IPCC scenarios (IPCC 2001) which generally shows an increase in temperature over stipulated time lines. Increase in future temperature would obviously lead in the decrease in gas consumption. Gas is mainly used in domestic heating.

3.1.3 Annual electricity grid comparison analysis

The annual electricity grid consumption for current and the future climate variables at different time lines of 2020s, 2050s and 2080s with their respective four carbon scenarios of high, medium-high, medium-low and low all also show an observable relatively flat variability with apparently no change in the consumption over the stipulated time lines. This implies that the amount of electricity consumption will remain fairly the same despite change in climatic conditions. This trend is observed in all the ten building prototypes.

3.1.4 Percentage of building emission reduction

The trend of building emission rate for the current and the future climate variables at different time lines of 2020s, 2050s and 2080s with their respective four carbon scenarios of high, medium-high, medium-low and low all also show a progressive decrease variability. This declining trend is also observed in all the ten building prototypes with an average percentage decrease of 2.27, 5.49 and 8.72 for 2020s, 2050s and 2080s time lines respectively. This decline is also seen to be in consonance with the range of annual average temperature change predicted by the GCM based on the IPCC scenarios (IPCC 2001) which generally shows an increase in temperature over stipulated time lines. Increase in future temperature would obviously lead in the less building emission rate.

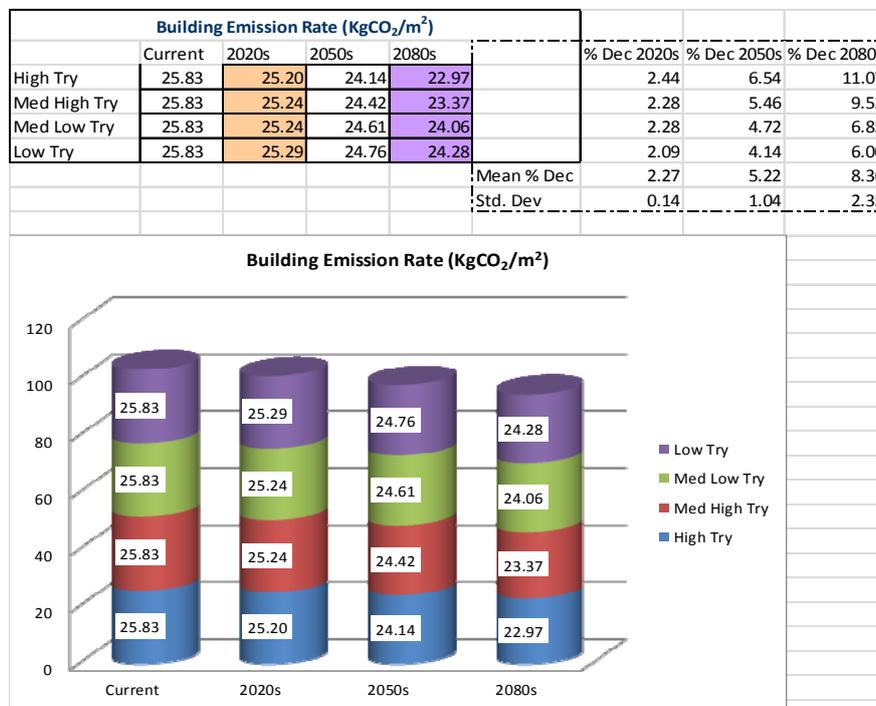


Fig. 16 Building emission rate analysis

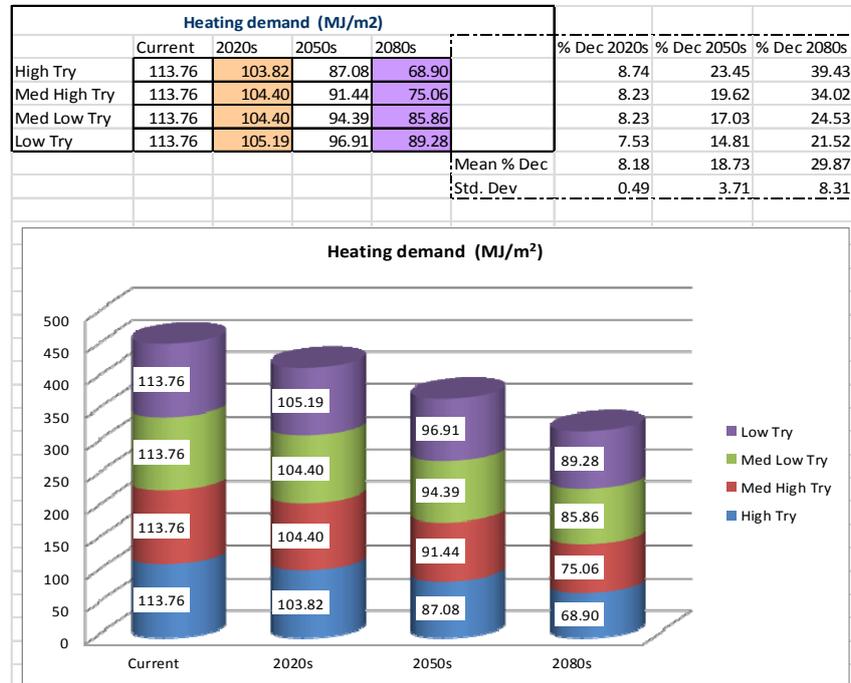


Fig. 17 Heating demand analysis

3.1.5 Percentage of heating demand reduction

The trend of heating demand for the current and the future climate variables at different time lines of 2020s, 2050s and 2080s with their respective four carbon scenarios of high, medium-high, medium-low and low all also show a progressive decrease variability. This declining trend is also observed in all the ten building prototypes with an average percentage decrease of 7.82, 18.43 and 29.46 for 2020s, 2050s and 2080s time lines respectively. This decline is also seen to be in consonance with the range of annual average temperature change predicted by the GCM based on the IPCC scenarios (IPCC 2001) which generally shows an increase in temperature over stipulated time lines. The study therefore points to the fact that increase in future temperature due to climatic variation would obviously have a significant declining impact on heating demand.

However, this scenario may lead to the influence of increased cooling demand for occupancy comfort. Thermal comfort depends on four basic environmental factors of air temperature, radiant temperature, air velocity and relative humidity. One of the main functions of residential buildings is to provide healthy and comfortable environments to the occupants. Buildings must therefore be designed and built by taking cognisance of the physiological reactions of the occupants due to temperature and humidity tolerance of occupants. The study therefore lends itself to overheating analysis to ascertain the need of cooling demand in the United Kingdom with future prediction of increasing temperature.

3.2 Heating and cooling demand analysis

Simulations were therefore run for the current weather data scenario and the worst case

scenario of increase temperature of 2080s high try. The results are presented in Figs. 18-25 which show variations in temperature and loads, radiant temperatures, humidity and loads, and total load profile for all zones between June 1 and August 31 – the three warmest months of the year with clear sky - for the current weather and the 2080s high try data sets.

A comparison of the variability of the temperature and loads analysis in Figs. 18 and 19 show a rise in the radiant temperatures from the current weather data to the worst case scenario, 2080s high try. In TAS system, the radiant temperature simulation takes into consideration the external temperature, the mean radiant temperature and the resultant temperature. Radiant temperature has much impact to body temperature variation than air temperature. Figs. 18 and 20 when compared to Figs. 19 and 21 give the ranges of radiant temperatures range from 6°C to 32°C with relative few periods going above 30°C mark for the current weather data set and from 8°C to 38°C with

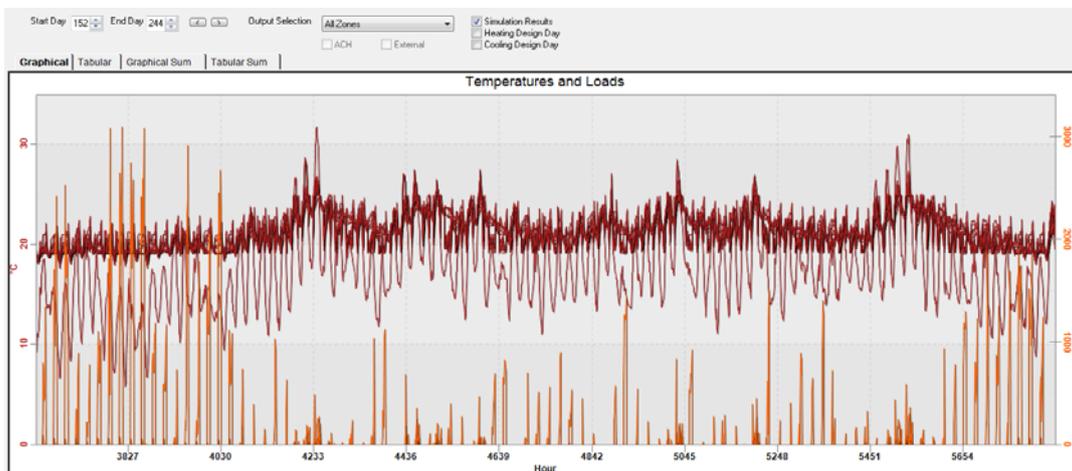


Fig. 18 Temperature and loads analysis - current weather data all zones

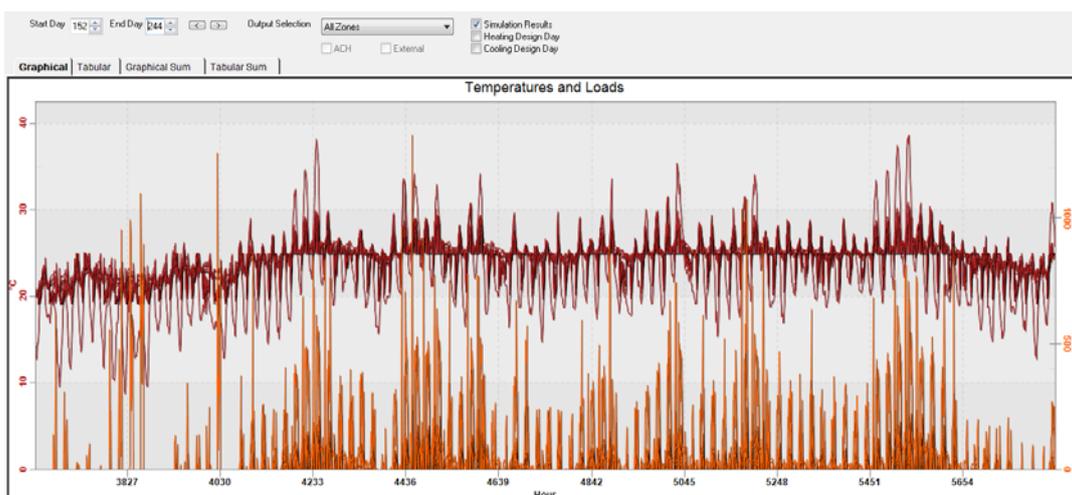


Fig. 19 Temperature and load analysis - 2080s high try all zones

relatively increase in periods for the worst case scenario of 2080s high try for the specified period of analysis respectively.

Climate factors of temperature and relative humidity are keys to determine thermal comfort of building occupants. The thermal environmental conditions for human occupancy standards are set out in the European Committee for Standardization (CEN), the International Organisation for Standardization (ISO) and American Standards of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) (Boduck and Fincher 2009).

Currently, no mechanical cooling is required in new dwellings during summer as most naturally ventilated buildings are free-running non air-conditioned buildings. The average monthly maximum temperature range for the three warmest months in the year in England from 1981 to 2010 is observed to be between 18.6°C and 20.7°C, and 20.2°C to 22.6°C for London; temperatures in England being higher than the rest of United Kingdom (Met Office 2013).

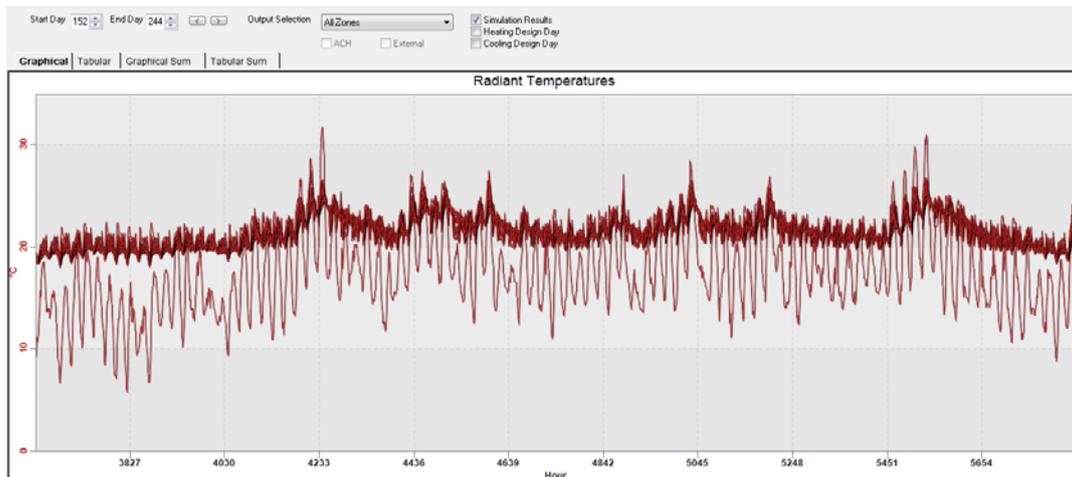


Fig. 20 Radiant temperature analysis - current weather data all zones

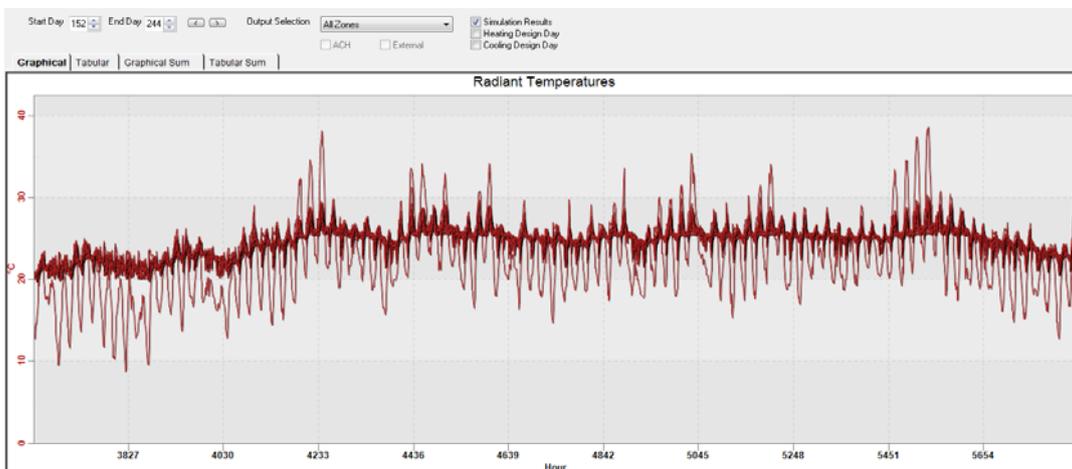


Fig. 21 Radiant temperature analysis - 2080s high try all zones

The European Committee for Standardization sets the recommended criteria for the indoor temperature of a dwelling based on a running mean outside temperature as between 18°C to 27°C for all categories of residential buildings and 20°C to 26°C for normal level of expectation recommended for new buildings and renovations (EN 15251 CEN 2007). The ASHRAE's Standard 55, Thermal Environmental conditions for Human Occupancy, stipulates the guideline room air temperatures for residences during summer to be in the range of 23°C to 26°C (ASHRAE Standard 55 1992).

The 2080s high try worst case scenario with the temperature range of 8°C to 38°C and the mean temperature of about 26°C indicates that the future length of cooling season may slightly increase, which might therefore necessitate the use of room conditioning systems to keep the indoor temperatures at specified levels to provide heat balance or thermal comfort.

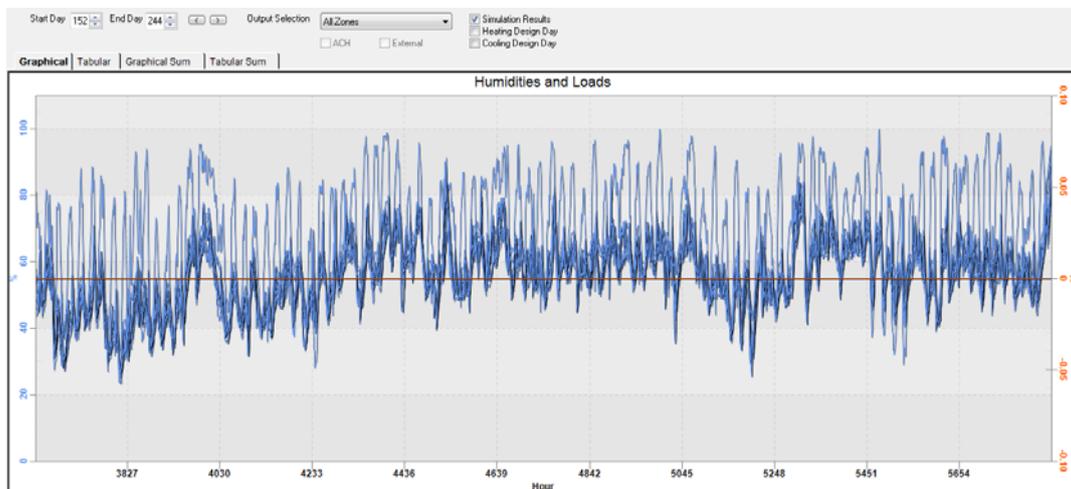


Fig. 22 Humidity and load analysis - current weather data all zones

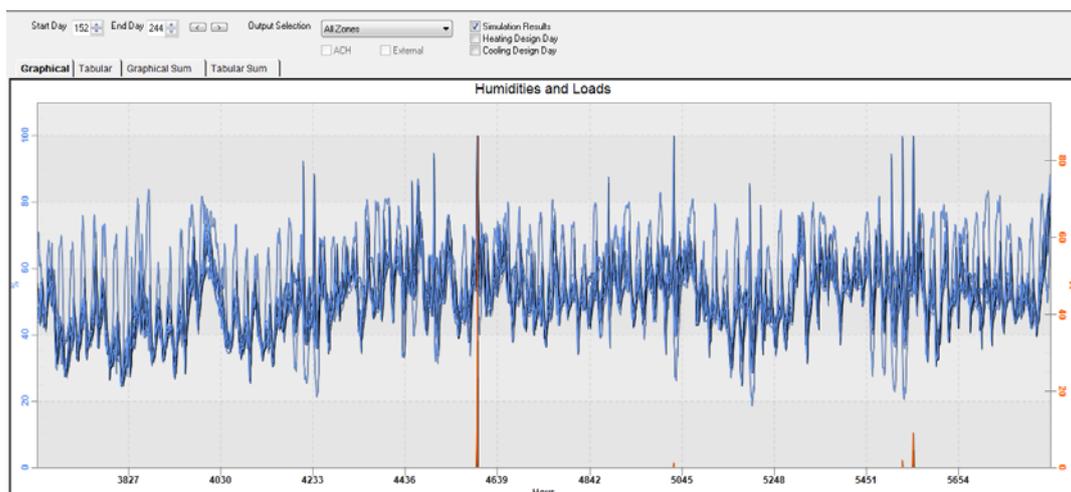


Fig. 23 Humidity and load analysis - 2080s high try all zones

A comparison of Figs. 16 and 17 give the variability of humidity and loads analysis within the specified period. In the TAS system, simulation of the humidities and loads takes into consideration the external humidity, relative humidity, latent removal load and latent addition load. Fig. 16 shows humidity range variability between 25% and 98% with most relative humidity between 40% and 60%. Fig. 17 gives the range variability to be between 20% and 96% with most relative humidity values between 38% and 58%. The higher the humidity the less evaporation of sweat, thus high levels of relative humidity leads to less body evaporation resulting in minimal cooling of the body. The converse leads to skin dryness and dryness and irritation of the eyes, throat and nose (Boduch and Fincher 2009). Relative humidity between 40% and 70% has little impact on thermal comfort (Thermal Comfort 2013). The base line for thermal comfort with reference to relative humidity is set within the range of 25% and 60% (Boduch and Fincher 2009). The International Organization for Standardization ISO 7730:2005 stipulates that humidity impact is limited at temperatures less than 26°C considering moderate activity levels (ISO 7730:2005). Unlike temperature effect on heat balance, thermal comfort is expressed over a wide range of relative humidity conditions. With this wide range, variability of relative humidity unlike temperature has only a minimal effect on thermal comfort (EN 15251 CEN 2007). Thus although there is evidence of some reduction in humidity in the worst case scenario of 2080s high try, the variability does not suggest a great shift to cooling demands.

A comparison of Figs. 24 and 25 give the total load profiles of heating and cooling loads for the specified period of analysis. The variability of the total load profiles in the current weather data scenario shows more of heating load profile with relatively little cooling load profile. The converse is observed in the worst case scenario of 2080s high try. The TAS system simulates sensible heat but not latent heat. Sensible heating or cooling process of air is related to the dry heat causing change in temperature but does not affect the moisture content of the air. However, latent heating or cooling process of air is the heat supplied or removed from air which leads to a change

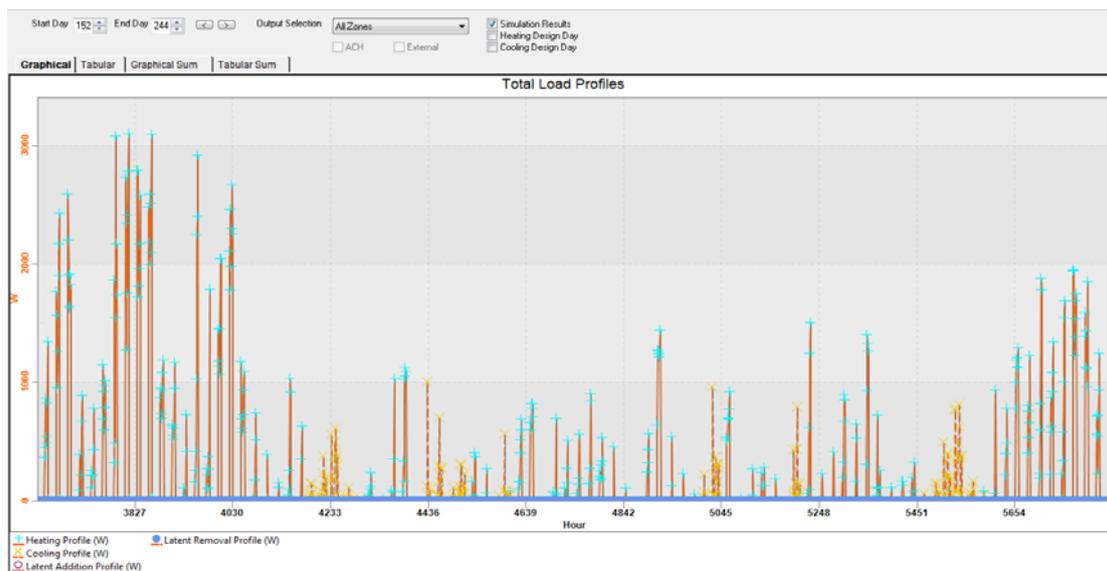


Fig. 24 Total load profiles analysis - current weather data all zones

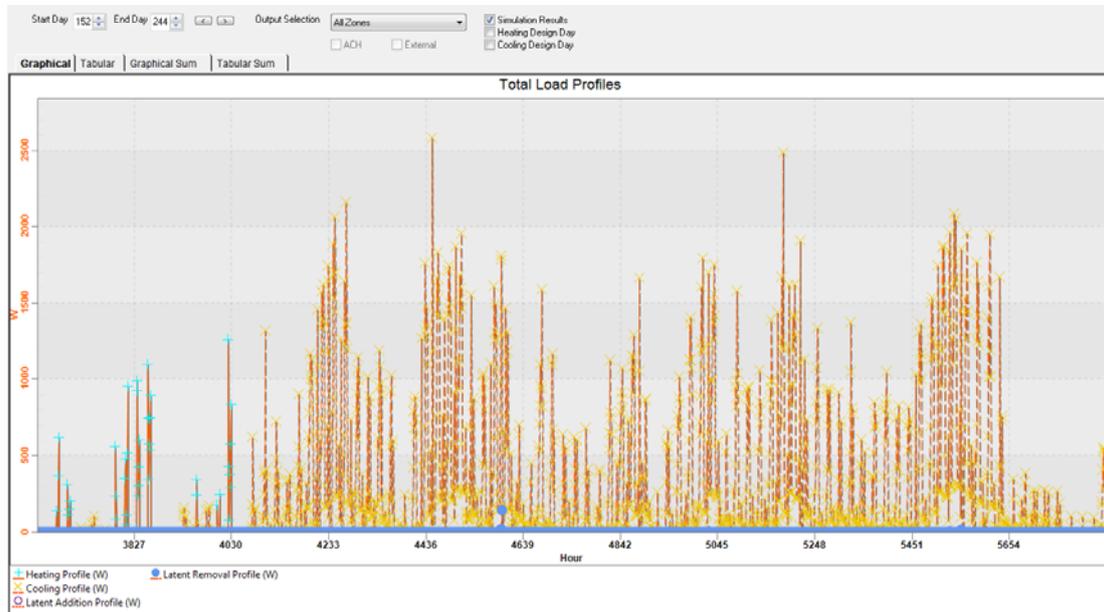


Fig. 25 Total load profiles analysis - 2080s high try all zones

of moisture content but does not affect the air temperature. Factors which influence the sensible cooling in the TAS system includes gains in solar, lighting, air movement, vent, occupant sensible, equipment sensible and building heat transfer, external conduction opaque and external conduction glazing.

4. Conclusions

The study investigated the variability of future climatic conditions on newly built detached dwellings in the United Kingdom. Analysis of simulation results leads to the predicting of consistent declining trend of annual building energy consumption, annual building natural gas consumption, building emission rate and heating demand but with no change in annual electricity grid consumption over the different time lines of 2020s, 2050s and 2080s used in the simulation.

The average percentage decrease for the annual energy consumption for current and future weather data set observed in all the ten building prototypes was 2.80, 6.60 and 10.56 for 2020s, 2050s and 2080s time lines respectively. A similar declining trend in the case of annual natural gas consumption was 4.24, 9.98 and 16.1, and that for building emission rate and heating demand were 2.27, 5.49 and 8.72 and 7.82, 18.43 and 29.46 for 2020s, 2050s and 2080s time lines respectively. These declines are in consonance with the range of annual average temperature change predicted by the GCM based on the IPCC scenarios which generally shows an increase in temperature over stipulated time lines. There was no observable change in the annual electricity grid consumption for current and the future weather data sets simulations over the stipulated time lines.

Analysis of the future heating and cooling demands of the three warmest months of the year with clear sky for the current weather and the worst case scenario data sets showed a reduction in

humidity in the worst case scenario. However, the variability does not suggest a shift to cooling demands as the range falls within the thermal comfort relative humidity tolerance associated with the physiological reactions of the building occupants. The worst case scenario analysis of radiant temperature indicated that the future length of cooling season may slightly increase, which might therefore necessitate the use of room conditioning systems to keep the indoor temperatures at specified levels to provide heat balance or thermal comfort.

The study thus establishes the significant impact of variability of climatic patterns on building performance taking cognizance of the future timelines which also coincides with building life span. It further affirms that predicted increase in future temperatures might result in reduction in energy use for space heating and emissions but conversely lead to the increase in cooling demand, thus offsetting the gains in heating demand. Increase in cooling demand has environmental implications as it results in increased electricity consumption leading to higher emissions.

This work has indicated that building performance simulation using variation of future climatic patterns can contribute to the reduction of the environmental implications to the built environment and facilitates the drive towards the attainment of future sustainability requirements. The focus on how to reduce cooling loads and improve building energy efficiency will challenge future innovative design and adapted technological processes. These will augur for climatic adaptation and mitigation strategies to effectively meet the future demand in the built environment. The measures would include planning and design options sensitive to varying climatic conditions and resilient building design which incorporates improved and better façade and building envelope, passive design technologies and high efficient HVAC and radiant systems with the aim to eventually reduce future total energy demands in dwellings. In addition emphasis should be placed on behavioural adaptations of building occupants to re-educate them in controlling building performance.

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