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OPTIMISED RETROFIT STRATEGIES FOR ENERGY REDUCTION AND COMFORT IN DWELLINGS FOR FUTURE CLIMATE SCENARIO IN SOUTHEAST ENGLAND

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Retrofit, Energy efficiency, Climate change, Dwellings, Thermal comfort, Overheating, United Kingdom.

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Abstract

This paper aims to find an optimum retrofit scheme utilising adaptation and mitigation techniques to a Sub-urban English old house, for an inevitable future climate change. It seeks its aims by investigating the energy performance, as well as the summertime comfort of old dwellings in current and future weather predictions. Studies shows that pre-1990 building stock represents one of the least energy-efficient, as these houses were built before the introduction of building envelope directives in building regulation. Specifically, uninsulated semi-detached houses of the inter-war period can potentially be an essential target for retrofits to reach the 2030 carbon emission goal. Previous researches showing the influence of warming climate on energy consumption and indoor comfort have been frequently explored in academic papers. Nevertheless, reviewed investigations were based on archetypal homes and not on a calibrated model. A sensitivity analysis examining current and future heating demand compared to building envelope main parameters was made to define two retrofit scenarios, the light retrofit scheme and the high retrofit scheme (LR and HR).

Study results show that anticipated hotter temperatures have a significant effect on energy consumption and thermal comfort, especially in retrofit models using highly insulated building envelope. Warmer climate conditions can lead to a decrease in space heating and rise in cooling demand; however, heating demand remains predominant. The study also shows that the moderate retrofit scheme (LR) can achieve more than 80% of energy reduction made in the higher retrofit scheme (HR).

The study reveals that overheating risk is very probable in the near future and shows that the pre-retrofitted dwelling demonstrates risks of overheating even in current weather. The occurrence of overheating in future weather data is inevitable, primarily when assessed against TM59 overheating assessment. However, overheating mitigation through adaptation strategies showed a better overheating evaluation in the light retrofit (LR) scheme compared to the high retrofit (HR) one. It is concluded that most of the energy reduction is conceived when applying the light retrofit scheme while potentially having better summertime comfort than the highly retrofitted one. The research recommends that in order to further establish a well acknowledge retrofit strategy, a greater sample size of dwellings of the same archetype is required. Further study over predicted embodied energy calculation and cost-effectiveness of the LR and HR, compared to their actual and predicted operational energy savings, can potentially materialise the idea of a light retrofit scheme.

Keywords

Retrofit, Energy efficiency, Climate change, Dwellings, Thermal comfort, Overheating, United Kingdom.

1. INTRODUCTION

1.1 Context

The Intergovernmental Panel on Climate Change (IPCC) in their newest assessment report (AR5) has specified that the further and extensive release of greenhouse gases will lead to an increase in chances of a dangerous, prevalent and irrevocable impact on humans and ecosystems. Climate change awareness and constant cuts in GHGs accompanied by human adaptation can limit this inevitable scenario (IPCC, 2014).

In 2008, The Climate Change Act announced an agreement that paves the way to an 80% reduction in the UK's GHG emission by 2050 (HM Government, 2008). Emissions have fallen positively ever since that date reaching a reduction of 43% (CCC, 2018), with the heating sector contributing to around 37% of overall emission. Noting that the transport sector remains the largest emitter of GHG, the residential sector is third most emitter with 18 per cent of the total GHG emissions. Around 60% of these emissions are attributed to the gas fired central heating systems (DECC, 2013). The government has created a variety of programs and incentives to decrease the amount of emissions in the housing industry, including economic assistance for the assembly of energy-saving policies, to fulfil the objectives set by the Climate Change Act (CCC, 2008). Given that there will still be 87% of current structures in 2050, much of this focus is correctly directed at the current building stock (DCLG, 2013).

In both, academics and UK strategy, suburban climate adjustment is fairly overlooked (Williams, 2015). There is still no law regulating thermal comfort or preventing houses from overheating. Besides, the standard evaluation method for overheating was considered insufficient by specialists, and both are largely ignored in the building rules (HOC, 2018). Only in 2011 did adaptation policy begin to emerge (Gupta and Gregg, 2011). While the guidelines from academic studies and building sector suggested that retrofits include adjustment steps (Gupta and Gregg, 2012) (Kendrick et al., 2012) were excluded in legislative frameworks (CCC, 2018).The most prevalent kinds of residence in England are three-bedroom semi-detached houses, constructed between 1919 and 1964, and maybe at the most severe danger for future weather adaptation. The probable existence of older adults in such households improves the threat seriousness (BRE, 2014).

Quarter of the British population is foreseen to be over 65 of age by 2040(GOS, 2016). The elderly are most at risk from the negative health impacts of overheating because of their physical susceptibilities. The danger of elevated temperatures is usually higher for elderly individuals with physiological research indicating that the reaction to the body's heat is reduced with age (P Kenny et al., 2009), and that it has chronic or severe disorders such as heart conditions, respiratory problems or even mental illness (Gasparrini et al., 2011).

1.2 Literature Review

The latest progress report of the IPCC shows a deduction of the total amount of direct GHG emission from the building sector. A drop of 2% from 2017 makes the buildings account for 17% of the total GHGs. Majorly, the built fabric in the UK is made of housing, which represents more than 2/3 of emission related to this sector (CCC, 2019).

The current housing sector is dominated by houses that date back before the introduction of legal laws and legislation into the building regulation (Dowson et al., 2012). The lack of insulation and building envelope awareness in houses made before the 1990s is leading to an increased amount of heating demands in current and future weather profiles. More than one-third of the houses located in the UK were built in the phase between the inter-war and post-war period (MHCLG, 2018). Semi-detached dwellings were the most common construction type at that time (DCLG, 2001). With a carbon-free target to reach by 2050, this group of uninsulated houses can potentially be one of the main targets for future retrofit and leads to reach the 2030 carbon emission target.

Figure 1 shows that these houses, according to the SAP ratings, represent the second most inefficient houses when it comes to energy consumption, their SAP ratings range from 1 to 55.

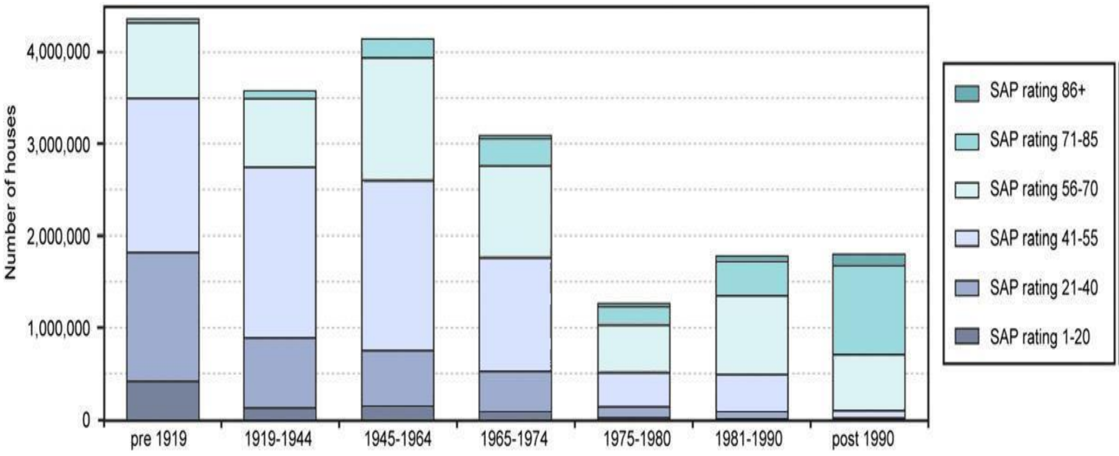

Fig.1: SAP rating

DECC shows that heating load is the major consumer of energy in these dwellings (2013). Heating load represents 62% of the total energy use, proving the large amount of heat loss found in these holdings.

Currently, the retrofit stage in the UK encompasses three main categories, whole house retrofit, fabric first retrofit, and insulate then generate (Baeli, 2013). The first strategy identified as 'deep retrofit' takes into account the occupants, sites, fabrics and facilities, the improvement of project facilities and plans, and the fitting of renewable energy systems (Mabey and Owen 2015). It aims to reach a reduction of 80% in GHGs, which is only possible by applying higher standards of retrofits. The second strategy is less wide-ranging and focuses only on the building fabric, limiting the heat loss before the implementation of additional proceedings. The third, insulate then generate, is very comparable to the approach of the "fabric first." This initiative aims to decrease energy requirement through passive construction methods (for example, building envelope, thermal masses and airtightness and ventilation) and then satisfy the remainder by using techniques of micro-generation.

Carbon emissions decrease is the primary driver of retrofit (Maby and Owen 2015). Therefore, there are target emissions rates in the implementation of building energy standards for retrofitting. The 2014 'Retrofit for the Future' Program (RfF), of the Technology Strategy Board, promotes a complete building approach, with a perspective of achieving an 80-per-cent CO2 decrease of 1900 baselines, 97 KgCO2/m2. Comparatively, some of RfF retrofit case researches have also embraced the AECB silver star standard, which aims at reducing CO2 pollution by 70% and the Passivhaus EnerPHit standard aims at achieving 80%. The AECB Gold Star strives to further reduce CO2 emissions by 85 to 90 per cent (Baeli, 2013). Table 1 shows a comparison between different retrofit standards currently used in the UK.

Table 1 : UK standards for retrofit

Mandatory and voluntary standards	Limiting u-value W/m^2K Wall	Pitched Roof	Flat Roof	Floor	Window	Air permeabiltiy $m^3/m^2.h@50pa$	Target space heating energy $kWh/m^2.yr$
ADP L1A new dwelling	0.3	0.2	0.2	0.25	2	10	
ADPL1A notional dwelling	0.18	0.13	0.13	0.13	1.4	5	
ADP L1B new element	0.28	0.16	0.18	0.22	1.6	-	
ADP L1B retained element	0.55 or 0.35	0.16	0.18	0.25	-	-	
Passivhaus new dwelling	0.15	0.15	0.15	0.15	0.80	n50 ≤ 0.6h-1	15
EnerPHit retrofit	0.15	0.12	0.12	0.15	0.85	1	25.00
AECB Silver standard	0.25	0.15	0.15	0.20	1.50	1.5 or 3	40
AECB Gold standard	0.15	0.15	0.15	0.15	0.8	0.75	15

All in all, the predictions indicate warmer and wetter winters. The natural variation of the climate system will still produce cold summers and drier summers, but we expect them to be less frequent. In summer, the trend is to hotter and drier summers, but again with some colder summers and wet summers (UKCP18, 2018). These trends broadly comply with UKCP09, which can partly reflect our improvement in the way probabilistic scenarios are generated instead of a new approach. Fig.2 shows that the South of England exhibits the principal concern of the warmer climate with an 8C-degree elevation on the RCP8.5 90th percentile (UKCP18, 2018).

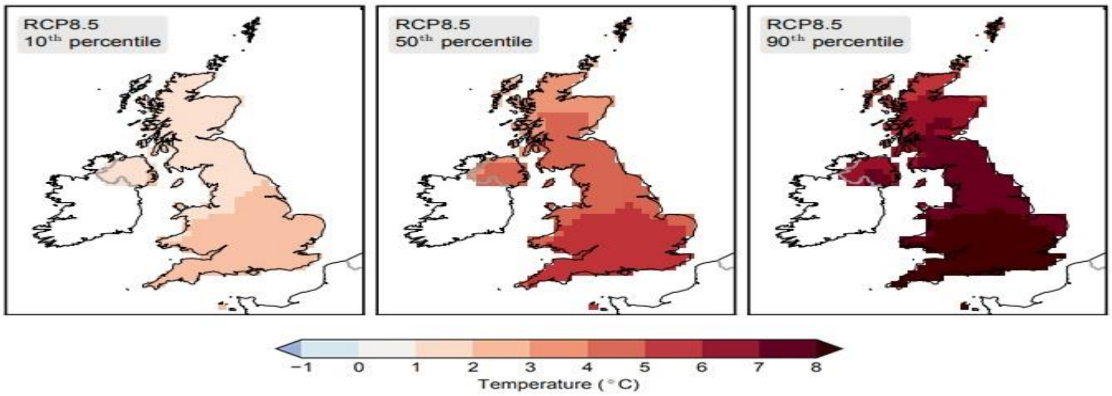

Fig. 2: Summer mean temperature anomaly for 2080-2099 minus 1981-2000

Climate change evidence is swiftly growing (Energy White Paper, 2003). The UK has estimated that the thermal efficiency of the residential area will be affected by climate change and the practical action to enhance thermal efficiency. (Gaterell and McEvoy, 2005). However, the average global temperatures are likely to rise from 4°C to 6°C, if emissions proceed on their current path, and this increase can have harmful implications. Higher temperatures will influence the performance of the built environment (Gaterell and McEvoy, 2005). Furthermore, the effectiveness of specific interventions intended to enhance houses 'thermal properties' is expected to be vulnerable to the fundamental nature of climate change in the UK. However, how the anticipated climate modifications in the UK will be brought about in the next 50 years is quite uncertain. Decisions are therefore focused on the present heat supply for the constructed setting. It is essential, thus, to define those that stay efficient under the broadest possible spectrum of climate uncertainties before implementing any retrofitting interventions (Gaterell and McEvoy, 2005).

Significant consequences can be made from a warming climate, and figure 3 shows the extent to which climate change is probably to have an impact. It describes the possible consequences of a changing climate for key building performance indices, including energy use and summertime comfort.

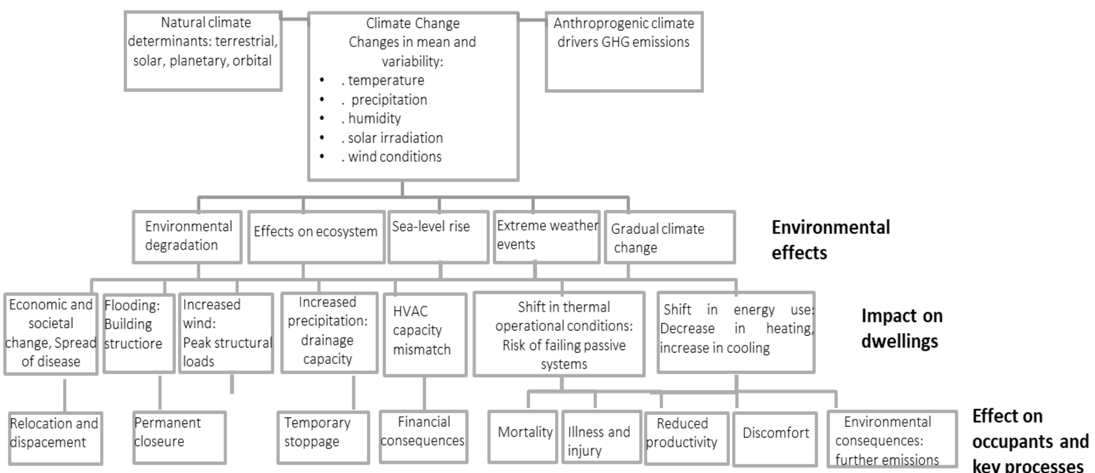

Fig.3: Overview of the impacts of climate change on buildings. (adapted from Coley and Wilde, 2012)

In 2010, the threat of overheating already appeared in 122,000 current English households (BRE 2014). Houses constructed before building envelope regulation were provided with little protection from solar thermal gains (BRE, 2016). By contrast, it is also recognised that new, extremely insulated, airtight homes are overheating (ZCH, 2015). Increasing cooling degree days may profit from a decrease in the carbon diameters owing to thermal demand overheat (CIBSE TM36, 2005), but there is a greater danger than naturally ventilated structures will face the threat of overheating (Collins, Natarajan and Levermore 2010).

2. METHODOLOGY

This research will be conducted using a quantitative methodology employing real-life monitoring and digital model calibration. Quantitative data implementing calibrated simulation will be adopted to assess the impacts of future climate on an actual 1930s dwelling in the midlands of the UK. The basic model will be first calibrated with real monitored data. Both mitigation and adaptation scenarios will then be applied to the model, using current and future weather data. Energy consumption and summertime thermal comfort (overheating risk) will be analysed with UKCP18 future weather scenarios and CIBSE TM59 guidance. Calibrated simulation includes the compilation of measured building performance information, which are then tailored to a real measured data into a dynamic simulation system. The system is validated by utilising statistical indicators.

The method may be subject to different levels of detail: the more details, the higher the chance to be accurate (Fabrizio and Monetti, 2015). Table 2 adapted from Fabrizio and Monetti shows the different levels of accuracy for calibration, the study used level 5.

Table 2: Levels of calibration (adapted from Fabrizio and Monetti, 2015)

Calibration Levels	Utility Bills	As-built data	Site visit or inspection	Detailed audit	Short-term monitoring	Long-term monitoring
Level 1	X					
Level 2	X	X				
Level 3	X	X	X			
Level 4	X	X	X	X		
Level 5	X	X	X	X	X	
Level 6	X	X	X	X	X	X

2.1 The Case Study

The house monitoring was the very first step for the study, where a period of 67-day was monitored between high on 1st of June, at 12 am, until the 6th August 2019, at 5 pm. The timeframe of this study was solely collected for the summer period, meaning no data was collected for the winter period.

The modelling was made using the 5.55 version of DesignBuilder software employing EnergyPlus calculation. Table 3 shows the simulation settings used throughout the calibration.

Table 3: Design Builder model options

Criteria	Settings for calibration	Settings for energy consumption	Settings for Overheating
Weather data file	TRY 2030 m 50%	TRY Weather files	DSY Weather files
Simulation period	1 January - 31 December	1 January - 31 December	1 January - 31 December
	All periods	All periods	All periods
Time steps per hour	4	4	4
Temperature control	Air temperature	Air temperature	Air temperature
Solar distribution	Full Exterior	Full Exterior	Full Exterior
Shadowing intervals	20 days	20 days	20 days

The case study is a semi-detached sub-urban dwelling located in Slough. Slough is a commuter town located in East Berkshire and is surrounded by essential motorways, namely the M4, M25 and M40. Particularly, Slough is 5 miles away from London Heathrow Airport and 24 miles from central London. The city centre is primarily urbanised, yet the residential buildings are on the south-eastern side of the city, bordered north by the vast Richings Park and south by Ditton Park. The lake of the Queen Mother is also near the southern side of the city. Although Ditton Park flanks the Southern side of the cul-de-sac, its northern side is near the A4 that connects the city to the M4 and Heathrow by a busy thoroughfare.

Fig.4: Dwelling front and rear elevation (not to scale)

Dwelling age goes back to the inter-war period, and its design is very much similar to semi-detached houses built in this period (BRE, 2012). Plans, elevation and building envelope specification were sourced from the house occupant and were compared to BRE RdSAP manual, SAP 2012 for 1930s houses. The following figures show the plan layout of the house. The gross internal area (GIA) is 101 m^2, and the treated floor area (TFA) is $96m^2$.

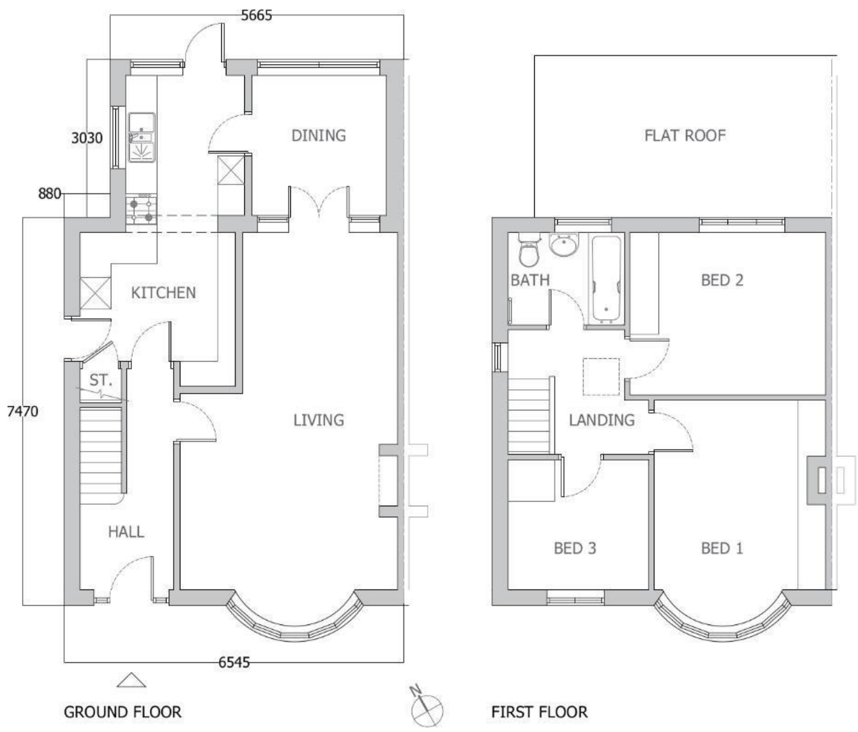

Fig.5: Dwelling floor plans (not to scale)

House construction and U-values were determined with the guidance of BRE RdSAP manual, SAP 2012 for 1930s houses and with the current inhabitants of the property, table 4 shows a summary. A couple currently occupies the building, one working full time from home and one working full time in office.

Table 4: Building envelope specification

	Description	**Values**	
Walls	Cavity walls with two layers of brick, plaster and wallpaper. Retrofit cavity insulation	0.43	**W/m^2K**
Main pitched roof	1930s clay tile pitched roof on felt and battens	2.93	**W/m^2K**
Flat roof to extension	1970s uninsulated concrete flat roof, suspended plasterboard ceiling, polystyrene tiles	1.52	**W/m^2K**
Main ground floor tiled	Suspended timber floor with floorboards, cement board and porcelain tiles	1.63	**W/m^2K**
Ground floor to extension	Concrete slab, screed, cement board, porcelain tiles	1.82	**W/m^2K**
Windows	1980s / 90s Double glazed 6mm clear, 12mm air-filled gap	2.7	**W/m^2K**
External doors	UPVC doors with double glazed panels	2.66	**W/m^2K**
Internal and party walls	Single brick plaster and paper	1.69	**W/m^2K**
First floor ceiling	Plyboard, 220mm insulation between joists, plasterboard	0.16	**W/m^2K**
Air tightness	**Comparable with bre air leakage database and leb database**	**15.9**	**ach@50pa**

The building had previously a minimal building envelope retrofit, where wall insulation was introduced to the cavity area, lowering down the U-value from 1.06 W/M2K to 0.43 W/M2K. Air infiltration, windows, openings, and walls are expected to be the most likely source of heat loss. Although the latter has a relatively small u-value, the walls cover the most significant region exposed. The heat gain from the roof is undoubtedly substantial because of the lack of insulation and its positioning in the ceiling.

2.2 Employed Strategy

Selection and comparative analysis of weather data were chosen to fit current weather, baseline weather and 2050 weather projection. The model calibration has shown that the current weather is very much closer to the 2030 50% probability medium emission scenario, hence, this file was chosen to represent current weather. Control year is used to describe the baseline level of energy use, and the 1990 weather file was selected. As of the future weather scenario, the worst-case scenario from the 2050 90% probability high emissions was chosen. Aiming to adapt the building to high carbon emission rates, making it resilient to any leaner scenarios. Weather projection for later years was unexploited as the dwelling lifespan is doubtful to last past 2050.

The building was tested to several setups using a sensitivity analysis. Three main building features were looked at, as those three were the ones with most beneficial to lower down the heating demand. The sensitivity test was applied to the U-values of the walls, the U-values of the roof, and the building airtightness. From these simulations, two scenarios were deducted, the higher specification retrofit scenario (HR) and the light specification retrofit scenario (LR). Along with the pre-retrofitted house scenario and current retrofit of the house, these scenarios were then put against each other to understand the effect of different retrofit on energy reduction and interior comfort, specifically overheating analysis.

The second part of the analytical part focused on applying adaptation strategies to improve the performance of the building in what regards the cooling demand and limit overheating risks. Those strategies compromised the use of Low-E coating to windows, shading, occupant-controlled external blinds with a high reflective surface. Night-time purge ventilation was employed as well. Improved windows and more aperture were introduced as well. The following methodology flow chart (Figure 6) shows the sequence of this study.

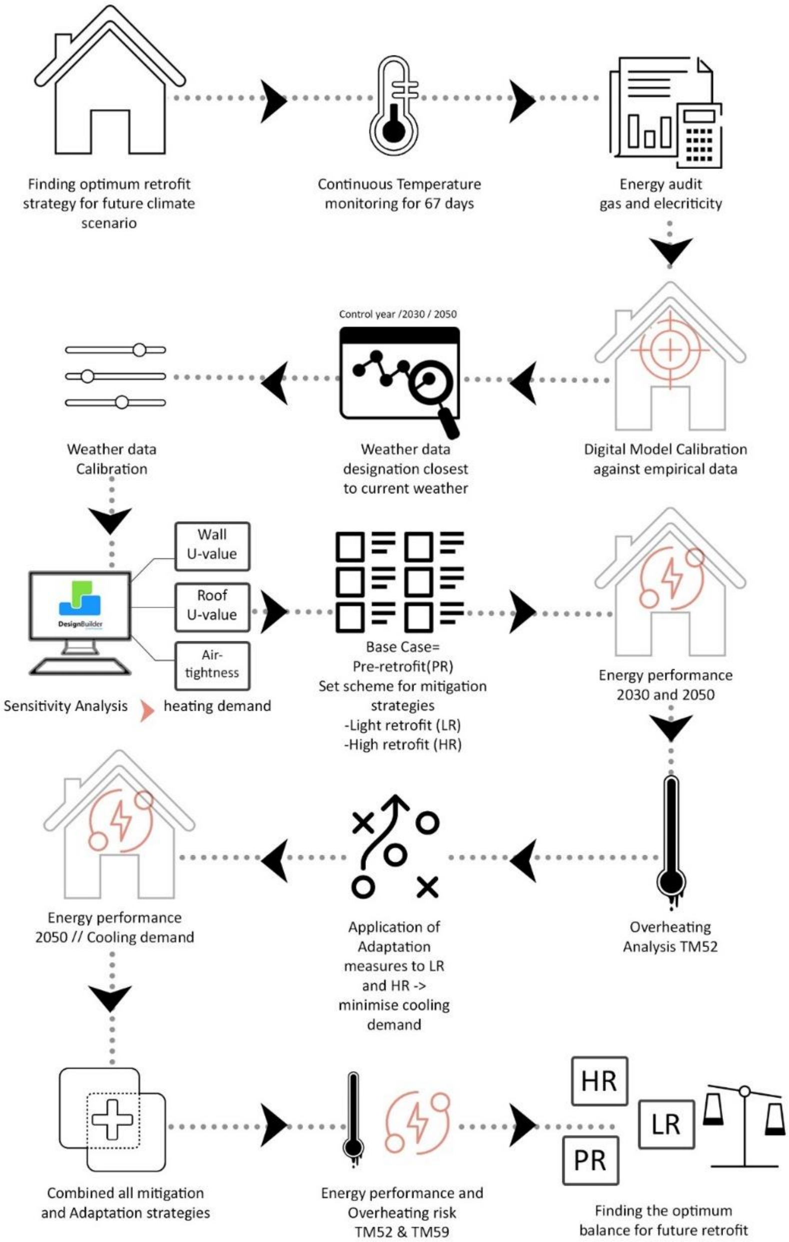

Fig.6: Methodology flow chart

3. RESULTS AND DISCUSSION

3.1 Future Weather Effect on Energy Consumption

The study shows a noteworthy reduction in future heating demand; the sensitivity analysis has shown a 32% heating load reduction in 2050 weather for the current pre-retrofitted. It is important to note that current heating load was simulated using 2030 medium emission of the 50th percentile, which was found to be the closest to current load. The findings align with a 2012 study led by Kendrick et al. and targeting London dwellings. A 25% reduction is found in space heating energy in 2050 when compared to 1990 control year. More significant reduction has been seen in the study, the following table shows a comparison in space conditioning load.

Table 5: percentage variation in space conditioning energy due to climate change in 2050 from the current

	Pre-retrofit	Current retrofit	LR	HR	LR + adap	HR + adap
Heating Demand	64.35	37.09	20.23	10.21	15.79	6.42
Cooling Demand	17.55	10.39	8.42	10.11	4.93	4.64
Space conditionning	81.89	47.48	28.65	20.32	20.72	11.07
% reduction in heating demand		42.36%	68.57%	84.14%	75.46%	90.02%
% reduction in cooling demand		40.80%	52.02%	42.39%	71.91%	73.53%

As seen in the table 5 heating demand can be reduced from 64 kWh/m2.yr to 6.42 kWh/m2.yr from the pre-retrofit state to HR+adap scenario. The LR+Adap scenario shows a less effective reduction when it comes to heating demand (15.79 kWh/m2.yr) and a slight difference for the cooling demand with the HR+adap being 0.29 kWh/m2.yr less energy consumption.

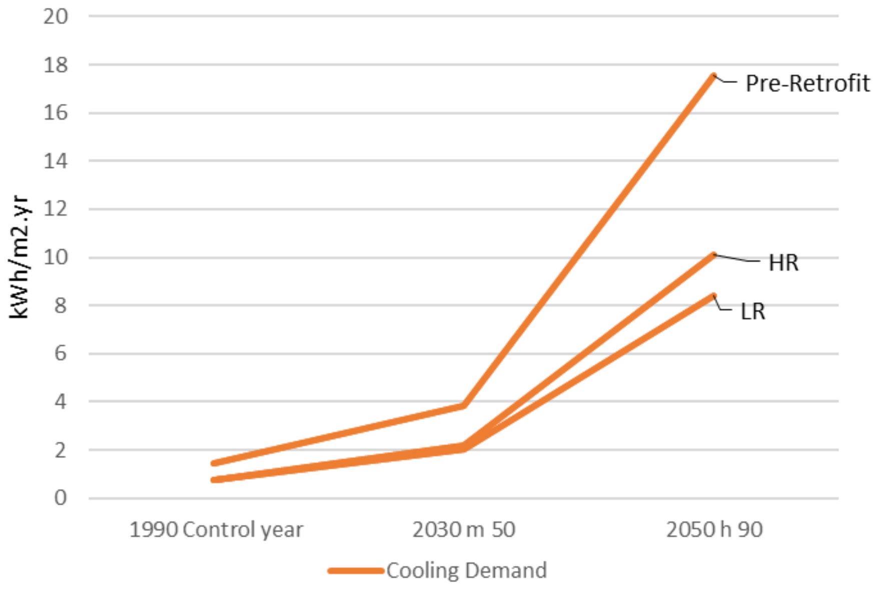

Fig.7: Cooling demand comparison

Figure 7 shows a distinct increase in the cooling energy demand caused by climate change. The differences are dependent on the level of insulation applied to the dwelling and its airtightness. Lower u-values and higher airtightness will lead to higher heating demand reduction and a more significant increase in cooling energy. The LR scheme is slightly more efficient than the HR scheme when the cooling energy demand is compared.

The study shows that the heating demand is still dominant over cooling demand, although an apparent rise in cooling demand and a decrease in heating demand is noticed. Collins, Natarajan and Levermore, in a study endeavoured in 2010 has shown similar findings for heating and cooling load on the UK building stock in both 2050 and 2080 weather prediction. A more recent research focused on highly insulated buildings located in London shows that heating load will still be dominant and should not be neglected in future scenario (Sajjadian, 2017).

Each of the retrofit strategies employed in this study provided a reduction in CO2 emissions when compared to the pre-retrofit state. Remarkably, when comparing like to like retrofit strategies, a rise in CO2 emission is noticed from 2030 to 2050 weather. This is due to the increase in electricity demand in the 2050 weather prediction. Adding the adaptation strategies to limit cooling load has proven to be efficient in both LR and HR strategies. The HR strategy applied in the 2050 weather shows the most substantial amount of CO2 reduction with a 52% reduction from pre-retrofit current emissions.

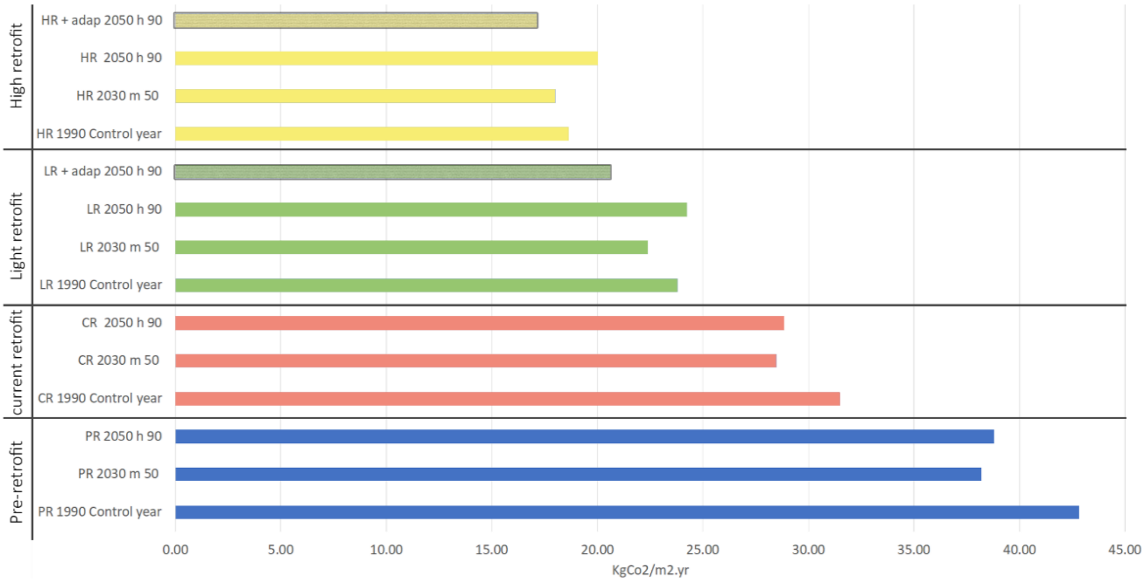

Fig.8: Co_2 emission comparison

CO2 emission is further expected to decrease in the forthcoming future with the decarbonising of the electricity supply. The Department of Business, Energy and Industrial Strategy (BEIS), in its latest Energy and Emissions Projection (EEP) published in January 2018, showed that the Carbon Factor would fall intensely from 495 grams of CO2 in 2014 to just 66 grams in 2035. Therefore an additional reduction in CO2 emission can be achieved in electrification of heat, which is projected to happen shortly (Gillich, Saber and Mohareb, 2019).

The study has shown that primary energy demand is set to decrease by 55% with HR+adap scenario and 46% in the LR+adap from pre-retrofit stage in 2050 weather. The adaptation strategies shows an increase reduction in energy in both schemes LR and HR.

Table 6: Primary energy demand comparison in 2050

	Pre-retrofit	Current retrofit	LR	HR	LR + adap	HR + adap
Primary energy demand	219.61	163.30	137.30	113.46	116.68	97.11
% reduction from pre-retrofit		25.64%	37.48%	48.33%	46.87%	55.78%

3.2 Overheating Risk in Future Weather

Throughout this study, climate change has shown that overheating risk is an issue of high importance and needs to be handled with high vigilance. Overheating risk could not be wholly eliminated with the employed adaptation measures applied to the dwelling. Both TM52 and TM59 were used in this study; employed retrofit strategies were enough to eradicate overheating in the TM52 but was unable to pass TM59 criterion under the 2050 weather data.

The pre-retrofit dwelling failed TM52 assessment against 2050 weather projection. The findings show there is a need to retrofit the old UK building stock. These findings come in line with a 2015 study endeavoured by Gupta and Gregg, which found that 1950s semi-detached dwelling failed against TM52 in both 50% and 90% probability estimates for 2050.

The study has shown that overcoming TM59 cannot be achieved on the dwelling case study, especially the second criterion. A static criterion directed towards bedroom spaces which requires 1% of annual occupied hours to be under the 26 C during night-time yearly. Thermal comfort has always been an adaptive measure that takes into consideration several variables and especially external temperature variation. Humphreys formula for indoor comfort could be a way of finding the ideal comfort temperature in the future, notably 2050 weather. Table 7 shows a comparison between the different overheating assessment made in this study.

Table 7: TM52 and TM59 under 2050 weather

TM52 2050 High emission 90th percentile DSY

Pre-retrofit

Block	Zone	Criterion 1 (%)	Criterion 2 (K.hr)	Criterion 3 (hr)	Pass/Fail
GF	Dining	2.90	11.50	0.00	Pass
GF	Kitchen	3.05	18.00	0.00	Fail
GF	Larder	0.00	0.00	0.00	Pass
GF	Hall	5.07	19.00	0.00	Fail
GF	Living	1.13	9.75	0.00	Pass
FF	Bath	13.51	30.50	4.00	Fail
FF	Bed2	8.99	33.25	3.25	Fail
FF	Bed3	13.32	46.00	10.25	Fail
FF	Bed1	7.16	24.50	3.50	Fail

Current retrofit

Block	Zone	Criterion 1 (%)	Criterion 2 (K.hr)	Criterion 3 (hr)	Pass/Fail
GF	Dining	0.37	3.25	0.00	Pass
GF	Kitchen	0.61	6.00	0.00	Pass
GF	Larder	0.00	0.00	0.00	Pass
GF	Hall	0.45	4.00	0.00	Pass
GF	Living	0.21	2.25	0.00	Pass
FF	Bath	2.87	14.50	0.00	Pass
FF	Bed2	1.38	12.25	0.00	Pass
FF	Bed3	1.84	19.50	0.00	Pass
FF	Bed1	1.21	9.50	0.00	Pass

LR

Block	Zone	Criterion 1 (%)	Criterion 2 (K.hr)	Criterion 3 (hr)	Pass/Fail
GF	Dining	0.00	0.00	0.00	Pass
GF	Kitchen	0.07	0.75	0.00	Pass
GF	Larder	0.00	0.00	0.00	Pass
GF	Hall	0.40	3.25	0.00	Pass
GF	Living	0.00	0.00	0.00	Pass
FF	Bath	4.93	15.25	0.00	Fail
FF	Bed2	4.44	19.25	0.00	Fail
FF	Bed3	4.08	21.00	0.00	Fail
FF	Bed1	3.42	13.75	0.00	Fail

HR

Block	Zone	Criterion 1 (%)	Criterion 2 (K.hr)	Criterion 3 (hr)	Pass/Fail
GF	Dining	0.00	0.00	0.00	Pass
GF	Kitchen	0.00	0.00	0.00	Pass
GF	Larder	0.00	0.00	0.00	Pass
GF	Hall	0.00	0.25	0.00	Pass
GF	Living	0.00	0.00	0.00	Pass
FF	Bath	0.00	11.00	0.00	Pass
FF	Bed2	3.36	13.50	0.00	Fail
FF	Bed3	3.51	13.50	0.00	Fail
FF	Bed1	2.71	9.00	0.00	Pass

LR + Combined adaptation strategies

Block	Zone	Criterion 1 (%)	Criterion 2 (K.hr)	Criterion 3 (hr)	Pass/Fail
GF	Dining	0.00	0.00	0.00	Pass
GF	Kitchen	0.00	0.00	0.00	Pass
GF	Larder	0.00	0.00	0.00	Pass
GF	Hall	0.00	0.25	0.00	Pass
GF	Living	0.00	0.00	0.00	Pass
FF	Bath	0.00	0.00	0.00	Pass
FF	Bed2	3.36	0.00	0.00	Pass
FF	Bed3	3.51	0.00	0.00	Pass
FF	Bed1	0.10	1.75	0.00	Pass

HR + Combined adaptation strategies

Block	Zone	Criterion 1 (%)	Criterion 2 (K.hr)	Criterion 3 (hr)	Pass/Fail
GF	Dining	0.00	0.00	0.00	Pass
GF	Kitchen	0.00	0.75	0.00	Pass
GF	Larder	0.00	0.00	0.00	Pass
GF	Hall	0.00	3.25	0.00	Pass
GF	Living	0.00	0.00	0.00	Pass
FF	Bath	0.31	3.25	0.00	Pass
FF	Bed2	0.22	8.00	0.00	Pass
FF	Bed3	0.00	0.00	0.00	Pass
FF	Bed1	1.59	21.75	0.00	Pass

TM59 2050 High emission 90th percentile DSY

LR + Combined adaptation strategies

Block	Zone	Criterion A (%)	Criterion B (%)	Pass/Fail
GF	Kitchen	0.00	N/A	Pass
GF	Living Bay	0.00	N/A	Pass
FF	Bed 2	0.22	294.25	Fail
FF	Bed 3	0.00	319.00	Fail
FF	Bed 1	1.59	280.00	Fail

HR + Combined adaptation strategies

Block	Zone	Criterion A (%)	Criterion B (%)	Pass/Fail
GF	Kitchen	0.00	N/A	Pass
GF	Living Bay	0.00	N/A	Pass
FF	Bed 2	0.00	254.25	Fail
FF	Bed 3	0.00	261.00	Fail
FF	Bed 1	0.00	211.00	Fail

3.3 LR Vs HR Finding the Balance

In this paper, two schemes were set under the scope, LR and HR. The primary aim for setting two schemes is to compare different retrofit strategies, namely a light retrofit strategy that aim to an 80% reduction from the highest possible standard for retrofit. The light retrofit scheme was set using a sensitivity analysis. The thermal envelope achieved was a 0.3 W/m2k wall and roof U-value and airtightness of 6 m3/m2.h @50pa. Table 8 shows that the LR+adap has achieved 84% of the HR+adap scenario. Proving that most of the possible energy reduction can be reached with average thermal envelope retrofit.

Table 8: Primary energy demand in 2050

	Pre-retrofit	Current retrofit	LR	HR	LR + adap	HR + adap
Primary energy demand	219.61	163.30	137.30	113.46	116.68	97.11
% reduction from HR+adap		45.97%	67.19%	86.65%	84.02%	100.00%

The study was focused on two folds, energy demand and summer thermal comfort. Both schemes showed future overheating risks when compared to TM59. However, the LR showed similar performance to the HR when assessed against TM52, and once adaptation strategies were combined with mitigation strategy overheating was eased. Table 9 shows a comparison between the two strategies, LR+Adap confirmed a better overheating assessment than the HR+adap. Therefore, a high standard of envelope insulation can provoke augmented risks of overheating.

Table 9: TM 52 for LR and HR with adaptation strategies

LR + Combined adaptation strategies						HR + Combined adaptation strategies					
Block	Zone	Criterion 1 (%)	Criterion 2 (K.hr)	Criterion 3 (hr)	Pass/Fail	Block	Zone	Criterion 1 (%)	Criterion 2 (K.hr)	Criterion 3 (hr)	Pass/Fail
GF	Dining	0.00	0.00	0.00	Pass	GF	Dining	0.00	0.00	0.00	Pass
GF	Kitchen	0.00	0.00	0.00	Pass	GF	Kitchen	0.00	0.75	0.00	Pass
GF	Larder	0.00	0.00	0.00	Pass	GF	Larder	0.00	0.00	0.00	Pass
GF	Hall	0.00	0.25	0.00	Pass	GF	Hall	0.00	3.25	0.00	Pass
GF	Living	0.00	0.00	0.00	Pass	GF	Living	0.00	0.00	0.00	Pass
FF	Bath	0.00	0.00	0.00	Pass	FF	Bath	0.31	3.25	0.00	Pass
FF	Bed2	3.36	0.00	0.00	Pass	FF	Bed2	0.22	8.00	0.00	Pass
FF	Bed3	3.51	0.00	0.00	Pass	FF	Bed3	0.00	0.00	0.00	Pass
FF	Bed1	0.10	1.75	0.00	Pass	FF	Bed1	1.59	21.75	0.00	Pass

Neroutsou and Croxford, in a study, endeavoured in 2016 has considered that the application of EnerPHit, a standard that is based on lower U-Values and consequently, more insulated envelope. It was thought that this alternative would achieve higher operational energy savings, which is translated into cost savings. Though the study proved this suggestion wrong, as the cost to be paid to EnerPHit to achieve these more considerable energy savings for IC, EE and ECO2 will make it less attractive than the current implemented retrofit model. This study shows a different hypothesis focused on the embodied energy calculation and cost-effectiveness. It has also proven that a milder retrofit strategy is more efficient than an EnerPHit one in a different approach.

4. CONCLUSION

The study has shown that anticipated climate change and warming climate will have a substantial impact on both energy and indoor comfort in semi-detached dwellings located in Southeast England. The research has shown that future weather will have a definite decrease in energy demand, notably a reduction in heating demand in 2050 weather prediction. Nonetheless, cooling demand has shown an increase in energy demand in 2050 weather. Showing alarming signs towards overheating risks, as mitigation and adaptation were not able to mitigate all overheating risk in the semi-detached house.

Results concerning retrofit schemes have shown that a moderately retrofitted dwelling with similar standards to current building regulation will have a slightly lower effective energy performance from the high building envelope insulated one. The LR+Adap retrofit scheme achieves 84% of the reduction achieved with the HR+Adap scenario. Notably, calculating the added embodied energy needed to reach HR from LR and can eventually shift the balance of the total CO_2 emission between the two schemes. It is important to note that future weather would imply the need for some mechanical cooling to achieve internal summer comfort. Findings have shown that the LR+adap is marginally better than HR+adap when it comes to TM52 overheating assessment. It is essential to mention that all strategies combining both mitigation and adaptation were not able to pass the static criterion of TM59 made for bedroom.

Previous papers have shown that externally fixed insulation with external shading and enhanced albedo surface can contribute to overheating reduction (Gupta and Gregg, 2015). The use of thermal mass in combination with natural ventilation at night can help improve indoor comfort (Kendrick et al, 2012). These researches support that finding a sample prototype that fits all of the UK building stock is quite a challenge. It also supports the thought behind no ‘one size fits all’ and promotes the need for an in-depth study to each retrofit case.

It is essential to state that the 2030 medium emission of the 50th percentile was used as representative of the current weather data. Throughout the calibration phase, monitored data were found to be closest to the 2030 than the 1990 control year weather file. Decisions on the proper overheating risk guidelines for the residence and occupants should be taken in the individual instances. If it is thought that the house will accommodate susceptible occupants (e.g. Elderly), adaptive techniques should be employed. Where time and funds allow, dwellings should be monitored in both heating and cooling period to enable a more accurate calibration, hence a more realistic simulation with a better understanding of the dwellings and their occupants.

4.1 Research Limitations

While results from the research shows significant finding in what concerns future retrofit, the sample size limits its significance. To further establish a well acknowledge retrofit strategy, a greater sample size of dwellings of the same archetype is required.

Calibration of the digital model is one of the significant variables in this study. Monitoring period was only possible during the summertime period; therefore, the absence of temperature data in wintertime could enlarge the accuracy gap in-between reality and simulation. Moreover, the weather data files used in the study were London Heathrow weather data which was chosen to be to closest to fit the current weather in Slough. The use of pre-prepared weather file can increase the model precision uncertainty.

The findings of digital modelling have a little ambiguity concerning thermal analysis. The same refers to the original house's airtightness values that did not have an airtightness test as they were based on expectations and occupant knowledge. The occupant's actions play a decisive role in the real and model energy use, and even though there are still a few unquantifiable considerations such as the use of equipment that influence inner heat gains, even though occupancy and thermostats have been created with the co-operation of the householder.

In terms of energy use, the adaptation methods used in this research are passive. While passive policies of adjustment are more useful as regards carbon emissions, it is necessary to consider, when comparing with passive strategies, the way that residents classify energy consumption interventions as air conditioning units. The amount of adaptation strategies to potential fieldwork should be increased to include initiatives for limit energy consumption.

4.2 Further Research

A more significant sample for a more comprehensive comprehension of results should be carried out in further studies. Findings should also be conducted on the assessments and comfort conditions for 2050 of the highest emission forecast conditions, as current weather conditions reflect those described in the 2030 weather forecast as seen in the study. A more in-depth sensitivity analysis should be done on a larger sample to be able to cross-relate findings and find a strategy that fits more than just one example. A cost and embodied energy analysis can also be done on the case study.

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