Remittances Review
April 2024,
Volume: 9, No: 2, pp.4581-4597
ISSN:2059-6588(Print)|ISSN2059-6596(Online)

Received : 30 March 2024, Accepted: 25 April 2024
DOI: https://doi.org/10.33282/rr.vx9i2.241

A Strategic Usage Of Thermal Mass to Control Temperature Profiles and Energy Consumption in UK Dwellings

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K E Y W O R D S

Global warming
Temperature profiles
Heavyweight
Energy Consumption
Dwelling details

A B S T R A C T

Global warming is adversely affecting the UK's climate, causing an increase in dwelling temperatures and more energy consumption to achieve better indoor conditions, resulting in more carbon emissions. In this research, thermally heavyweight construction benefits are identified and compared with the lightweight building fabric for not only current climatic constraints but also for future projections of London's temperature till 2080 are simulated. Multiple iterations are performed in the thickness and placement of the thermal mass of walls, floors and roofs to achieve lower temperature profiles and energy consumption for ambient conditions inside dwellings. In all our findings, heavy-weight dwellings performed well under different scenarios to achieve set objectives. We recommended various dwelling construction details which produce low-carbon and can be used as per the availability and suitability of materials.

1. Introduction

The housing industry is the main field of concern in terms of its energy efficiency and thermal comfortability [1]. The overheating problem in summer in lightweight houses in the UK is catching the attention of many companies and legislative authorities [2]. As the environmental conditions are changing every year, due to global warming, the summer temperatures are becoming intolerable in the UK [3], because people are acclimatised to low-temperature ranges.

People are thinking of using some sort of air-conditioning or at least fans in the domestic sector [4]. This trend would increase the use of electricity in houses, resulting in more carbon emissions. The winter indoor temperatures are mostly very low and the use of heating becomes inevitable [5].

The threat of climate change [6] has drawn the attention of scientists and politicians to call for greater awareness relating to energy generation and consumption (Royal Commission on Environment Pollution 2000) as well as more public involvement in energy planning (Local Government Association 1999) and a higher level of public engagement in the energy Debate (PUI 2002). All these concerns are driving forces for scientists to control energy consumption in the housing sector. Make a comfortable environment in the house, but do not compromise enough on the atmosphere.

This research would come up with a possible solution to overheating in summer and thermal comfort in winter by natural means, minimising dependency on energy resources. The UK's not only peak temperatures increasing but

also, average outside temperatures are going high. When outside temperatures are higher they also affect the inside

temperature profiles achieved across the building fabric [7], which acts as a barrier between the two. In this paper, we will analyse different fabric and skin details of UK dwellings to see which one is performing better in the current climatic constraints and concerns. This research is mainly focused on answering the following questions;

- ✓ How the housing industry could be made low carbon emissions?
- ✓ What are the problems with lightweight house construction?
- ✓ What are the problems with heavy-weight construction?
- ✓ How a housing sector can be made energy efficient?
- ✓ What are the properties of thermal mass and how it be used in the housing?
- ✓ How thermal comfort could be achieved in dwellings of the UK?
- ✓ Where thermal mass would be more appropriate to place in the dwellings like in the floor, walls and roof.
- ✓ Where the mass is more effective and with what thickness?

2. Background and Literature Review

The United Kingdom consists of four countries namely England, Wales, Scotland and Northern Ireland. It lies between Ireland and the mainland (Europe). It is the largest island in the Europe and eighth largest in the world. The UK experiences a relatively warm summer and cool winter with plentiful precipitation throughout the year. The four distinct seasons would be summer (June-August), winter(November-March), spring(March-May) and autumn(September-October) [8]. UK lies on the borderline of convergence of tropical warm air to the south and cold polar air to the north. This is the area where large temperature variations create instability, which is the major factor in its unpredictable weather change in a single day. The temperature extremes are 38.5C and -27.2C in England and Scotland respectively, Table 1.

Table 1 Extreme Temperature Profiles ever recorded in the UK [9] [10]

Records	Scotland	N. Ireland	Wales	England
Maximum Temp.	32.9C (2003) Greycrook	30.8C (1976) Knockarevan	35.2C(1990) Hawarden Bridge	38.5C(2003) Brogdale
Minimum Temp.	-27.2C (1895) Braemar	- 17.5C(1979) Magherally	- 23.3C(1940) Rhayader	- 26.3C(1982) Newport

Thermal comfort (As defined by the ASHRAE, as "That condition of mind which expresses satisfaction with the thermal environment") within the occupied spaces in developed countries like the UK is one of the major issues ISO (7730) [11]. Government and politicians are very much concerned about this issue. Further, the human body generates a different amount of heat from the body while performing different activities, for instance, sleeping-40W/m2, seating-60W/m2, walking-150W/m2 and domestic work-80-200W/m2 etc, [12]. This heat would also increase indoor temperatures. As per the standard requirements of comfort [13], it is necessary to maintain certain conditions of temperature, clothing level(clo), and activity metabolism in different spaces of dwellings in the UK Table **2**.

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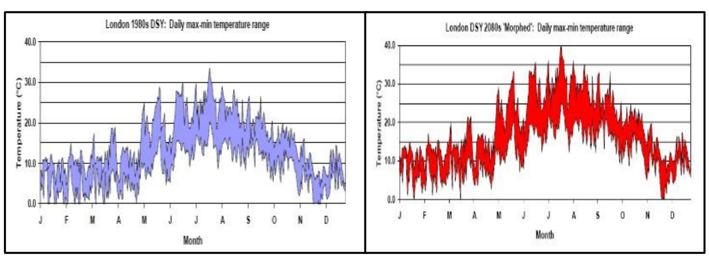
Table 2 Comfort Standards to Meet in the United Kingdom [13]

Spaces	Air Temp. C		Clothing Clo.[1]		Activity Met.[2]	
	Summer	Winter	Summer	Winter	Summer	Winter
Bath Rooms	26-27	26-27	0.25	0.25	1.2	1.2
Bed Rooms	17-19	23-25	2.5	1.2	0.9	0.9
Stair Hall	19-24	21-25	0.75	0.65	1.8	1.8
Kitchen	17-19	17-19	1.0	0.65	1.6	1.6
Living Room	22-23	23-25	1.0	0.65	1.1	1.1

People are acclimatized to their climate. If any noticeable change occurs in the climate, people respond to it [14]. Climate change can be noticed by observing the climate of the last 30 years time. "The effects of climate change can be seen in our everyday lives [15]. During the last 40 years, the UK's winters have grown warmer, with heavier bursts of rain. The summers are growing drier and hotter - one of the starkest changes over the last 200 years is our summers have become drier causing widespread water shortages [16]. The last 10 years have seen nine of the ten warmest years since records began" [17]. The effect of climate change on the UK could be (i) the overall climate will become warmer (ii) the temperature of coastal water will increase (iii) higher summer temperatures will become more frequent and lower winter temperatures [18]**.** below shows this effect that the minimum and maximum temperatures between 1980-2080 have a significant difference, it would be up to 6C higher in summer and 3.5C in winter.

Figure 1 the DSY (design summer year) daily min-max temperature range for London 1980s(left) & 2080(right) [18].



It is believed that since the climate is changing concrete has thermal mass, which has the potential to solve this problem [19]. Increasing energy demand, high prices and climate change are forcing building developers to make use of fabric energy storage (FES) ideas. Using thermal mass and night ventilation. This is the idea that gives a passive and sustainable alternative to air-conditioning and minimises energy use [20].

If the climate would go on changing, like the present condition, where would the world be standing in the next 70-100 years times? In the UK the condition would be so worse that the use of air-conditioning would be a vital part of building services, even in houses [21]. The amount of energy that is needed to run this air-conditioning would be huge

[1] Where Clo, "the unit of thermal insulation of clothing".
1 clo=0.155m2.K/W

[2] Met, "the unit use to express the physical activity of human". 1 met. =58.2w/m2. One met is an average metabolic rate of person when seated.

enough, as electricity is the cause of carbon emission, it will be impossible to control the carbon emission. This indirectly would increase global warming and conditions would worsen in future [22].

A low-energy house in one, which gives maximum comfort at the expense of minimum use of energy, as this house is compared with another house of the same dimensions. The three main sectors in the UK, where energy is mostly consumed are industry(21%), building(45%), and transport(33%) [23]. The major domestic areas of energy consumption in the UK are lighting, space heating, hot water, mechanical ventilation and appliances [23] [24] [25]. The housing sector contributes about 28% of UK CO^2 emissions. By making energy-efficient buildings we can reduce these values. The energy-efficient house will require low running costs and less environmental impact.

In the history of building construction, different techniques were used to control the overheating in residential buildings [26]. These techniques involved the use of massive construction. It is believed that buildings made of concrete, masonry or earth have a significant role in the reduction of heating and cooling loads [27]. This use of thermal mass has made the building comfortable even in some hot countries without the use of air-conditioning. It is proved by experiments in history that buildings using thermal mass have much lower energy demands than the same buildings made of lightweight construction [28]. The use of thermal mass helps in the absorption of heat from the external source or the internal appliances. It helps in the delay of energy swing in the building.

“Thermal mass materials have the ability to store and conduct energy, both heat and cold, and release that energy back into space, when it is required, in the later times, when outside temperature would be lower.” The time-lag property of thermal mass makes it possible to use off-peak hours energy as it stores heat for a certain time and releases it back when the conditions are more favourable like in the evenings, resulting the less consumption of energy [29].

This use of thermal mass is only effective in countries where the day temperature is higher outside than inside. And night temperature is lower outside. It is effective in countries, which have high diurnal swings of temperature. Low night temperature is good for reversing the heat flow at night. It helps not only lower the peak temperatures but also delay the peak time.

Materials commonly used for thermal mass are;

- Brick or mud brick
- Stones and natural rocks
- Concrete blocks and slabs
- Earth-shelter

Qualities of good thermal mass include;

- It should have high heat capacity. It will increase its capacity for heat storage.
- It should have high density. Denser the material the more heat it can store.
- It should have low thermal conductivity. As if it will have high conductivity it will gain or lose heat quickly.

2.1 Different Ways of Thermal Mass Usage

Different ways in which thermal mass can be utilized [30]

- Exterior thermal insulation, interior mass (Int-mass)
- Exterior mass, interior thermal insulation (Ext-mass)
- Exterior mass, core thermal insulation, interior mass, and (CIC)
- Exterior thermal insulation, core mass, interior thermal insulation (ICI).

It is found that the placement of thermal mass is more effective on the inside. These values are taken from the energy calculation for the same house.

2.1.1 Lightweight construction

The lightweight construction is mainly consisting of materials like timber and wood products. Wood consists of cells whose cavities provide thermal insulation [31].

2.1.2 Heavyweight construction

Heavyweight construction mostly uses brick and concrete blocks as the main material [32]

Table 3 Construction options of light and heavyweight walls in the UK

Sr. No.	Lightweight Construction Options	Heavyweight Construction Options
1	92 mm vertical t&g board 16 mm plywood Air cavity 51 mm thermal insulation Air cavity 16 mm plasterboard	102.5 mm concrete facing brick 50mm clear cavity air space 30mm foam insulation 100mm lightweight concrete block 13mm lightweight plaster U-value =0.35w/m2.k
2	Wall 130.5 mm 18 mm tongue and groove boards 8 mm chipboard 80 mm thermal insulation 12 mm air cavity Oiled paper vapour barriers 12.5 mm plasterboard	102.5mm fair-faced brick worked 75mm blown rock wool, full-fill cavity insulation 100mm lightweight blockwork 13mm standard dense plaster finish U-value =0.35w/m2.k
3	Wall 232 mm 21 mm outer board 21mm inner board Ventilated cavity 30 mm battens 15 mm wood cement particleboard 2 layers of 60 mm thermal insulation 12,5 mm air cavity Vapour barrier 12.4 mm plasterboard	Brick outer leaf 50mm air cavity Partial cavity filled with 25mm insulation board 150mm lightweight block 13mm plaster U-value =0.35w/m2.k
4	Wall 180 mm 16 mm wood-cement particleboard 19 mm air cavity 120 mm thermal insulation Vapour barrier 25 mm structural grade plywood	Finish 13mm lightweight plaster (or minimum 6mm purge* coat Plus 12.5mm plasterboard on dabs) Block work 100mm (min) dense block work Cavity 75mm cavity Block work 100mm (min) dense block work Finish Minimum 6mm purge* coat plus 12.5mm plasterboard on dabs (or 13mm lightweight plaster)
5	Wall 120 mm 30 mm boarding outside 60 mm mineral fibre thermal insulation Polyethylene vapour barrier 30 mm boarding inside.	Finish 13mm lightweight plaster (or minimum 6mm purge* coat plus 12.5mm plasterboard on dabs) Block work 100mm (min) lightweight block work (density 1350kg/m3 - 1600kg/m3) Cavity 75mm cavity Block work 100mm (min) lightweight block work (density 1350kg/m3 - 1600kg/m3) Finish Minimum 6mm parge* coat plus 12.5mm plasterboard On dabs (or 13mm lightweight plaster

3. Methodology

The simulation tool HTB2 is used for the thermal analysis of two types of construction details i.e. thermally lightweight and heavyweight. The methodology is divided to answer the two main research objectives (i) to look for the internal temperature profiles to assess which fabric type is more efficient for controlling summer heat and maintaining lower internal temperatures and (ii) to find out which house type is more efficient in consuming winter heating energy.

In the beginning extensive literature review is conducted to know the construction details of both types, along with the comfort conditions required inside. The weather file of London is used for thermal modelling.

Further, the weather file was modified with future tentative temperature projections up to 2080, again results were analysed for better temperature profiles. In the third phase, the thickness and placement of thermal mass in the house elements like walls, floors and roofs were changed to find the best configuration. The temperature profiles of internal spaces are checked for extreme summer conditions.

The understanding of the software was very well done before the simulation was initiated. The validation of the software is well-checked. The results of all types of construction are put together and compared with the required temperature levels in the different spaces.

The energy consumed by different house fabric details to maintain the temperature of 21C for the entire 8 months of winter is analysed to find the better fabric for the heating season.

At the end of this research, some recommendations are given for future houses in the UK. The step-wise research flowchart is presented in the schematic of **Figure 2**.

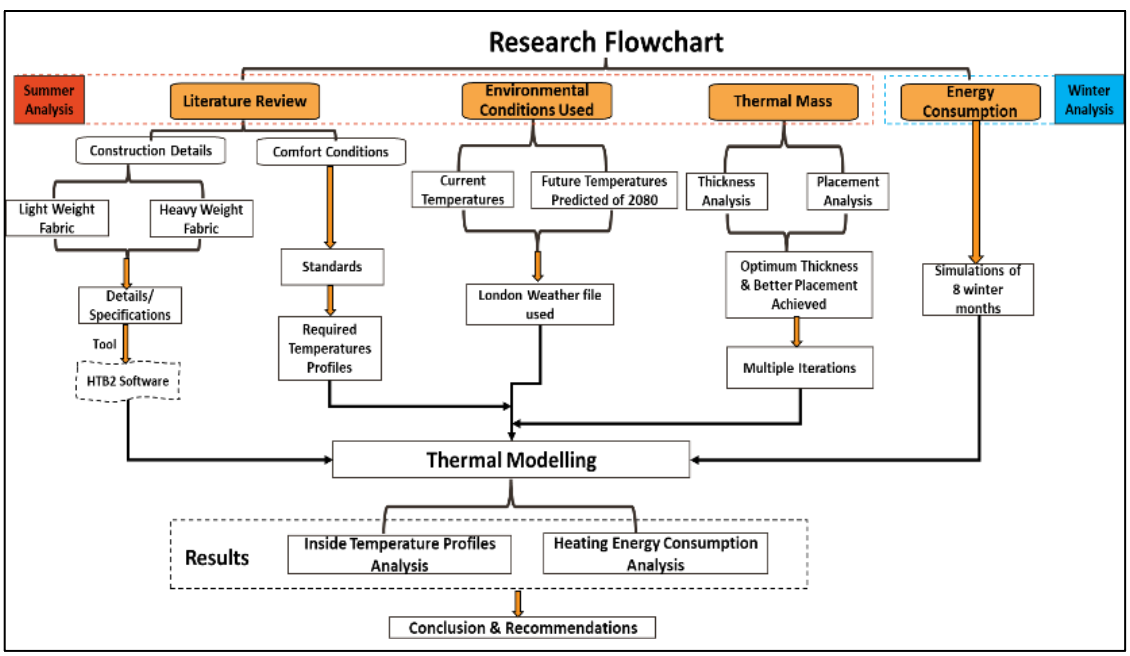


Figure 2 Research Flowchart

Volume: 9, No: 2, pp.4581-4597
ISSN:2059-6588(Print)|ISSN2059-6596(Online)

4. Simulation and Results

For the thermal analysis purpose house plan is made in the HTB2 simulation software. Broadly, we have made changes to the fabric details to see which one is performing better to keep the temperature profiles inside within the accepted ranges throughout the year. The average weather data file of London is used for all analyses.

Analysed House Plan: The following house plan is taken from the literature review. This house has been checked for thermal analysis (work has been done by the ARUP, and the plan has been taken from the report prepared by Feilden Clegg Bradley, Architects LLP). The selection of this house plan is random as we are not concerned with the design part of it but rather the thermal behaviour of its fabric Figure 3 & Figure 4. The space nomenclature, floor areas, height and volumes are given in

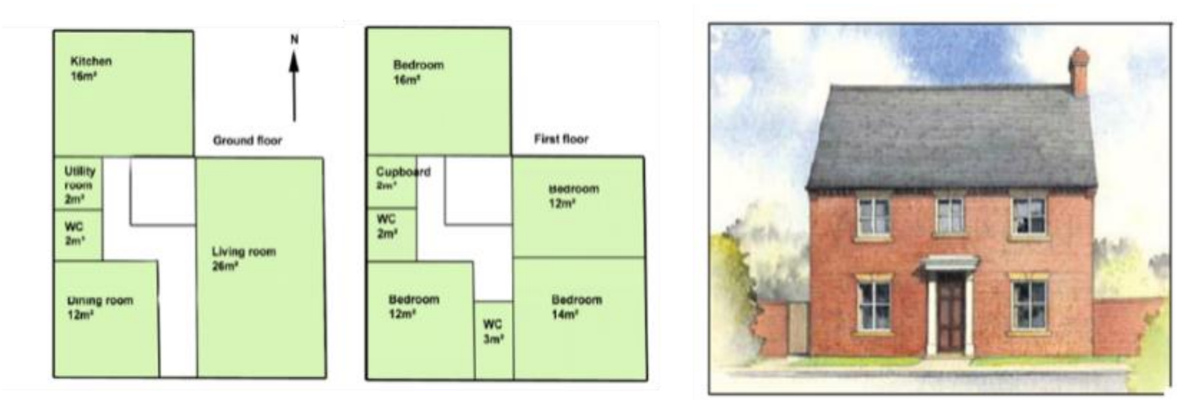


Figure 3 House Plan & Elevation for Analysis

Table 4 Floor Area and Volume Details of Analyzed House

Areas/Spaces	Floor Area (m^2)	Height (m)	Volume (m^3)
Dining room and bedroom on the first floor (spaces 1 & 6)	12 (3.5X3.5)	2.4	29.4
Bath ground and first (spaces 4 & 9)	4.5 (3X1.5)	2.4	10.8
Living room and living bed on the first floor (spaces 2 &7)	26 (6.5X4)	2.4	62.4
Kitchen and kit. Bed first floor (spaces 5 &10)	16 (3.5X4.5)	2.4	37.8
Circulation ground/first both (space 3 &8)	12 (3.5X3.5)	2.4	29.4

Note: (All windows areas are taken 20% of the floor area. Some modifications are done in the ground/first-floor plan. It is made the same as the ground floor for the sake of simplicity)

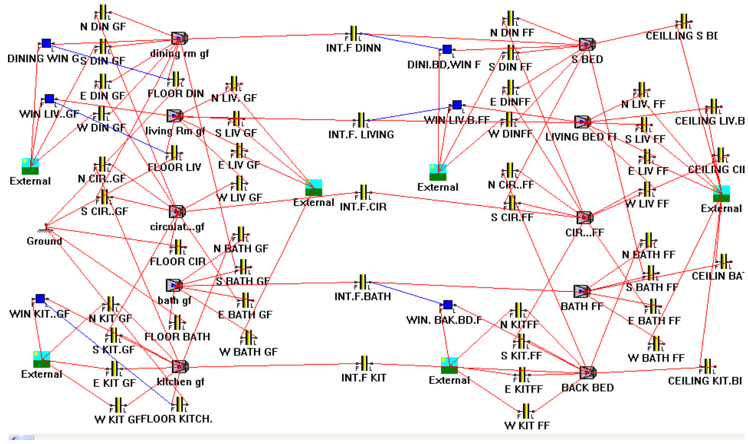


Figure 4 The schematic (construction) of the ground floor and first-floor plan in HTB2 software

Table 5 Materials Details of Light & Heavyweight Construction

	Light-Weight Construction Details	Heavy-Weight Construction Details
	Material/U-value	Material/U-value
Walls	-aerated concrete/0.060 -cavity normal/0.200 -urea formaldehyde foam/0.060 -gypsum plasterboard/0.012	- brick (outer leaf)/0.103 -cavity normal/0.050 -polyurethane foam board/0.100 -concrete (heavy mix)/0.150 - plaster light/0.012
Partition walls	-perlite plasterboard/0.012 -cavity normal/0.050 -perlite plasterboard/0.012	-plaster light/0.012 -aerated concrete/0.105 -plaster light/0.012
Ground Floor	-flooring board/0.025 -cavity normal/0.100 -perlite plasterboard/0.012	-flooring board/0.025 -concrete(heavy mix)/0.100 - earth/1.000
Intermediate floor	-flooring board/0.025 -cavity normal/0.100 -perlite plasterboard/0.012	-flooring board/0.025 -aerated concrete/0.100
Window details	-window glass/0.008 -cavity normal/0.0007 -window glass/0.008	- window glass/0.008 -cavity normal/0.0007 - window glass/0.008
Roof details	-ceiling tiles mineral/0.012 -cavity normal/0.500 -glass wool/0.200 -perlite plasterboard)/0.012	- clay tiles/0.012 - cavity normal/0.500 -glass wool/0.200 - concrete (heavy mix)/0.200

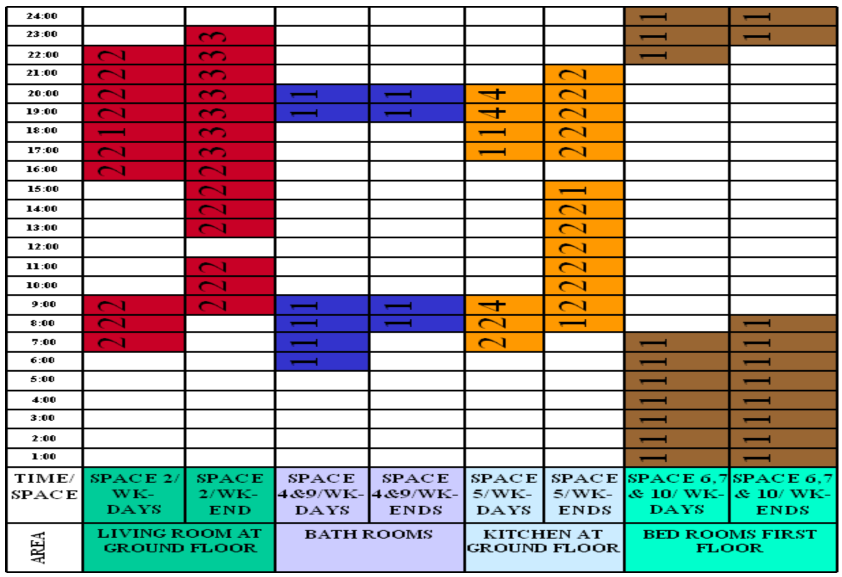


Figure 5 Occupancy Schedule of House Plan Used in Simulation

4.1 Temperature Analysis of House Plan

The analysis is based on the thermal behaviour of different fabric construction to maintain better/required temperature profiles inside the occupied spaces facing South. We applied lightweight, heavyweight, lightweight with heavy partitions(Case-1) and lightweight with heavy slabs(case-2) details to the simulation models Table 6. All simulations are done for detached and attached house scenarios. The space-wise analysis (Table 6) of the detached house is briefly given below;

Space 1(dining room), it is seen that heavy weight is 1.8 C more efficient than lightweight. Case-1 & case-2 are 0.6 & 1.1 C more efficient than lightweight construction. Between the two cases, case-2 is 0.5 C more efficient than case-1.

Space-2 (living room), it is seen that heavy weight is 2.9 C more efficient than lightweight. Case-2 is 1.3 C more efficient than lightweight construction. Between the two cases, case-2 is 1.3 C more efficient than case-1.

Space-3 (circulation-G.F), it is seen that heavy weight is 2.3 C more efficient than lightweight. Case-1 & case-2 are 2.6 & 1.0 C more efficient than lightweight construction. Between the two cases, case-1 is 1.6 C more efficient than case- 2.

Space-4 (bath-G.F), it is seen that heavy weight is 3.1 C more efficient than lightweight. Case-1 & case-2 are 2.3& 1.2 C more efficient than lightweight construction. Between the two cases, case-1 is 1.1 C more efficient than case-2.

Space-5 (kitchen), it is seen that heavy weight is 2.4 C more efficient than lightweight. Case-1 & case-2 are 1.1 C more efficient than lightweight construction. Between the two cases, they behave equally.

Space-6 (bed above dining), it is seen that heavy weight is 2.5 C more efficient than lightweight. case-1 & case-2 are 0.6& 1.9 C more efficient than lightweight construction. Between the two cases, case-2 is 1.3 C more efficient than case-1.

Space-7 (bed above living), it is seen that heavy weight is 2.2 C more efficient than lightweight. Case-2 is 2.2 C more efficient than lightweight construction. Between the two cases, case-2 is 2.2 C more efficient than case-1.

Space-8(circulation-F.F), it is seen that heavy weight is 2.9 C more efficient than lightweight, case-1 & case-2 are 2.6 & 2.3 C more efficient than lightweight construction. Between the two cases, case-1 is 0.3 C more efficient than case- 2.

Space-9(bath-F.F), it is seen that heavy weight is 3.3 C more efficient than lightweight, case-1 & case-2 are 1.6& 1.7 C more efficient than lightweight construction. Between the two cases, case-2 is 0.1 C more efficient than case-1.

Space-10 (bed above the kitchen), it is seen that heavy weight is 3.0 C more efficient than lightweight, case-1 & case-2 are 1.1& 2.3 C more efficient than lightweight construction. Between the two cases, case-2 is 1.2 C more efficient than case-1.

In general, the heavyweight house is better in all the spaces, and next comes the case-2 house. The detailed temperature profiles of the same house when attached from both sides with other houses are provided in (Table 6).

Table 6 Maximum Temperatures Observed in Different Spaces with Various Construction Details

South Facing	Temperature	Light-weight	Heavy-weight	*Case-1	*Case-2
Detached House					
Spaces	Outside(C)	Inside(C)	Inside(C)	Inside(C)	Inside(C)
Space 1	26.6	24.4	22.6	23.8	23.3
Space 2	26.6	27.1	24.2	27.1	25.8
Space 3	25.1	22.2	19.9	19.6	21.2
Space 4	23.2	22.0	18.9	19.7	20.8
Space 5	25.1	22.8	20.4	21.7	21.7
Space 6	26.6	27.4	24.9	26.8	25.5
Space 7	26.6	29.0	26.8	29.0	26.8
Space 8	25.1	25.5	22.6	22.9	23.2
Space 9	23.2	25.7	22.4	24.1	24.0
Space10	25.6	25.9	22.9	24.8	23.6
Attached House					
Space 1	21.7	23.4	22.1	22.8	22.3
Space 2	26.6	26.0	23.6	25.8	24.4
Space 3	25.6	21.3	19.7	18.5	20.4
Space 4	23.2	19.6	18.4	17.5	18.8
Space 5	25.1	21.0	19.8	20.0	20.2

Space 6	26.6	26.7	24.7	26.1	24.5
Space 7	26.2	28.2	26.1	28.3	26.3
Space 8	25.1	24.5	22.4	22.2	22.5
Space 9	23.2	23.7	21.6	22.0	22.3
Space10	25.1	24.1	22.4	23.3	22.6

*Case 1 = lightweight having heavy partition walls

*Case 2 = lightweight having heavy slabs of concrete

4.2 The temperature projections (up to 30 & 40 C) and their effects on the temperature profiles of spaces

To check the future scenarios of higher temperatures outside, how the different building fabrics would behave to maintain desired internal temperature profiles. We have modified the weather file to increase the temperature to 30 & 40C and simulated their effects on different fabric details. The results are shown in

Table 7.

we see that the heavy-weight house performed well in maintaining lower temperatures in the hot weather in all studied scenarios

Table 7. When we see the results of lightweight, case-1 and case-2, we found that Case-2 house better kept the temperatures at the lower level(which is by putting some thermal mass at the floors and roof of the lightweight house)

Table 7. Under severe temperature scenarios, an attached house is better than a detached house, because it is covered from two sides and not directly exposed to outer climatic constraints

Table 7. We have observed that when some thermal mass is added in lightweight construction details either in partition walls(Case-1) or in the floor and roof slabs(Case-2), it becomes better to lower the internal temperature profiles.

Table 7 Temperature Projections and Their Effects in Different Sapacs

Space/ South facing	LW (30C)	HW (30C)	CASE-1 (30C)	CASE-2 (30C)	Better-Without HW(30C)	LW (40C)	HW (40C)	CASE-1 (40C)	CASE-2 (40C)	Better-Without HW(40C)
					Detached House					
Space 1	24.8	22.5	23.7	23.4	Case-2	32.7	24.7	31.3	31.5	Case1
Space 2	28.4	24.2	28.3	27.0	Case-2	34.8	31.4	34.4	33.5	Case-2
Space 3	22.8	20.4	19.5	21.8	Case-1	31.3	23.4	23.5	23.9	Case-1
Space 4	21.7	19.5	19.5	21.0	Case-1	30.4	22.1	23.7	23.0	Case-2
Space 5	22.8	21.3	23.6	23.1	Case-2	32.8	24.1	31.7	31.5	Case-2
Space 6	28.9	26.0	28.0	26.6	Case-2	36.0	31.6	34.4	32.5	Case-2
Space 7	30.8	28.1	30.6	28.2	Case-2	37.8	33.3	37.4	34.6	Case-2
Space 8	26.9	23.4	22.8	23.6	Case-1	34.4	30.6	30.7	31.4	Case-1

April 2024,
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Space 9	25.5	22.2	22.7	23.1	Case-1	33.8	28.6	31.2	31.4	Case-1
Space 10	28.4	24.0	27.8	25.2	Case-2	35.8	30.8	34.7	32.7	Case-2
Attached House										
Space 1	23.5	21.7	22.6	22.4	Case-2	31.2	23.6	29.4	29.2	Case-2
Space 2	27.3	22.8	26.8	24.2	Case-2	33.5	30.0	32.9	32.2	Case-2
Space 3	21.8	20.0	18.8	20.8	Case-1	30.0	22.6	22.6	24.7	Case-1
Space 4	19.7	18.4	18.0	19.2	Case-1	24.2	20.1	21.4	22.8	Case-1
Space 5	22.4	20.5	21.6	21.5	Case-2	30.3	22.5	28.0	24.7	Case-2
Space 6	28.0	24.4	24.8	24.7	Case-2	34.8	30.3	33.0	31.7	Case-2
Space 7	29.5	27.3	29.7	27.4	Case-2	36.7	32.2	36.3	33.6	Case-2
Space 8	25.8	22.9	22.3	22.8	Case-1	33.5	29.6	30.5	30.9	Case-1
Space 9	23.2	21.1	21.4	21.9	Case-1	31.5	23.5	29.1	29.8	Case-1
Space 10	26.8	23.1	25.2	23.6	Case-2	34.0	28.6	32.5	31.3	Case-2

LW (30)= Outside temperature 30 degrees C (lightweight)
HW (40)= Outside temperature 40 degrees C (heavyweight)
Case 1 = Lightweight having heavy partition walls
Case 2 = Lightweight having heavy slabs of concrete
(Note: In the comparison column the heavyweight is not taken, because it is better in all the spaces)

4.3 **Multiple Iterations in Construction and Thickness**

In a special set of simulations, we have made the house plan simple, by taking the ground and first floor as one single space separately (detached south-facing). However, the overall areas of all partition walls are considered as one mass, rather than as designed spaces. We wanted the check the multiple scenarios and note how different construction and thickness details would affect the temperature profiles inside. We see that in all cases the maximum temperature observed on the ground floor is less than on the first floor Table **8**. The heavyweight house could achieve the lowest temperature and lightweight with the highest temperature profiles on both levels. Is seen as we increase the thickness of walls and floors of lightweight construction, the maximum internal temperatures start decreasing Table **8**. Decreasing 10% of the glazing area gives the benefit of 1C only(Case-6). The results of different scenarios are presented in Table **8** and can be helpful under different situations to make changes in the retrofitting process as required to achieve the desired results.

Table 8 Multiple Iterations in Construction and Thickness Details

No.	Construction Details South Facing	Ground Floor Temp. C	First Floor Temp. C
01	LW	24.5	27.2
02	HW	21.8	24.0
03	CASE-1	23.2	26.2
04	CASE-2	23.2	24.2
05	CASE-3	22.3	24.2
06	CASE-4	22.8	26.0
07	CASE-2-A	23.1	24.4

08	CASE-2-B	22.9	24.3
09	CASE-2-C	22.7	23.7
10	CASE-2-D	22.5	23.2
11	CASE-1-A	23.0	26.1
12	CASE-5	24.1	26.9
13	CASE-6	23.5	26.7

LW= Lightweight construction
HW= Heavyweight construction
Case-1= Lightweight with only partition walls heavy-mass
Case-2= Lightweight with floors and roof of a heavyweight
Case-3=Both partition walls and floors of lightweight construction are replaced with heavyweight.
Case-4= Lightweight construction, but external walls are changed with heavy-weight materials
Case-2-A=Lightweight with heavy floor and roof slab (as case-2), but the thickness of the intermediate slab is increased from 100mm to 150mm(concrete slab)
Case-2-B=Light weight with heavy floor and roof slab (as case-2), but the thickness of the intermediate slab is increased from 100mm to 200mm(concrete slab)
Case-2-C=Light weight with heavy floor and roof slab (as case-2), but the thickness of the roof slab is increased from 20mm to 50mm(concrete slab)
Case-2-D=Lightweight with heavy floor and roof slab (as case-2), but the thickness of the roof slab is increased from 20mm to 100mm(concrete slab)
CASE-1-A=Lightweight house with heavy partition walls, but, the thickness is changed from 105mm to 150mm(concrete slab)
CASE-5= Lightweight house as it is, but, the thickness of the external concrete block is increased from 60mm to 100mm.
Case-6= Percentage of window size is decreased from 20-25% to 10-15%

4.4 Fabric Thermal Analysis for the Heating Energy Requirement

In this analysis procedure, we simulated our house plan with different fabric details to know which envelope consumes less amount of heating energy to maintain a constant temperature of 21C inside. We considered continuous (X) and intermittence (Y) heating system turning-on modes for 8 months of the winter season attached and detached houses facing south Figure 6.

In all the cases and for different time schedules, it is seen that a heavy-weight house is better in the energy consumption of all spaces (Table 9). It is 21%(X) & 23% (Y) better in detached and 15%(X) & 17%(Y) in attached houses respectively

Remittances Review
April 2024,
Volume: 9, No: 2, pp.4581-4597
ISSN:2059-6588(Print)|ISSN2059-6596(Online)

Table 9. If we compare the energy use of case-1 & case-2, both behave equally overall, like in half of the spaces one is better and vice versa. It is seen that the first floor is better with case-1 and the ground floor is better with case-2 in consuming less heating energy.

(X) = Heating will turn on whenever the temperature goes under 21 C, 08:00-24:00(continues)

(Y) = Heating will turn on whenever the temperature goes under 21 C, 08:00-09:30 & 18:00-24:00(intermittence)

Figure 6 Heating Energy Consumed in 8 Months of Winter

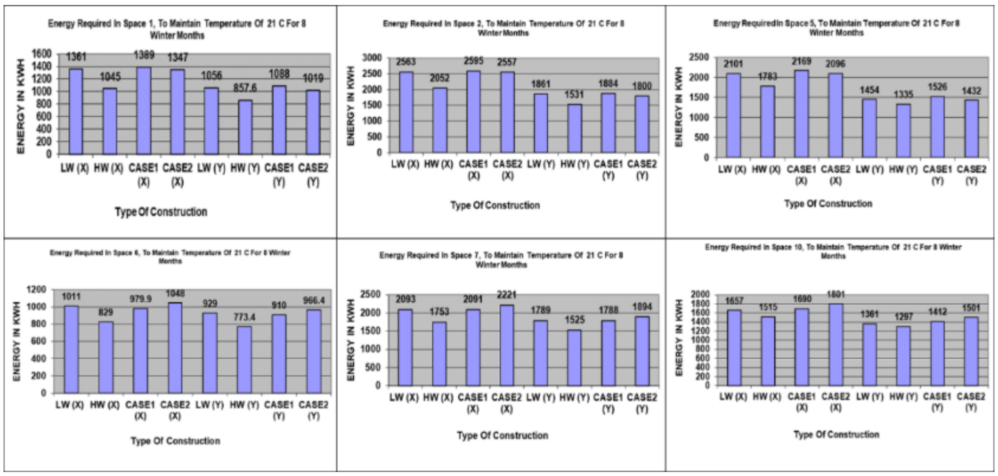

Table 9 Winter Heating Energy Required Under Different Scenarios (KWh)

Space/South Facing	LW (X)	HW (X)	CASE-1 (X)	CASE-2 (X)	Better Without HW	LW (Y)	HW (Y)	CASE-1 (Y)	CASE-2 (Y)	Better Without HW
					Detached House					
Space 1	1361	1045	1389	1347	Case-2	1056	857.6	1088	1019	Case-2
Space 2	2563	2052	2595	2557	Case-2	1861	1531	1884	1800	Case-2
Space 3	1722	1351	1904	1716	Case-2	1283	1099	1418	1253	Case-2
Space 4	647.7	530.7	685.3	642.3	Case-2	457.2	417.0	497.6	449.5	Case-2
Space 5	2101	1783	2169	2096	Case-2	1454	1335	1526	1432	Case-2
Space 6	1011	829.0	979.9	1048	Case-1	929.0	773.4	910.0	966.4	Case-1
Space 7	2093	1753	2091	2221	Case-1	1789	1525	1788	1894	Case-1
Space 8	1156	988.3	1209	1245	Case-1	1077	948.6	1116	1171	Case-1
Space 9	471.5	422.0	490.1	504.6	Case-1	394.4	373.5	418.0	431.4	Case-1

Remittances Review
April 2024,
Volume: 9, No: 2, pp.4581-4597
ISSN:2059-6588(Print)|ISSN2059-6596(Online)

Space 10	1657	1515	1690	1801	Case-1	1361	1297	1412	1501	Case-1
Total	14783	12269	15202	15178		11662	10157	12058	11917	
					Attached House					
Space 1	1305	968.9	1331	1286	Case-2	1047	825.4	1081	1011	Case-2
Space 2	2525	1947	2690	2501	Case-2	1889	1520	2029	1828	Case-2
Space 3	1601	1266	1644	1601	Case-2	1176	1004	1172	1154	Case-2
Space 4	611.4	461.9	622.7	599.6	Case-2	471.4	399.4	494.8	460.0	Case-2
Space 5	2050	1659	2095	2028	Case-2	1505	1329	1565	1475	Case-2
Space 6	856.3	713.1	828.5	876.9	Case-1	824.1	687.7	807.4	851.1	Case-1
Space 7	1835	1532	1796	1916	Case-1	1636	1385	1605	1716	Case-1
Space 8	1005	906.0	1091	1094	Case-1	921.7	838.7	992.3	1013	Case-1
Space 9	358.9	317.7	350.9	373.4	Case-1	344.0	312.0	345.2	367.1	Case-1
Space 10	1399	1284	1404	1487	Case-1	1243	1168	1271	1342	Case-1
Total	13547	11056	13853	13763		11057	9469	11363	11217	

5. Conclusion and recommendations

In this research, we wanted to know the type of construction details of the UK's dwellings which will control over-heating in the summer and would provide a comfortable winter environment inside by consuming less energy. Broadly, thermally lightweight and heavyweight construction details are applied to the study house plan, and multiple simulations are performed to know which fabric construction details are better for indoor temperature profiles and energy consumption. The current weather file of London is used for analysis and it is modified for the future scenario of 2080, which would have an external temperature of 40C. The thickness and placement of thermal mass are checked for performance and the best-fit model is presented.

As the current UK housing construction industry is moving towards lightweight materials, the current research has found that some thermal mass should be added to the fabric details to achieve better results, hence emitting less CO^2. The placement of thermal mass has seemed to be better at the floors and ceiling. It is less effective in partition walls.

Conclusive words

Keeping in mind the future conditions of climate and environment, the following recommendations are made;

- Heavy-weight house construction should be taken, provided the materials used can be made low CO^2 emissive by controlling the embodied energy.
- The best orientation of the house is deemed as South & North.
- The main source of heat in the space is solar, so the window sizes must be checked. It is seen that 20-25%(of floor area) window sizes as allowed by Law, are less effective for the future condition. It is seen that the 10-15% window sizes are better (of floor area) in south-north facing houses.
- The thermal mass if taken in a lightweight house, is better to put in the floors and roof slabs.
- Thermal mass in partition walls is less effective than in slabs or roofs.
- The roof slabs having 50-100mm thick concrete mass is recommended to make the situation better.

- The intermediate slab thickness of 150mm is optimum. More mass does not have a much-enhanced effect.
- In terms of winter heating energy savings heavyweight house is roughly 23%(detached) and 17% (attached) more efficient than lightweight constructed houses.

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