Sustainable Design Theory & Practice: Integrated Energy Retrofit design proposal for a Victorian end Terrace house built in 1920s

Master of Science in BIM and Digital Built Environment

Supervised by: Dr Yingchun Ji

By: @00785471
May 2025, Manchester

Integrated Energy Retrofit Design application for a Victorian end Terrace House

Using IES-VE Platform

University of Salford

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Assignment 2 (~ 3300 words used)

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What to Expect

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Background

This paper uses IES VE simulations to examine the retrofit plan for a Victorian end-terrace house built in Manchester during the 1920s. Beginning from the current base model (Phase 0) and working through fabric upgrades, heating system enhancements, and airtightness measures, it uses a phased retrofit strategy. The model was carefully simulated key parameters like occupancy profiles, heating set points, penetration rates, and ventilation techniques. Results of simulations show how changes in facade, heating set point, and infiltration control help to lower energy demand. With considerable decreases in heating demand, carbon emissions, and enhanced thermal comfort, every retrofit phase demonstrated increasing gains. With an almost 60 percent decrease in energy demand overall, the fabric-first approach was rather successful. The report also emphasises how integrated modelling helps to balance energy efficiency, occupant comfort, and heritage preservation.

1. Introduction

Meeting world carbon reduction targets depends on bettering the energy performance of current buildings. Retrofit projects are vital in the United Kingdom since 85% of the present building stock is estimated to be in use by 2050 (Department for Business, Energy and Industrial Strategy, 2021). Older structures like the Victorian end-terrace house from the 1920's studied here have specific difficulties because of obsolete construction and low thermal performance. By entering the simulation stage with IES VE, this project advances the earlier retrofit proposal design. Although the first proposal document called for renewable technology, this report relies mostly on fabric improvements, heating system upgrades, infiltration management, and ventilation enhancement. A major benchmark, influencing improvements in U-values for walls, roofs, flooring and windows is Part L of the Building Regulations (HM Government, 2021). By means of thorough modelling, the paper assesses phased retrofit plans, therefore proving the efficiency of a fabric-first strategy accompanied by better ventilation and heating efficiency. The results show how architectural heritage might be preserved while upgrading old homes to current energy efficiency criteria. Starting with basic model construction and working through parameter definition, simulation results, and a critical assessment of the overall retrofit strategy, the paper uses a methodical manner.

2. The Base Model (Phase 0)

Analysing particular inefficiencies required first knowledge of the construction and design elements of the 1920's Victorian end-terrace house under use in this project. To replicate the current conditions (Phase 0), a dynamic thermal model was constructed in IES VE including comprehensive information on building dimensions, fabric qualities, internal conditions, and Manchester meteorological data. The adjacent house was represented as a void to suit retrofit modelling criteria; the shared party wall was treated as adiabatic, and chimneys were not included. U-values from EN ISO 6946 (IES VE has this standard) determined thermal characteristics for walls, ceilings, floors, windows, and doors. Examining the effects of later retrofit phases depends critically on this basic concept. The designated building for the base model is shown in the table below.

Parameter	Details
Orientation	The front of the building faces south, influencing solar gain and passive heating potential.
External Walls	225 mm solid brickwork with internal plastering; cavity with 225 mm brickwork and 45 mm EPS slab.
Partition Walls	115 mm brickwork with 13 mm internal and external plastering; connections to cavity include plastering and 225 mm brickwork.
First Floor	Synthetic carpet and timber flooring with cavity and plaster.
First Ceiling	Timber board with 100 mm glass-fiber quilt insulation, cavity, and plaster.
Roof	Stone chipping with felt/bitumen layers and slate tiles.
Ground Floor	Synthetic carpet and timber flooring with cavity and dense cast concrete.
Glazing	6 mm Pilkington single glazing.
Attributes	Background infiltration rate of 1 ACH (Air Changes per Hour).
Occupancy	Assumed to be a working couple with one children, influencing daily heating, lighting, and appliance usage patterns.
Lighting	Controlled by occupants, primarily used in the evening when home, except during sleeping hours.
Internal Gains	Heat gains from lighting and appliances in the living room (e.g., 8W/m² when occupied).
Ventilation	Natural ventilation via openable windows, providing up to 6 ACH in summer.
Heating System	Ideal heating system assumed by default, with set points at 20°C and operating when occupants are present.

Table 1. Construction and design features of the 1920s Victorian end-terrace house.

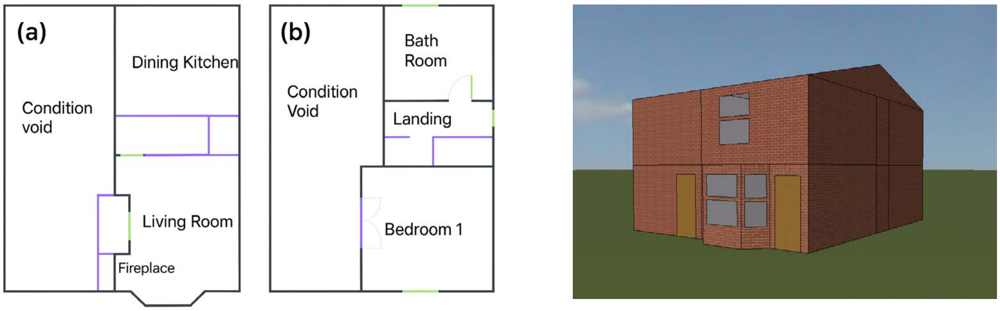


Figure 1 Ground Floor and First Floor (a & b), 3D Perspective.

3. Model Parameters

Carefully constructed in IES VE, the simulation model reflected the baseline and later retrofit stages of the 1920s Victorian end-terrace house. Understanding the effect of every retrofit intervention on energy demand and thermal performance depends on accurate modelling of important parameters. Together with an outline of the phased retrofit approach, the primary parameters under consideration are discussed below.

3.1. Occupancy Profile

The occupancy profile developed shows a typical family of two adults and one child, which affects internal gains from human presence, lighting, cooking, and appliance use. Near realistic simulation of energy consumption and thermal loads in IES VE depends on precise capture of these patterns. The house is mainly empty during working hours on weekdays; on weekends the family spends more time at home. To represent occupancy fluctuations, a thorough daily room use schedule was included. Lighting was active mostly in the evening; television and electronics were modelled in the living room during evenings and weekends; cooking gains were assigned to the kitchen or dining area during mealtimes; and the refrigerator was modelled as a continuous internal gain. Accurate simulation of heating loads and near realistic assessment of retrofit effectiveness depend on these presumptions.

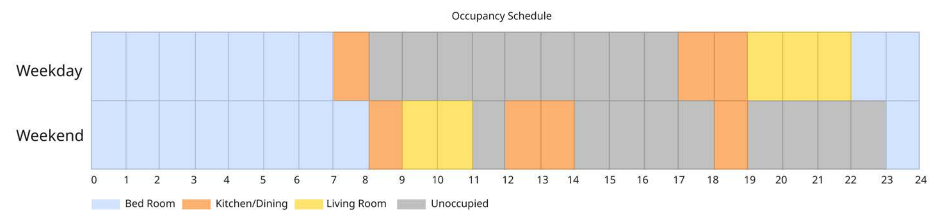


Figure 2 Occupancy schedule of two adults and a child.

3.2. Heating Set Points

Thermal comfort and energy consumption of a building directly depend on heating set points. This experiment examined five heating set points from 19^{0}C to 23^{0}C in the baseline model to evaluate their effects on general performance and space heating demand. During simulations, every set point was set based on occupancy profile both during the day and at night to precisely assess how annual heating demand is affected by indoor temperature targets. Depending on things like thermal envelope performance and infiltration rates, every 1^{0}C increase can typically raise heating energy usage by roughly 7 to 10 percent (International Energy Agency, 2022). Testing several set points helps the model to estimate the sensitivity of energy use to occupant comfort preferences and spot operational energy saving possibilities. Section 4.1 offers more discussion on heating set point influence.

3.3. Phased Fabric Retrofit Assumptions

Targeting particular building elements in sequence to progressively increase the thermal performance of the Victorian end-terrace house, the phased retrofit plan in this project follows a disciplined manner. The aim was to separate the effects of every action on energy demand prior to their combined influence. Phase 1 concentrated on roof insulation, testing small impacts on heat loss by installing mineral wool at 100 mm, 150 mm, and 200 mm. Phase 2 matched with Part L criteria coupled roof improvements with replacement of single-glazed windows and doors using high-performance double-glazed systems. Phase 3 brought wall insulation and tested internal and external choices at different thicknesses (50 mm, 75 mm, 100 mm, and 150 mm). Phase 4 covered ground floor insulation using a 100 mm stiff layer above the concrete. U-values followed Part L direction throughout all phases to guarantee reasonable performance criteria. This sequential approach made it possible to evaluate the contribution of every building element to general improvement of energy performance.

3.4. Infiltration Assumptions

Heat demand is strongly influenced by infiltration, especially in older buildings like the Victorian end-terrace house this study models. Reflecting common air leakage in older buildings, the baseline model and throughout Phases 1 to 4 maintained constant the infiltration rate at 1 air change per hour (ACH), therefore enabling independent assessment of fabric improvements independent of airtightness modifications. Using simulations at progressively lower rates of 0.8 ACH, 0.6 ACH, 0.4 ACH, and 0.2 ACH, Phase 5 incorporated infiltration reduction as a specific retrofit strategy. These figures show ever high degrees of envelope performance. The project emphasises the great energy-saving possibilities of draught-proofing and airtightness improvements as fundamental components of an efficient retrofit plan by evaluating the effect of infiltration reduction on heating demand.

3.5. Ventilation

The dynamic thermal model was built with a natural ventilation approach to reduce overheating during the retrofit stages. Summer window opening logic allowed windows to open during occupied hours when inside temperatures surpassed comfort standards (above 23 0c and CO2 more than 1000ppm) and in case the outside temperature is below 28 0c. This passive approach kept indoors comfortable without depending on mechanical cooling. With 2 ACH for living rooms and bedrooms to balance fresh air needs with heat retention and 6 ACH allotted to kitchen areas to control cooking-related heat and moisture, ventilation rates approximated typical household activities. These presumptions fairly caught the relationship among building performance, internal gains, and natural ventilation. Together with fabric improvements and infiltration control, the ventilation plans enhanced thermal comfort and indoor air quality while reducing energy consumption.

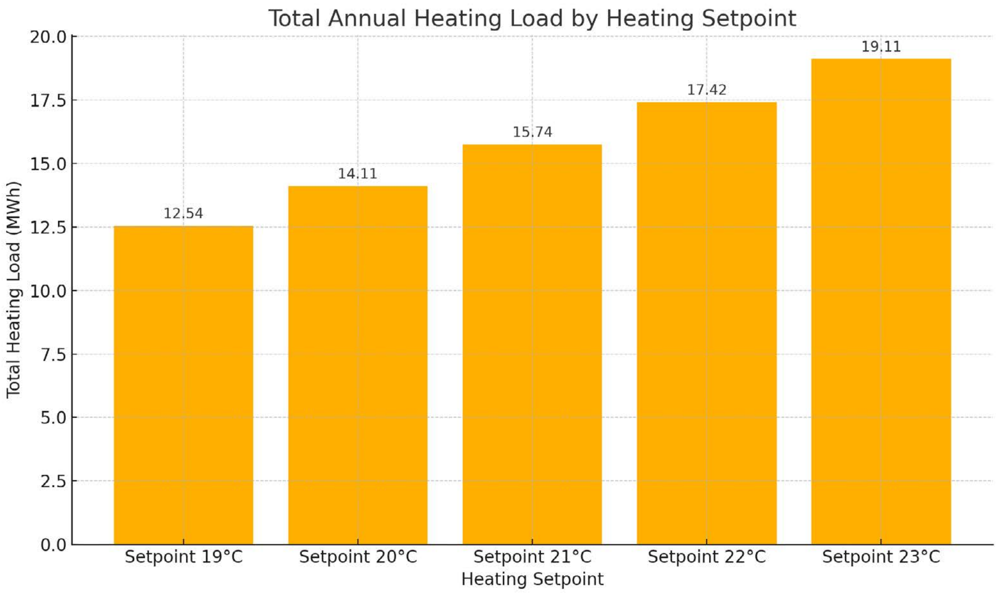
4. Results

4.1. Heating Set Points and Their Impact

· Building load

Using five distinct heating set points 19⁰C, 20⁰C, 21⁰C, 22⁰C, and 23⁰C simulations were run for the baseline model to evaluate their impact on heating energy demand. Higher set points clearly increase heating loads, according to results; annual demand rises from 12.54 MWh at 19⁰C to 19.11 MWh at 23⁰C, therefore reflecting an overall increase of about 52 percent. Monthly trends followed seasonal fluctuations; the winter months had the largest heating loads and clearly varied all months as set points changed. The results line with accepted wisdom, whereby a 1⁰C rise usually results in a 7 to 10 percent increase in heating energy demand. This emphasises the important part occupant behaviour plays in building energy performance and shows how well careful heating set point management can save energy even without physical retrofit actions.

Figure 3 Total annual heating load by heating setpoints.



· Air temperature

Internal air temperatures were investigated for Bedroom 1, Dining/Kitchen, and Living Room following the heating load study. Increasing the heating set point consistently produced steadily higher indoor air temperatures across all spaces during occupied times. Temperatures in the bedroom roughly matched set points during nighttime occupancy, then dropped during unoccupied hours. Under influence of culinary operations, the dining/kitchen area had strong temperature peaks in morning and evening especially at higher set points. Similar evening temperature rises in the living room connected with set point increases. Although set point differences in both seasons were significant, seasonal fluctuations were evident with lower interior temperatures in January than in July. These results demonstrate that heating set point decisions greatly affect occupant comfort levels; higher set points consistently produce warmer environments but result in greatly higher energy demand.

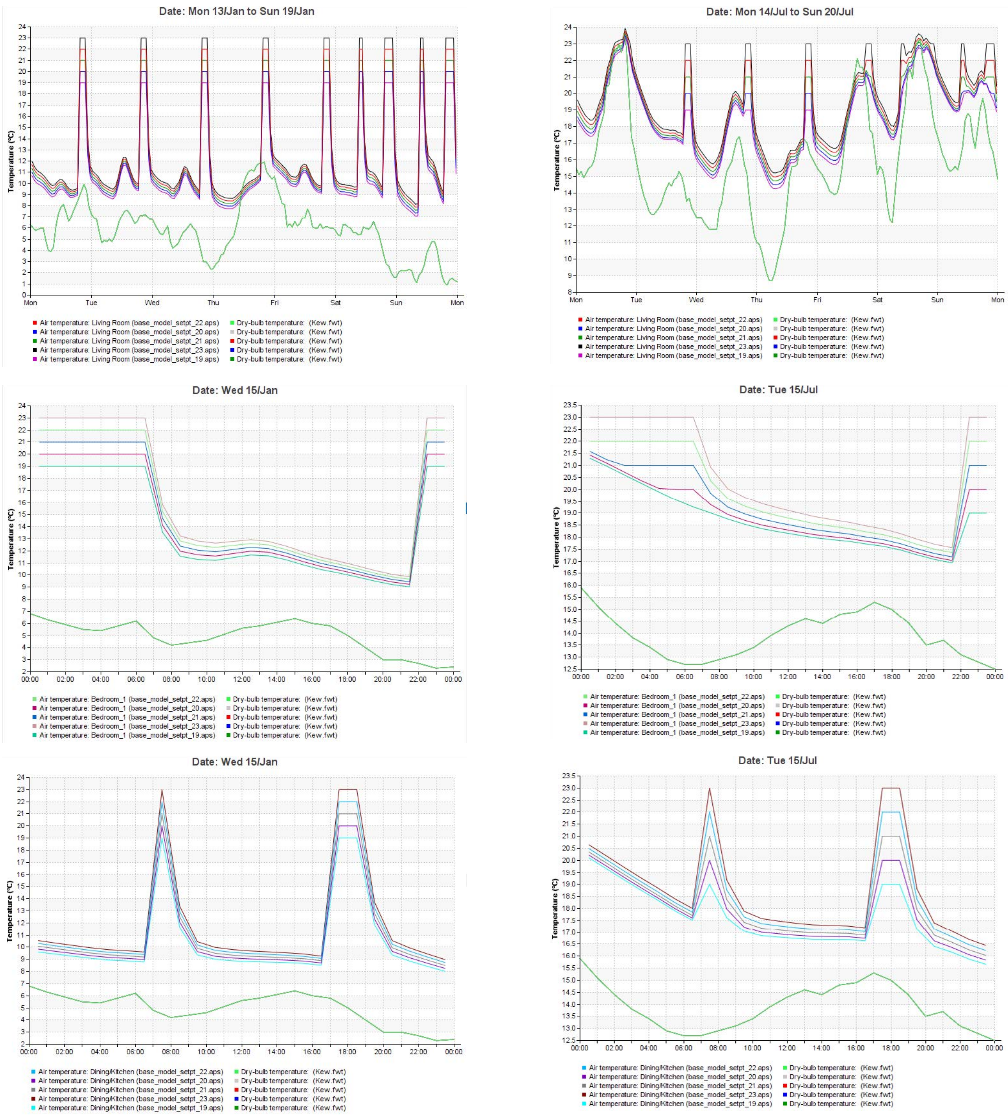
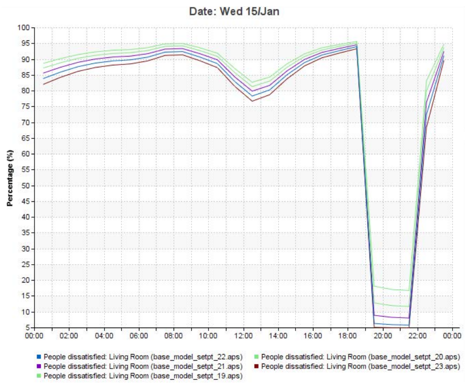


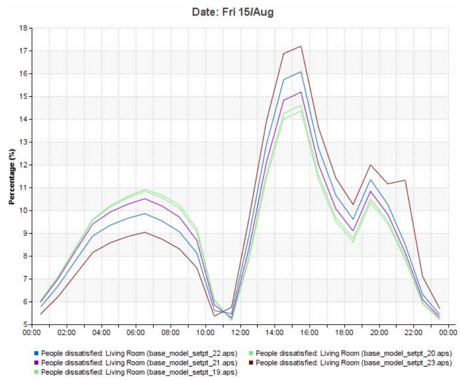
Figure 4 Air temperature of indoor spaces(Living room, Bedroom1, Dining/kitchen top to bottom respectively) affected by different heating setpoints.

· Comfort

Analysing the expected percentage of people dissatisfied (PPD) in the living room under various heating set points allowed one to evaluate occupant thermal comfort. Higher set points (22°C and 23°C) in January produced reduced displeasure rates; lower set points (19°C and 20°C) indicated somewhat higher PPD values during occupied hours. Higher set points notwithstanding, PPD stayed high—often reaching 80%—reflecting the poor thermal conditions common of uninsulated ancient structures. Dissatisfaction percentages in August were far lower, ranging from 5% to 17%. These findings show that although raising set points might somewhat enhance winter comfort, the benefits are small when compared to the notable rise in energy demand. This emphasises the more significance of fabric and infiltration improvements than depending merely on heating set point tweaks to increase sustainable comfort.

Figure 5 Living room comfort affected by the heating set-points.

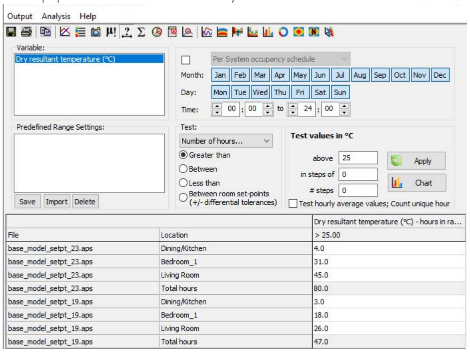




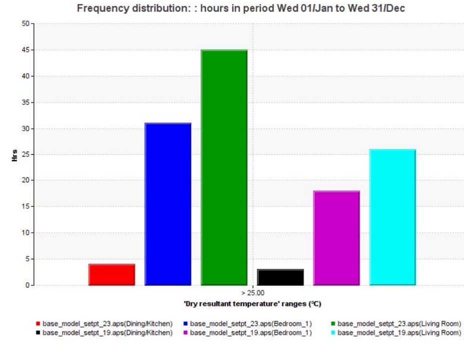
· Temperature over 25 °C

The frequency of internal temperatures exceeding 25°C was analysed to assess potential overheating risks. Under a 23°C heating set point, living room saw the maximum number of hours above 25°C (approximately 45 hours annually), followed by the bedroom and the Dining/kitchen. On the lower 19°C set point, on all areas, the number of overheating hours dropped dramatically.

Figure 6 Temperature over 25 °C to see overheating.



File	Location	Dry resultant temperature (°C) - hours in ra... > 25.00
base_model_setpt_23.aps	Dining/Kitchen	4.0
base_model_setpt_23.aps	Bedroom_1	31.0
base_model_setpt_23.aps	Living Room	45.0
base_model_setpt_23.aps	Total hours	80.0
base_model_setpt_19.aps	Dining/Kitchen	3.0
base_model_setpt_19.aps	Bedroom_1	18.0
base_model_setpt_19.aps	Living Room	26.0
base_model_setpt_19.aps	Total hours	47.0



These results imply that higher winter set points not only raise heating energy demand but also help to increase summertime overheating risk, especially in more thermally sensitive environments such as bedrooms. Thus, in an efficient retrofit design, controlling heating set points alongside ventilation methods is essential in balancing thermal comfort and reducing the risk of overheating.

4.2. Energy Demand Proportions

Finding priority areas for retrofit projects depends on an awareness of the proportionate contribution of various building components to heating energy demand. Examined in this part is the impact of the building facade and infiltration on general energy performance.

- **Building Facade**

Selectively applying adiabatic conditions to some surfaces while leaving others exposed allowed one to evaluate the effect of particular architectural elements on heating demand. Showed in Figure 2, the data demonstrate that side walls account for around 18 percent of the total heating demand and are the main causes of heat loss. Openings, including windows and doors, contribute around 15 percent; closely followed by infiltration losses at 14 percent.

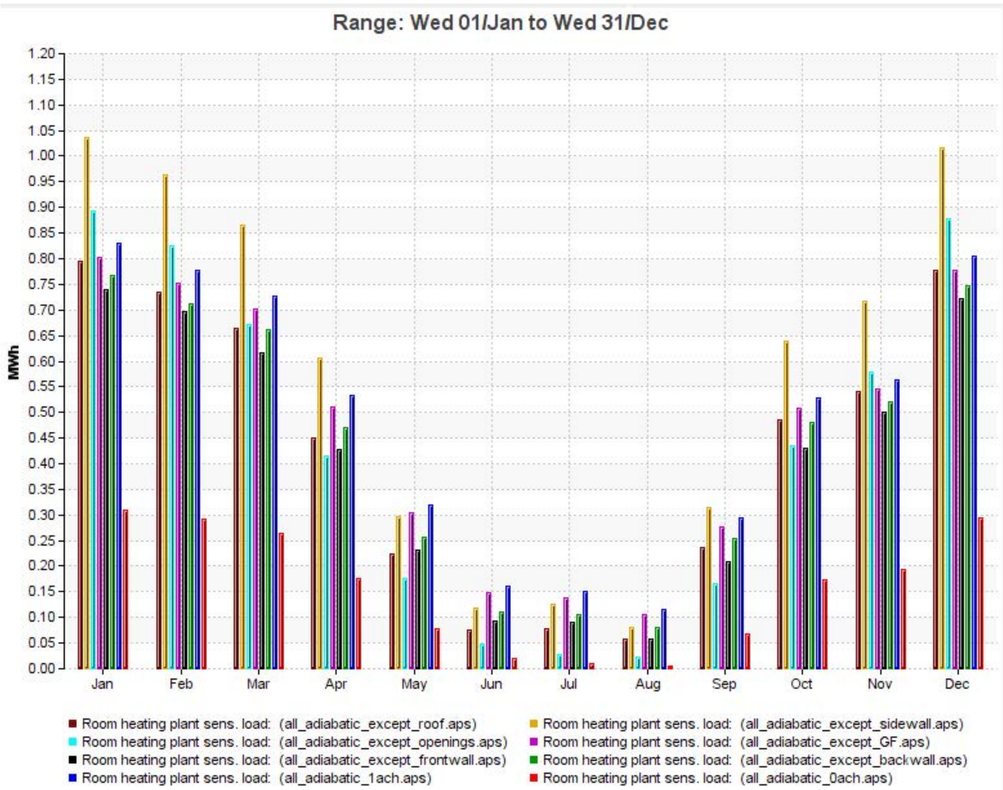


Figure 7 Energy demand proportions of different building elemnts under adiabatic conditions.

While the rear wall and front wall contribute somewhat less, at roughly 13 percent apiece, the ground floor and roof both contribute about 14 percent. While all factors greatly affect the total heating demand, it is obvious that the largest gains would come from bettering the insulation of side walls and openings as well as from lowering intrusion. These three components by themselves account for about half of the entire building heat loss, which emphasises the need of focused retrofit actions to start addressing these top priorities.

4.3. Retrofit Phases and Their Impact

All retrofit phases are conducted using a heating set point of 200c and shading is not used due to moderate summer temperatures and limited solar radiation in Manchester.

Phase 1: Roof Insulation

- **Heating Load**

Three thickness levels 100 mm, 150 mm, 200 mm introduced roof insulation. Every case of insulation revealed definite lower heating demands than the base model. The three insulation levels varied very little, though, which implies that most of the possible energy savings were already captured by 100 mm of insulation.

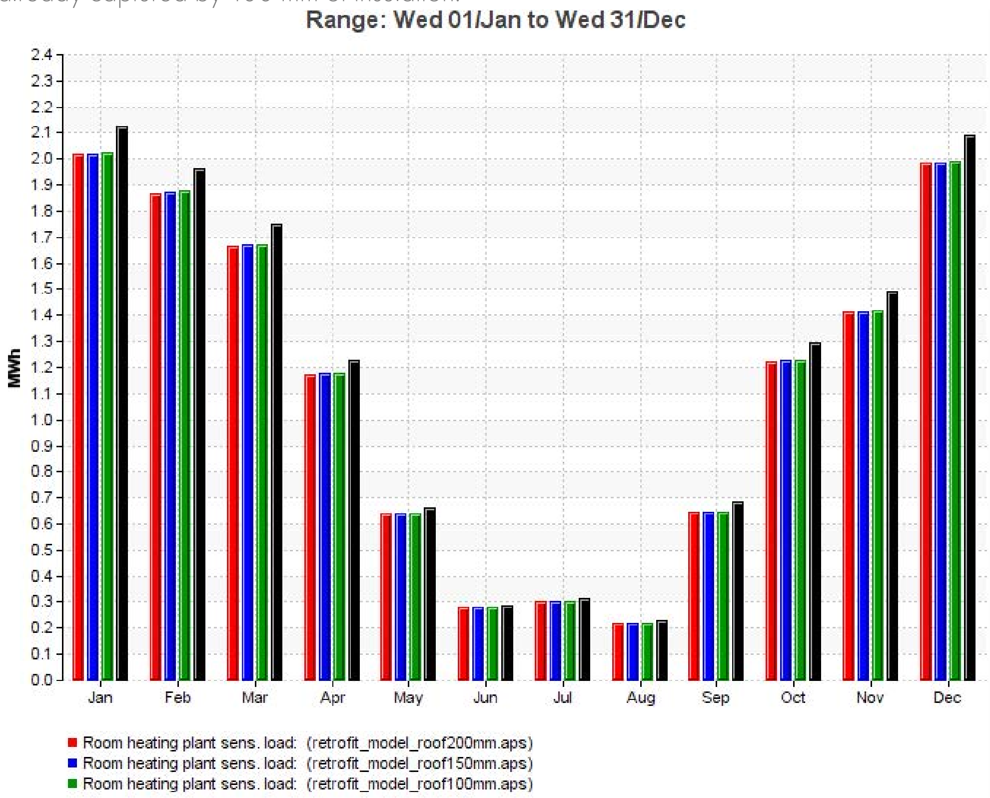


Figure 8 The effect of roof insulations on the annual heating load.

- ## Air Temperature

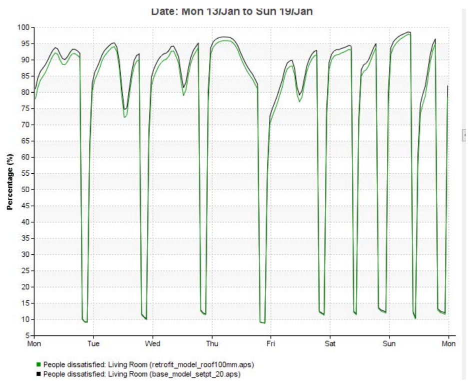
Indoor air temperatures improved slightly after roof insulation, particularly during winter nights in Bedroom 1. Modest temperature increases were also observed in the Living Room and Dining/Kitchen spaces, especially overnight. However, the changes remained relatively limited, indicating that roof insulation alone could not fully stabilize indoor conditions.

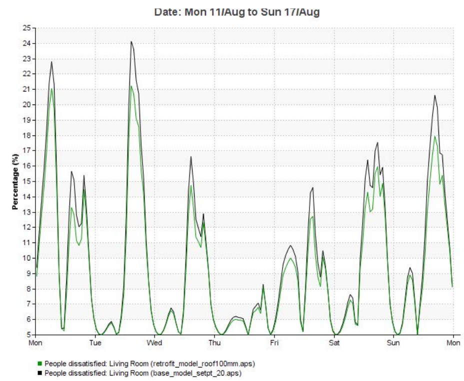
Figure 9 Air temperature of indoor spaces(Living room, Bedroom1, Dining/kitchen top to bottom respectively) affected by roof insulation.

• Comfort

Comfort analysis based on predicted percentage dissatisfied (PPD) showed minor improvements during winter weeks in the Living Room, with slightly lower dissatisfaction rates compared to the base case. In summer, both base and retrofit models maintained low dissatisfaction levels, with minimal differences. Overall, roof insulation provided small gains in thermal comfort but was insufficient to meet comfort standards on its own.

Figure 10 Living room comfort affected by roof insulation.





Phase 2: Roof Insulation + Openings

• Heating Load

The heating load further decreased after improving the openings alongside roof insulation. Comparing the retrofit model (roof 100 mm + improved openings) to the base model, a consistent reduction in heating demand across all months is evident. The most significant reductions occur in the colder months (January–March and November–December), showing that window and door upgrades provide additional insulation benefits beyond the roof intervention alone.

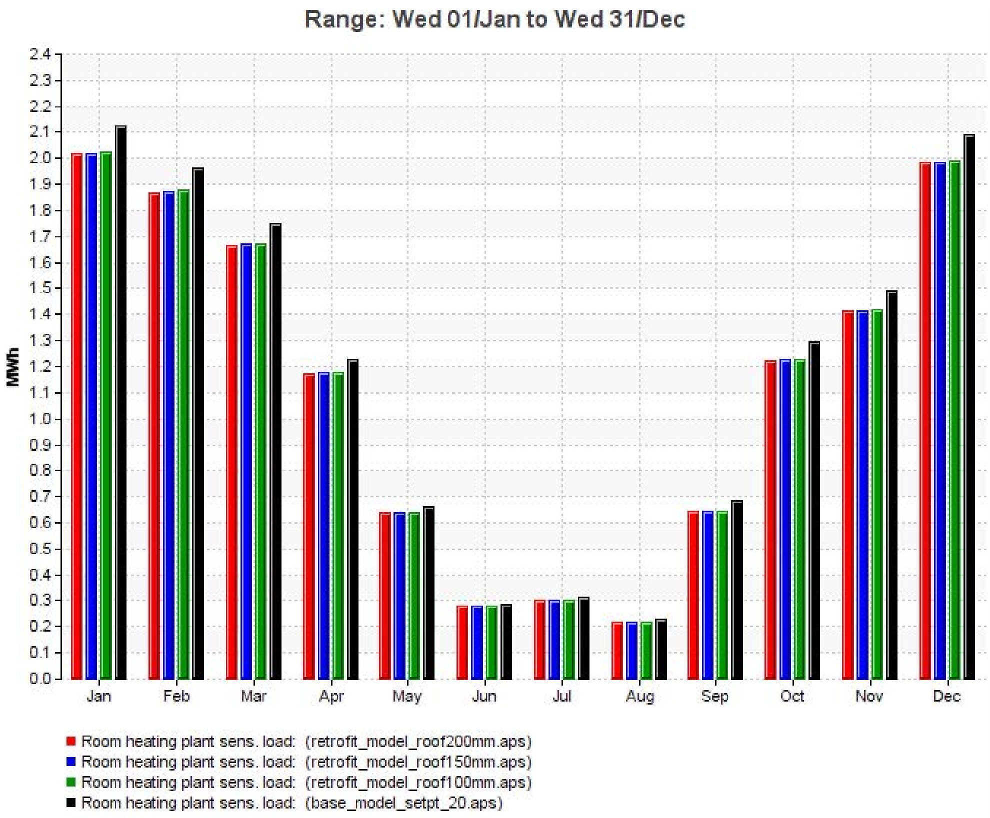


Figure 11 The effect of roof insulation and opening improvment on the annual heating load.

- **Air Temperature**

Across Bedroom 1, Dining/Kitchen, and Living Room, slight increases in internal air temperature are observed after upgrading the openings, particularly during the morning and evening occupied periods in winter (January). In summer (July), the temperatures remain relatively stable compared to the base model, suggesting that the improved openings did not cause overheating but contributed to slightly better temperature maintenance, particularly overnight.

Figure 12 Air temperature of indoor spaces(Living room, Bedroom1, Dining/kitchen top to bottom respectively) affected by roof insulation and openings improvment.

- **Comfort**

The Percentage of People Dissatisfied (PPD) showed a slight improvement after openings were upgraded, especially during the daytime in both winter and summer. Although the overall dissatisfaction remained high in winter, minor reductions were observed. In summer, discomfort slightly increased during certain daytime hours but remained generally manageable. Overall, comfort performance showed a modest improvement with better glazing performance.

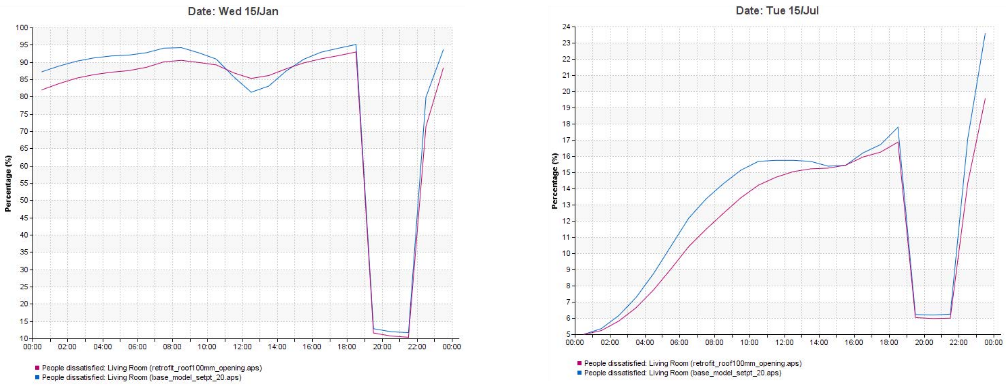


Figure 13 Living room comfort affected by roof insulation and openings improvment.

Phase 3: External Insulation Thickness Effect

· Heating Load

Increasing external wall insulation thickness reduced the room heating load year-round. The base model (green) had the highest peaks, surpassing 2.1 MWh in January and December. As insulation thickness increased, heating loads decreased: 50 mm (IWI) reduced January to ~1.35 MWh, 75 mm (IWI) to 1.34 MWh, and 100 mm (IWI) to 1.33 MWh. Interestingly, the 150 mm (EWI) case was slightly higher at ~1.39 MWh, suggesting diminishing returns beyond 100 mm or model sensitivity. Overall, insulation upgrades meaningfully reduced heating demand, with 100 mm providing an optimal balance.

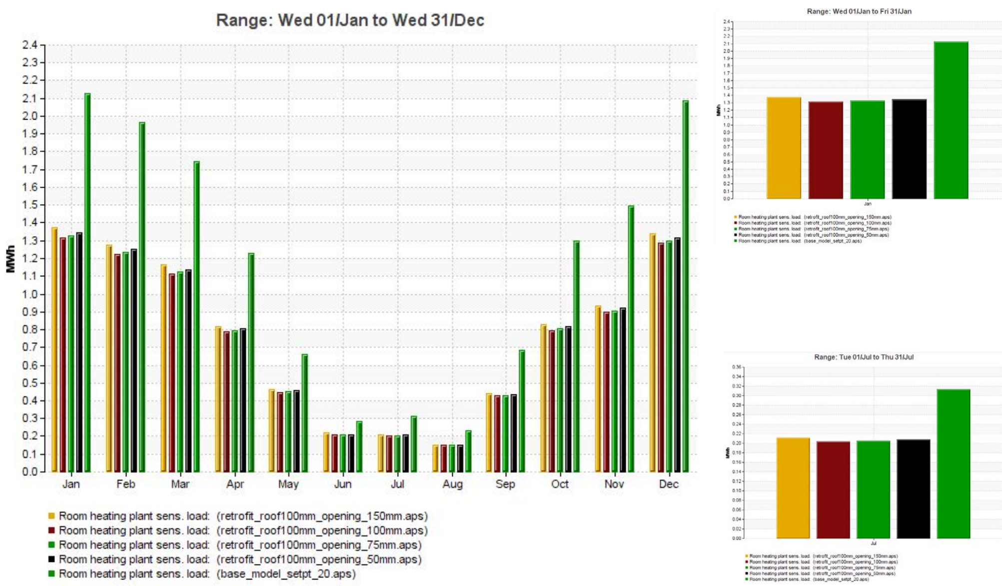
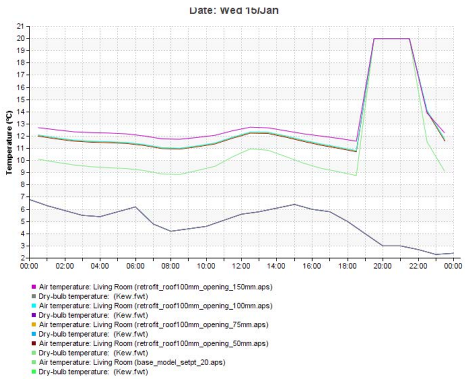


Figure 14 The effect of roof insulation, opening improvment, and Wall insulations on the annual heating load.

Air Temperature

In the living room, all retrofit models maintained higher air temperatures than the base in January. The 150 mm case performed best at 12–13 ^{0}C during occupied hours. In August, while all models experienced gains, 75 mm and 100 mm peaked over 23.5 ^{0}C by midday, slightly higher than the 150 mm case (~22 ^{0}C), likely due to better thermal resistance minimizing fluctuation. This reflects improved stability in internal temperatures with thicker insulation.



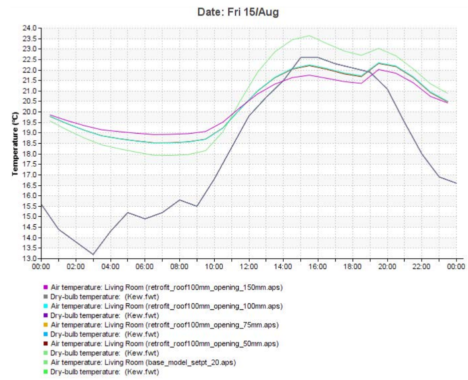
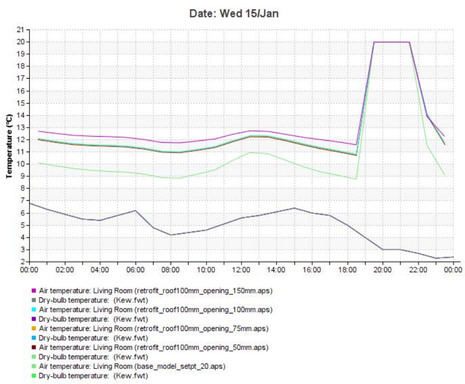


Figure 15 Air temperature of indoor spaces(Living room) affected by roof insulation, openings, and Wall insulations improvment.

Comfort

January PMV values for the base model ranged from -2.5 to -2.0, showing discomfort. Retrofits improved this, with 150 mm (~ -1.8) best, followed by 100 mm and 75 mm (~ -1.9). In August, the base model reached 0.6, while retrofits stayed closer to neutral. The 150 mm and 100 mm hovered around 0.3–0.4, maintaining more consistent comfort. Thus, insulation upgrades enhanced comfort by reducing thermal extremes in both winter and summer.



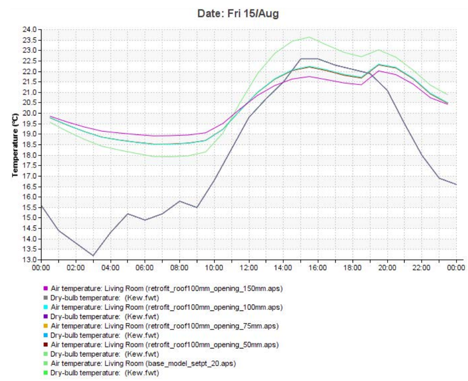


Figure 16 Living room comfort affected by roof insulation, openings improvment, and Wall insulations.

Phase 4: Ground Floor Insulation Effect

- **Heating Load**

The integration of 100 mm internal wall insulation with 100 mm ground floor insulation yielded a substantial reduction in annual room heating loads. Compared to the base model (green), which peaked at over 2.1 MWh in January and December, the retrofitted case (blue) reduced these peaks to approximately 1.15 MWh. This reduction persisted consistently across all months, reflecting the effectiveness of the combined insulation strategy in lowering heat loss, particularly during colder periods.

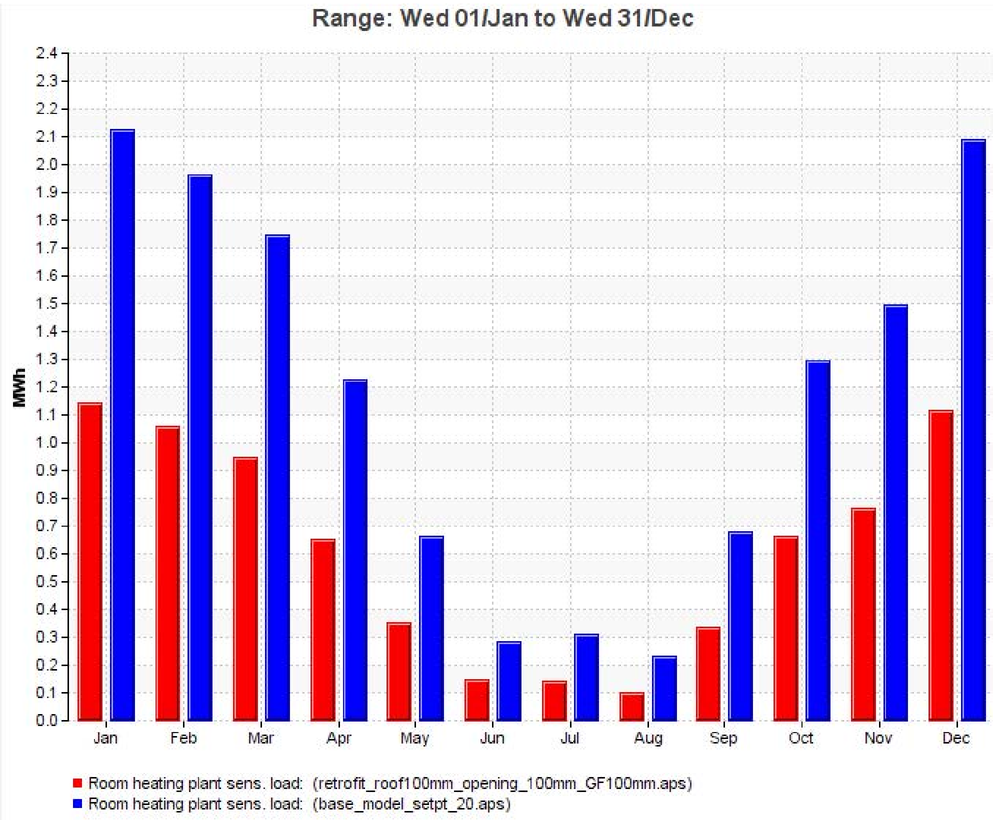


Figure 17 The effect of roof insulation, opening improvement, Wall insulations, and Ground floor insulation on the annual heating load.

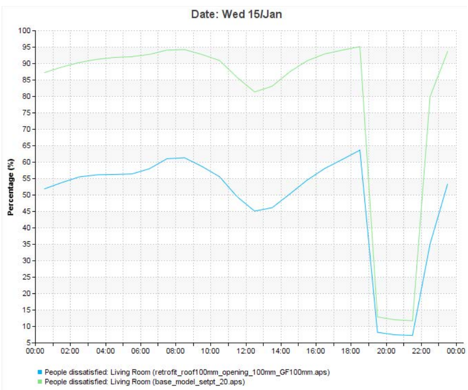
- **Air Temperature**

Air temperature data from January and July illustrate the thermal benefits of the combined retrofit across all major zones. In January, the bedroom temperature under retrofit conditions stayed around 16– 17 ^{0}C during occupied hours, clearly outperforming the base model which hovered between 11 and 13 ^{0}C. Similarly, the dining/kitchen and living room saw noticeable gains of 2–4 ^{0}C, with peak evening temperatures reaching 19–20 ^{0}C. During the summer, indoor temperatures were more stable in the retrofitted model, maintaining slightly lower and steadier values across the day compared to the base case, suggesting reduced thermal swings and better internal comfort.

Figure 18 Air temperature of indoor spaces(Living room, Bedroom1, Dining/kitchen top to bottom respectively) affected by roof insulation, openings improvment, .Wall insulation, and Ground floor insulation.

- **Comfort**

Thermal comfort assessed via the Predicted Percentage of Dissatisfied (PPD) index showed clear improvements in both seasons. In winter (15 Jan), dissatisfaction levels in the living room dropped significantly from 90–95% in the base model to around 45–55% under the retrofit condition. This represents a major shift toward acceptable comfort levels. In summer (15 Jul), the retrofit model maintained low dissatisfaction percentages under 7% for most of the day, while the base model exhibited a gradual rise peaking at over 20% in the evening. These results confirm that combined external and ground floor insulation substantially enhances thermal comfort year-round.



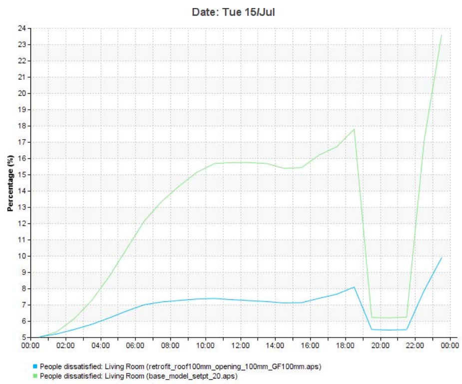


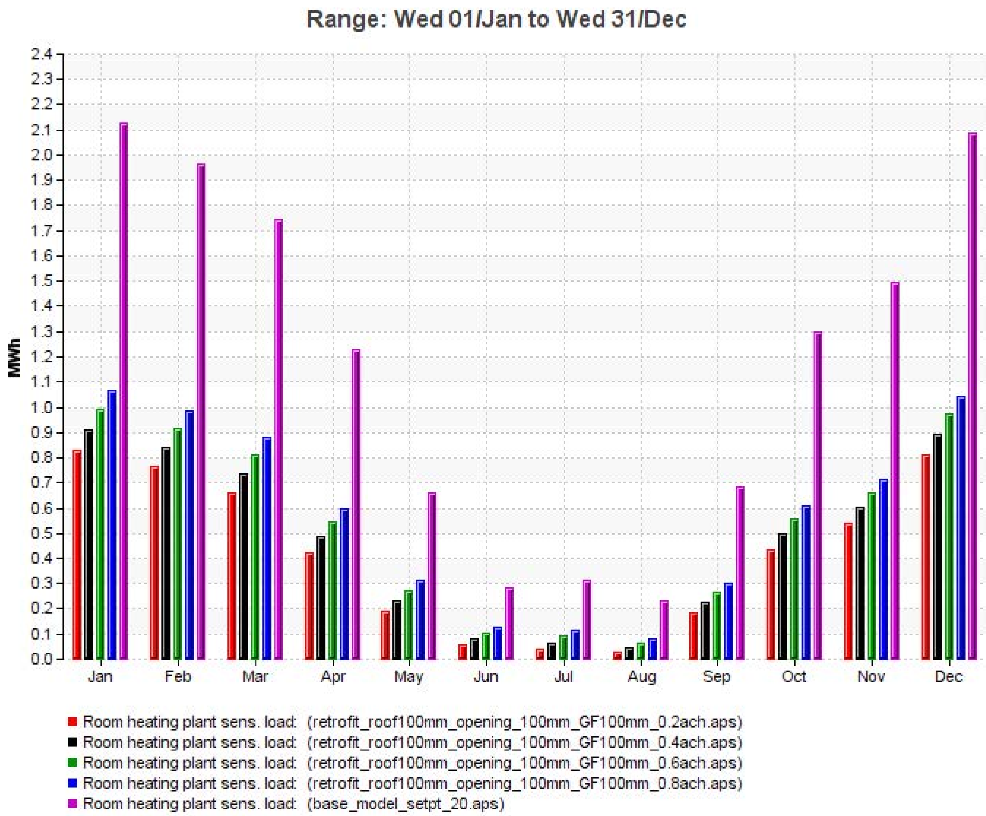
Figure 19 Living room comfort affected by roof insulation, openings improvment, Wall insulation, and Ground floor insulation.

Phase 5: Effect of Infiltration on Thermal Performance

· Heating Load

The chart shows that lowering the ventilation rate significantly reduced the room heating load throughout the year. The base model registered the highest heating demand, with peaks over 2.1 MWh in January and December. All retrofitted scenarios using 100 mm external insulation and 100 mm ground floor insulation demonstrated notable improvements. The best-performing case was at 0.2 ach, which achieved the lowest heating load (~0.8 MWh in Jan). Raising infiltration rates like 0.4 ach , 0.6 ach , and 0.8 ach progressively increased the load, confirming that reduced air change rates lower heat loss and energy demand.

Figure 20 The effect of roof insulation, opening improvment, Wall insulations, Ground floor insulation, and infiltration improvment on the annual heating load.



· Air Temperature

In the retrofitted examples, living room air temperature trends indicated greater indoor temperatures than in the basic model. The 0.2 ach case kept the hottest temperatures in January;

it peaked at about 16^{0}C during the evening hours and had a minor decline at increased ventilation rates. Following the same trend, all retrofitted examples in August were warmer than the basic model; 0.2 ach reached the highest midday temperatures (~23.5^{0}C), implying retained internal gains. This shows how well lowered ventilation reduces heat loss in winter and improves internal heat retention in summer.

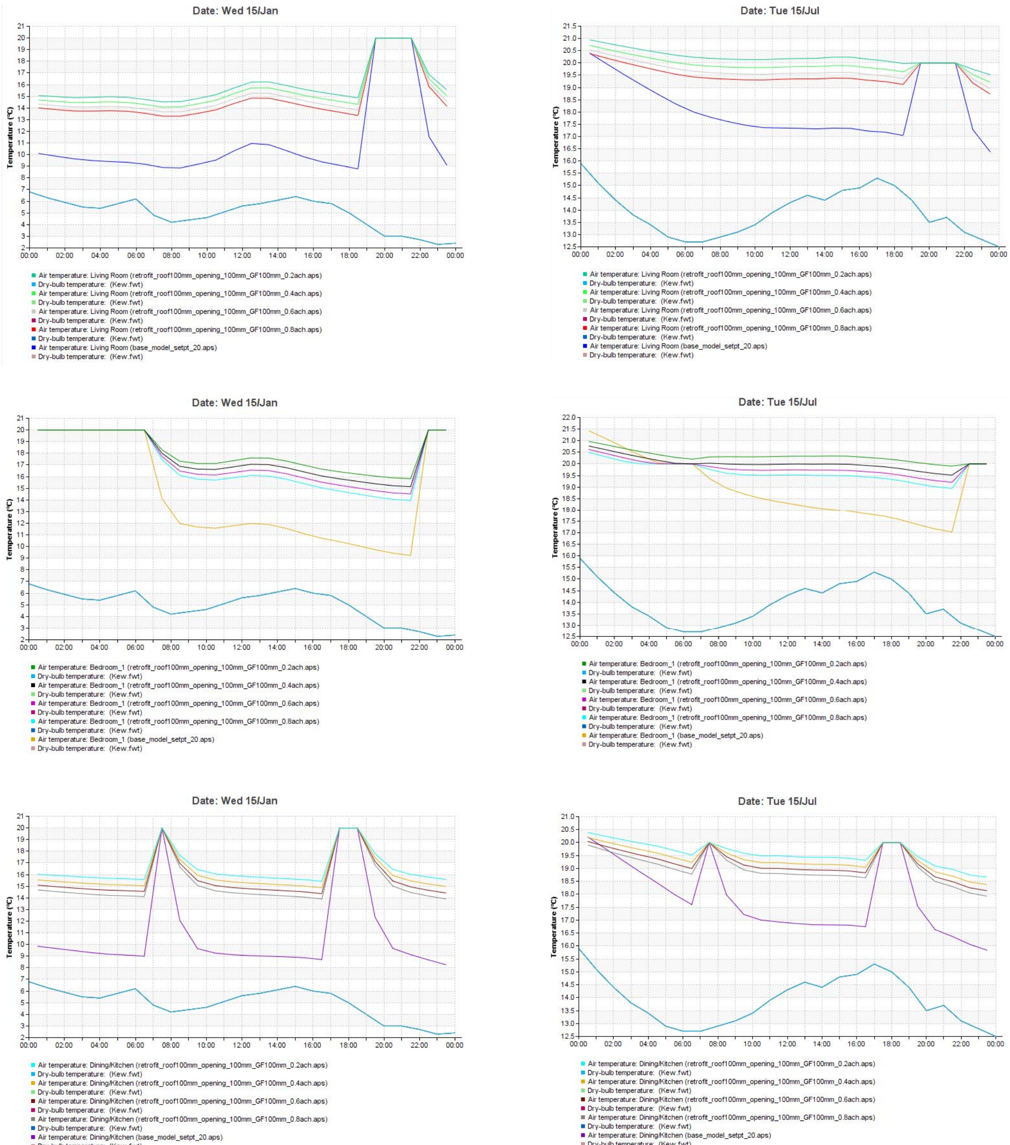
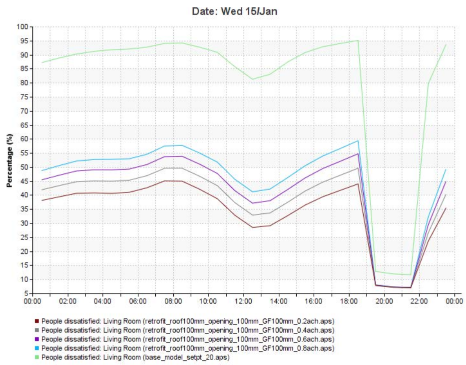


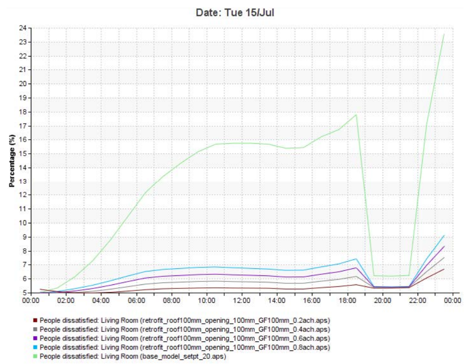
Figure 21 Air temperature of indoor spaces(Living room, Bedroom1, Dining/kitchen top to bottom respectively) affected by roof insulation, openings improvment, Wall insulation, Ground floor insulation, and infiltration improvment.

• Comfort

Reducing ventilation clearly helps according to comfort analysis based on the percentage of individuals unhappy (PPD). The standard model showed the poorest comfort (>90% unhappiness) in January; the 0.2 ach retrofit decreased dissatisfaction rates to ~30–35%. Though all stayed better than the baseline, higher ach values progressively deteriorated comfort. All cases in August revealed considerably reduced dissatisfaction (<15%). Once more, 0.2 ach confirmed its heat buffering capacity by offering the ideal comfort levels all day. In both seasons, overall lowering of ventilation rate greatly improved occupant comfort.

Figure 22 Living room comfort affected by roof insulation, openings improvment, Wall insulation, Ground floor insulation, and infiltration improvment.





Final retrofit was applied by replacing the **old boiler system** with a new highly efficient **boiler** and the results are as follows:

- **Heating Load**

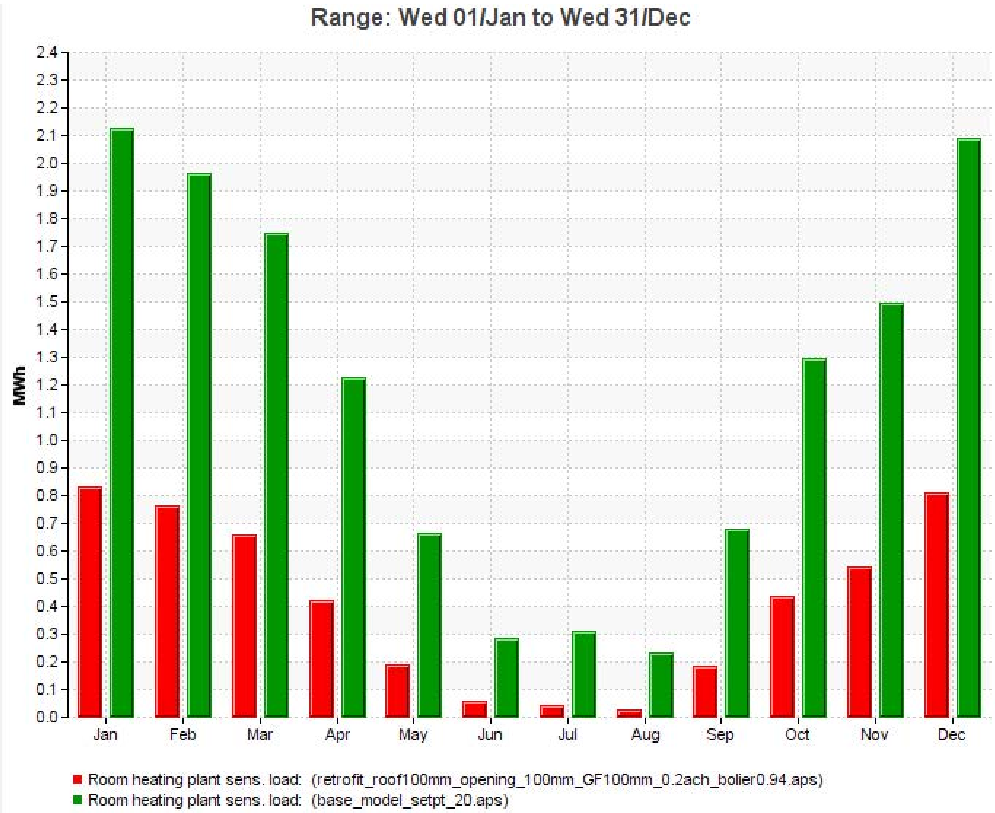


Figure 23 The effect of roof insulation, opening improvment, Wall insulations, Ground floor insulation, infiltration, and Boiler improvment improvment on the annual heating load.

· Air Temperature

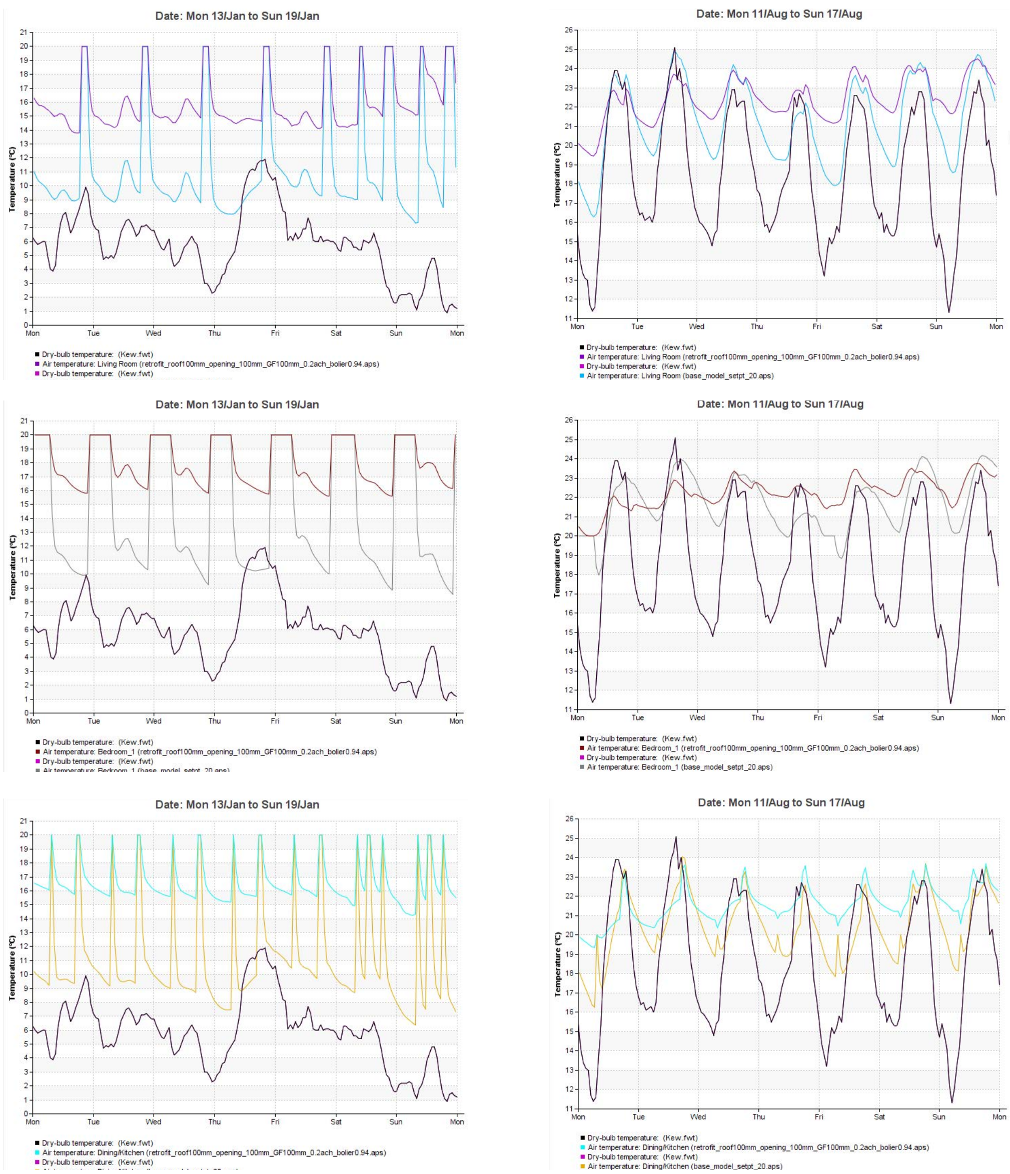


Figure 24 Air temperature of indoor spaces(Living room, Bedroom1, Dining/kitchen top to bottom respectively) affected by roof insulation, openings improvment, Wall insulation, Ground floor insulation, infiltration improvment and Boiler improvment .

- Annual Comfort (Living Room)

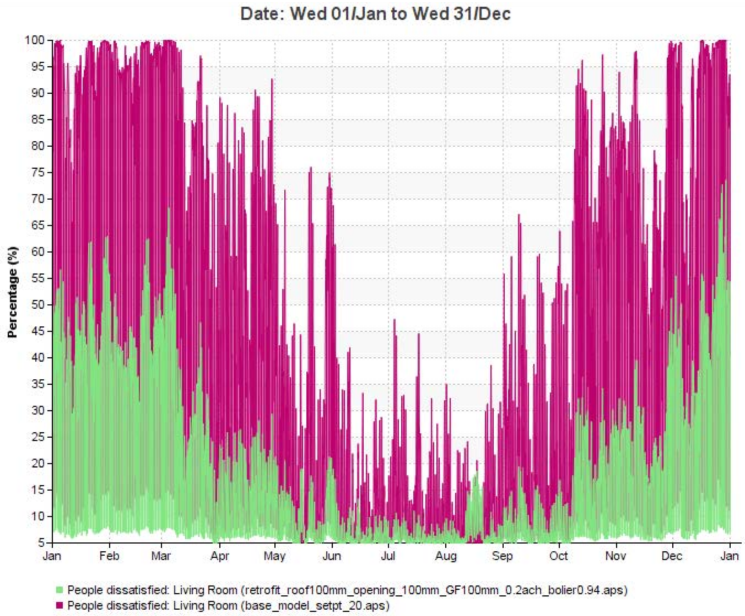


Figure 25 Living room annual comfort affected by full retrofit.

- Temperature over 25^{0}C

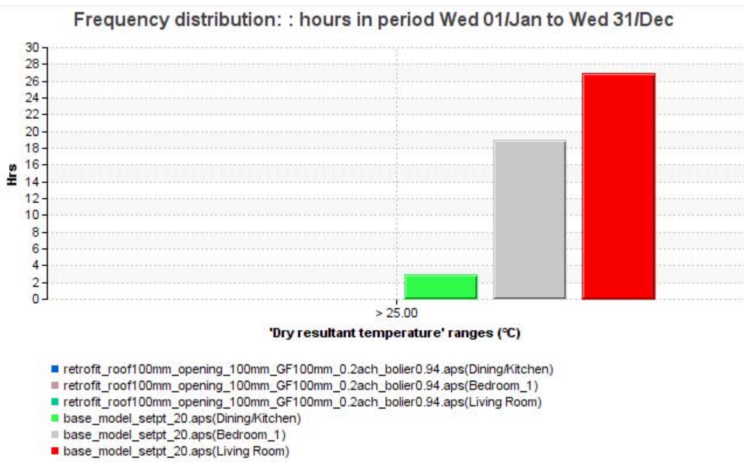
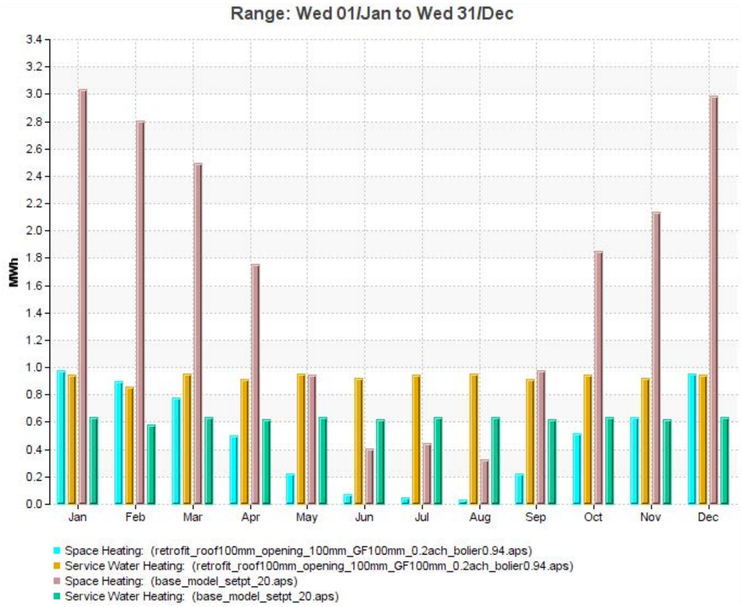


Figure 26 Temperature over 25 ^{0}C after full retrofit.

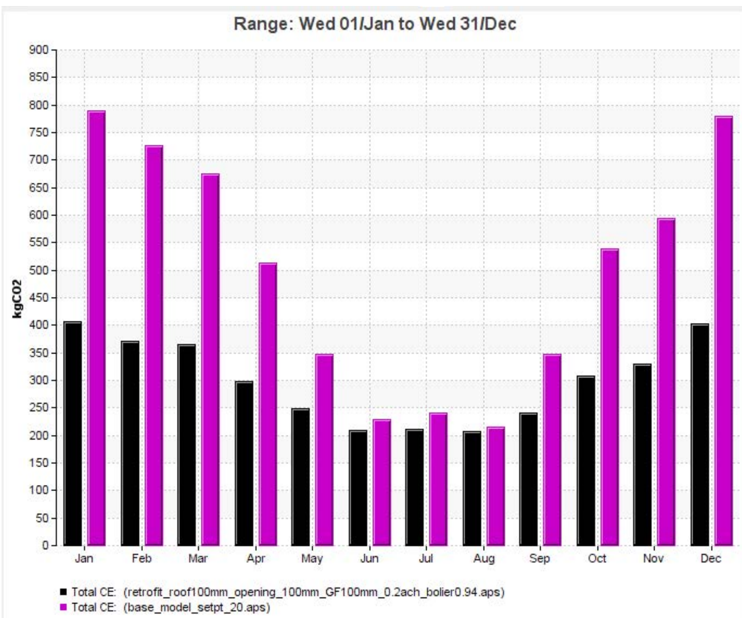
- ## Energy Breakdown Basemodel vs Retrofit

Figure 27 Energy breakdown comparisionof base model and full retrofit.



- ## Annual Carbon Emmision

Figure 28 Annual Carbon Emission comparision of base model and full retrofit.



· Effect of Annual Solar Gain

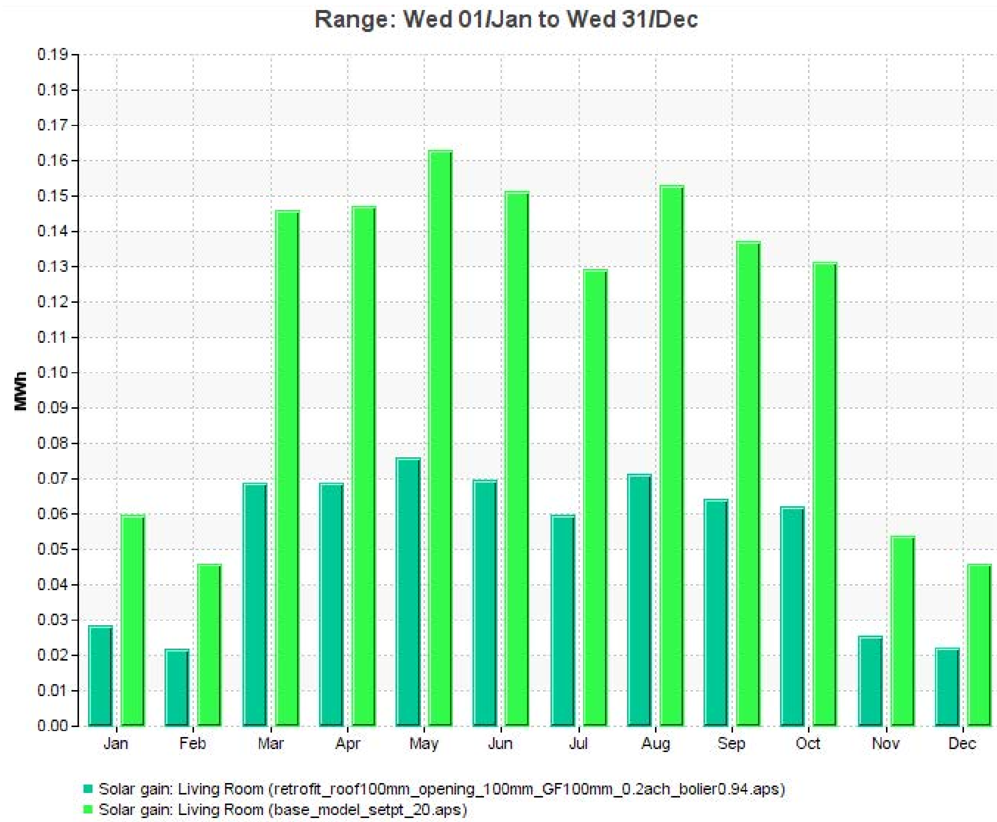


Figure 29 Effect of solar radiation comparision of base model and full retrofit.

5. Conclusion

This study validates that a phased retrofit combining roof, wall, floor, and opening insulation with increased airtightness can greatly increase the thermal efficiency of a historic Victorian end-terrace house. By around 60%, the integration of all interventions lowers peak winter heating demand from over 2.1 MWh in the base model to roughly slightly above 0.8 MWh in the fully retrofitted scenario (with very efficient boiler). Heating loads year-round were regularly dropped by more than 60%. Apart from energy savings, occupant comfort changed significantly; winter discontent rates dropped from over 90% to much below 50%. These results emphasise how decreasing energy use and improving indoor comfort in older homes depend on a complete building envelope approach.

6. References

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