SIMULATION OF DOMESTIC HEAT DEMAND SHIFTING THROUGH SHORT-TERM THERMAL STORAGE

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ABSTRACT

Heat demand management through demand shifting will be crucial to enable load balancing in a future electricity grid with large domestic heating loads.
Using dynamic models, in IES-VE and TRNSYS, of a 2-bedroom dwelling with typical operational schedules, this research demonstrated that a mixture of active and passive Thermal Energy Storage (TES) within the existing building infrastructure could enable up to 4 hours of heat demand shifting, without significantly affecting the indoor thermal comfort. However, this is strongly dependent on the building having very good thermal mass and performance to increase the TES effectiveness and decrease the thermal comfort degradation. The research provides a good starting point for developing more accurate models, which could enable greater understanding of the techno-economic feasibility of domestic scale TES, and the impact on the efficacy and benefits by variables such as household demography, building size, type and location.

INTRODUCTION

Climate change mitigation requires us to reduce our dependence on fossil fuel and increase the use of renewables. Mass uptake of these will lead to an energy system with a diverse energy generation mix, and greater electrification of the energy demand sectors. One effect of this is lower power quality due to the large-scale aggregation of energy from Renewable Energy Technologies (RET). Further, there would be large variability in electricity supply due to the intermittency in renewable generation such as wind power (ERP, 2011), (Hall, 2008). These are tough challenges, which will affect the security and resilience of the future energy system, and will need to be mitigated. In addition, the UK is legally bound to reduce its CO_2 emission by 80% by 2050, compared to the 1990 level (HM Government (2008). To meet this obligation, all energy demand sectors will need to be decarbonised by at least 80%, imposing additional constraints on the energy system.
The UK domestic building sector comprises of approximately 26 million homes, which are predominantly heated by natural gas. The sector is responsible for approximately 30% of the total CO_2 emission (HM Government, 2009). Therefore, considerable decarbonisation effort will be required in this sector, which adds to the challenges. An obvious solution to this is heating via decarbonised electricity, especially as heating (space and water heating) accounts for approximately 80% of the total energy use in domestic buildings (HM Government, 2009). Large scale deployment of heat pumps is predicted to provide the heating service needs, and predicted to attain over 50% penetration by 2030 and over 75% by 2050 (ERP, 2011). However, this will exert new challenges in the form of strong seasonal electricity demand variation. Furthermore, the daily peak to off-peak electricity demand could become unsustainable, as the heating systems switch on in the mornings and evenings, virtually all at the same time, creating disparity between peak and off-peak demands (ERP, 2011). Spreading the daily demand will require the heating systems to operate at different times. This is impractical without some form of Thermal Energy Storage (TES) capability in the dwellings, as the demand for heating is time linked. Successful deployment of effective TES is therefore critical to ensuring greater penetration of heat pumps, without which the domestic decarbonisation target could become unachievable.
The domestic building sector having over 13.7 million homes already fitted with hot water storage tank (ERP, 2011), presents us with a great opportunity to apply TES, to decouple the temporal link between the heating energy supply and demand, enabling the demand to be shifted in time. This will allow asynchronous management of the demand, providing options for mitigating the challenges.

Using dynamic building modelling and simulation, this research was intended to provide an insight into the energy performance and the thermal transient responses of a two bedroom detached property, during the months of January and February. It enabled the TES requirement to be analysed, indicating the levels of passive (high thermal mass building material retrofits) and active (hot water storage tank) storage necessary for achieving a 4-hour heat demand shift, from the period 6pm-10pm, to an off-peak period of 12am-7am. The model was used to identify the time and duration of the space temperature drop below a commonly acceptable level of 18°C, which is a key parameter that will affect the level of thermal comfort achievable (Yohanis et al., 2010), during the demand shift period.

The research provides a guide to developing more accurate and effective modelling of domestic scale TES, which could be used to assess the techno-economic feasibility and the effectiveness of TES application in domestic buildings.

METHODOLOGY

This study is based on a thermal energy performance-modelling case study of a detached dwelling located on Loughborough University campus. The dwelling is of standard brick construction and built to the 1990's building regulation standards. It was modelled in Integrated Environmental Solutions - Virtual Environment (IES-VE) and Transient System simulation program (TRNSYS). In each simulation tool, a 'Base Case' model as per the actual building construction was created. A further model, High Thermal Mass Case (Hi TM Case), was created with additional internal retrofits, which represented the building having high internal thermal mass and performance (see appendix A). Two occupancy schedules and a typical heating system operational schedule were used, to analyse the energy consumption and thermal performance of the building. A sensible TES system, in the form of a stratified cylindrical hot water storage tank, was added to the TRNSYS model to simulate thermal storage capability, which enabled heat demand shifting in time, from the electricity grid peak-time of 6pm to 10pm to between 12am and 7am.

Using two simulation applications meant that the model performance could be cross-checked, providing better accuracy and confidence in the modelling and the simulation process.

The building model

The 'Base Case' model was created (see figure 1) with the build and construction details extracted from the original drawings. Parameters, which were not present on the drawings, were based on the standard specifications of the 1990's building regulation requirements.

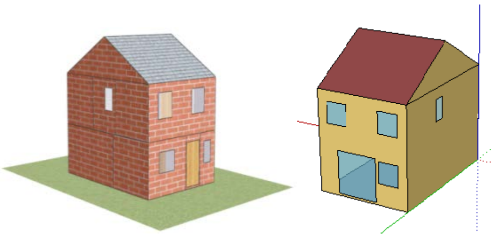

Figure 1. Screen shots of building model created in IES-VE and TRNSYS

Table 4 in Appendix A provides the building construction parameters used in the IES-VE models.

The underlined bold text highlight the building performance enhancing changes included in the Hi TM Case model. The air infiltration level was also reduced by 50% from 1 ACH to 0.5 ACH.

The TRNSYS models consisted of a Type-56 multi-zone building model adapted to include construction materials with identical or closely matching thermal and physical properties to those used in IES-VE, resulting in similar overall thermal characteristics. For example, the Base Case external wall representation in IES-VE and TRNSYS had overall U-values of 0.715 W/m^2K and 0.702 W/m^2K respectively.

IES-VE was used predominantly to carry out the transient thermal response analysis of the building, without active energy storage, essentially to validate the modelling process.

Model configuration and simulation control

The heating system in IES-VE was modelled within the ApacheHVAC modeller, as a water based central heating system with convector radiators, connected to a 20kW generic electrical heat source (see table 1). Proportional controllers were used to control the heating. The heating system also provided the domestic hot water.

The main TRNSYS heating system comprised of a hot water tank (Type-4) with internal auxiliary electrical resistance heating elements, connected to convector radiators (Type-1231) via a constant speed water pump (Type-36). ON/OFF controllers were used to control the water flow. The room temperature sensor/thermostat was set to provide 21°C dry-bulb temperature from 7am to 9pm and 4pm to 11pm.

The model was configured such that the space heating and domestic hot water needs were met by the main heating system during all periods except from 6pm to 10pm, during which they were met by the TES system (see figure 2).

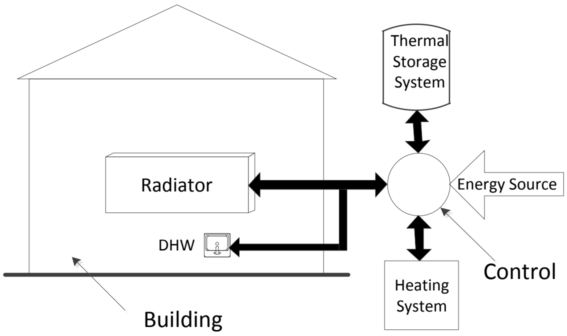

Figure 2. Model configuration block diagram (Thermal Storage System in TRNSYS model only)

The TES system comprised of a stratified cylindrical hot water storage tank (Type-4). Two tank volumes were considered, $1m^3$ and $2m^3$. Internal auxiliary electrical heating element, operating from 12am to 7am, provided the water heating, to a temperature of 95°C. Common radiators transferred heat into the space during the normal heating period as well as the demand shift period. Table 1 contains details of the key model parameters and the simulation configuration.

Table 1. Details of the occupancy schedules and other key model parameters.

Occupancy Type 1 **Adults:** No. of adults: 2 **% occupancy by time:** 80%:= 23.00 – 07.00 100%:= 07.00 - 09.00 50%:= 09.00-18.00 100%:= 18.00-23.00 **Child:** No. of children: 1 **% occupancy by time:** 80%:= 22.00 – 07.00 100%:= 07.00 - 08.00 0%:= 08.00-16.00 100%:= 18.00-22.00	**Internal gain** Cooking gain:= 200W Latent gain:20W Variation:= IES-VE mean TV gain:= 200W Latent gain:= 50W Variation: Occupancy related Lighting gain:=5W/m2 Variation:= IES-VE Average profile
Occupancy Type 2 Adults: No. of adults: 2 **% occupancy by time:** 50%:= 02.00 – 10.00 100%:= 10.00 - 16.00 50%:= 16.00-02.00	**Heating set point** Weekday ON:= 07:00-09.00 and 16.00-23.00 Temperature set point = 21°C
Infiltration Loft: 1 ACH continuously Room: 1 ACH continuously (Base Case) Room: 0.5 ACH continuously (Hi TM Case)	**People gain** Adult sensible gain: 90W Adult latent gain: 60W Child sensible gain: 70W Child latent gain: 80W
External door opening Closed all times (assumed insignificant)	**Weather data:** IES-VE: Nottingham (~15miles north of building site) TRNSYS: Sutton Bonnington (~5 miles north of building site)
Heating system (IES-VE) Water based central heating with 20kW generic electric water heater, 10kW Radiators, constant speed water pump.	**Heating system (TRNSYS)** Water based central heating comprising of hot water storage tank (Type 4) with 20kW heating element, 10kW Radiator (Type 1231), constant speed water pump
Simulation Period: 60 days from 1st January Time step: 1 minutes Data recording interval: 1 minutes	**TES system** Stratified hot water tank (Type-4) Size: 1m3 & 2m3

Two building occupancy schedules were used; 1) Occupancy Type 1- comprising of two adults (one working full-time day shift and one non-working) and one school age child, and 2) Occupancy Type 2 - based on two adults only, one working evening shift and one non-working. Occupancy was identical for both weekdays and weekends. It was assumed that for weekdays and weekends, there would not be a significant difference in the number of people occupying the building or the way it is heated during the 4-hour demand shift period. The internal gains comprised of lighting, cooking and a TV. The weather data used in TRNSYS and IES-VE are based on two locations; 1) approximately 5 miles north, and 2) approximately 15 miles north of the building location respectively. Simulations were performed for the months of January and February, when heating dominates the domestic energy consumption, creating extreme scenarios in terms of supply and demand. The simulation time resolution was 1 minute.

The actual heat energy delivered to the space was only used in calculating the heating energy consumption, ignoring the gains and losses associated with fluid transportation and storage.

RESULTS

Building transient response

There is considerable agreement between the output generated by the two applications for both the Base Case and Hi TM Case models, in terms of the building transient thermal performance and heat energy demand. Some differences were expected due to the different weather data and the slight variation in the building fabric models used in the two simulation packages.

The temperature drop at the end of the heating off period (18.00 to 22.00) varied between 9°C to 18°C. The daily heat energy required to achieve 21°C room temperature, as per the set point, were in the range 40kWh to 70kWh, and 45kWh to 80kWh for IES-VE and TRNSYS respectively.

During the heating-on period, it took approximately 30 minutes for the room temperature to reach 21°C for the Base Case and marginally less for the Hi TM Case. The rate of temperature drop is significantly high for the Base Case compared with that of the Hi TM Case, especially during the first hour after the heating switch off time (see figures 3). In the IES-VE example in figure 3, at the end of the four-hour demand shift period, the temperature dropped below 12°C for the Base Case and 17°C for the Hi TM Case.

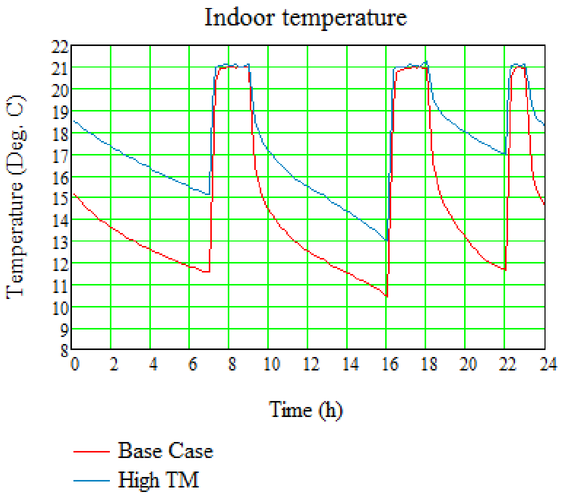

Figure 3. Example of the thermal response on 3rd January for the Base Case and Hi TM Case (IES-VE).

Figure 4 shows the heating load profile that ensures 21°C room temperature for the same example. The corresponding total energy demands are 68kWh and 58kWh for Base Case and Hi TM Case respectively. The energy used during the demand shift period is 24kWh and 13kWh respectively, which the TES system needs to supply.

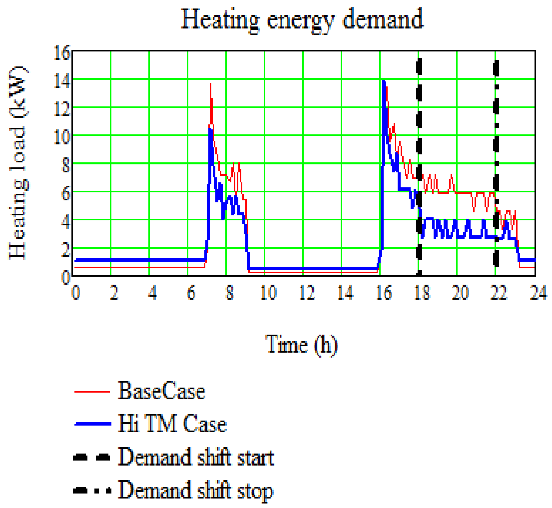

Figure 4. Example of the heating load for ensuring 21℃ room temperature on 3rd January for the Base Case and Hi TM Case (IES-VE).

Similar results were observed from the analysis carried out using the TRNSYS model as summarised in table 2. In the Base Case, the heat demand for the period 6-10pm varies from 12.08kWh to 22.69kWh. Occupancy type had very little impact on the minimum room temperature, and the hours the room remained below 18°C. However, in the Hi TM Case, the heat demand for the period 6-10pm varies from 5.96kWh to 11.37kWh, which is approximately 50% reduction from those of the Base Case.

Table 2. Summary of the TRNSYS Base Case and Hi TM Case thermal performance for the months of January and February (60 days).

BASE CASE				
Operational condition	Normal operational heat demand 6-10pm		Space condition without heat & TES between 6-10pm	
	Min (kWh)	Max (kWh)	No. of hours room Temp. < 18°C	Min. temp. (6pm-10pm) (°C)
Occupancy Type 1	12.08	21.72	234.1	9.8
Occupancy Type 2	13.05	22.69	234.6	9.3
HI TM CASE				
Occupancy Type 1	5.96	10.53	192.2	12.9
Occupancy Type 2	6.72	11.37	209.3	12.3

The minimum room temperature and the number of hours the room remained below 18°C, over the simulation period, improved significantly, from 9.8°C to 12.9°C and 234.6 hours to 192.2 hours respectively. These became slightly worse with occupancy type 2, indicating higher sensitivity in buildings with better thermal performance.

Impact of TES

The energy supplied by the two TES tank sizes to the building were 7.3kWh and 13.3kWh (see table 3), which were the maximum available from the systems. These remained the same throughout the simulation due to the higher demand for energy compared to that available from the TES tanks.

In the Base Case, the minimum room temperature between 6-10pm was 11.2°C and 10.7°C, for occupancy type 1 and 2 respectively (See Table 3). The room remained below 18°C for 199.5 hours with occupancy type 1, and slightly increased for occupancy type 2. Increasing the TES tank volume to 2m^3 had very little impact in increasing the minimum room temperature and in reducing the number of hours the temperature remained below 18°C.

In the Hi TM Case, significant improvement to the minimum room temperature and the hours the temperature remained below 18°C were observed. With a 1m^3 TES volume, the lowest room temperatures were 15.0°C and 14.4°C respectively for occupancy type 1 and type 2. Occupancy had a small impact in increasing the minimum room temperature, but a relatively large impact on the number of the hours the room remained below 18°C, increasing from 80.4 hours to 107.7 hours.

Table 3. Summary of the TRNSYS Base Case and Hi TM Case thermal performance with two sizes of TES tanks, for the months of January and February.

Operational condition	TES Energy $1m^3/2m^3$ (kWh)	No. of hours room Temp. < 18°C		Min. room temp. (6pm-10pm) (°C)	
		$1m^3$	$2m^3$	$1m^3$	$2m^3$
BASE CASE					
Occupancy Type 1	7.3 13.3	199.5	170.7	11.2	12.0
Occupancy Type 2	7.3 13.3	203.2	177.4	10.7	11.5
HI TM CASE					
Occupancy Type 1	7.3 13.3	80.4	25.6	15.0	16.1
Occupancy Type 2	7.3 13.2	107.7	46.0	14.4	15.5

Increasing the tank volume to $2m^3$ increased the room temperature to 16.1°C and 15.5°C respectively for occupancy type 1 and type 2. The largest impact was on reducing the room temperature falling below 18°C from 80.4 hours to 25.6 hours. Higher sensitivity of occupancy was visible with the room temperature falling below 18°C, rising from 25.6 hours for occupancy type 1 to 46.0 hours for occupancy type 2.

The spread of room temperature between 6pm to 10pm in the Base Case marginally improves with the addition of heat from the TES (see figure 5). The mean temperature increases from 14°C to 16°C. The graphs in figure 6 illustrate the percentage of time the room temperature remained at a certain temperature or higher. For example, for the Base Case with TES, the temperature remained at 18°C or higher for only 25% of the time, and only 4% of the time without TES (see figure 6).

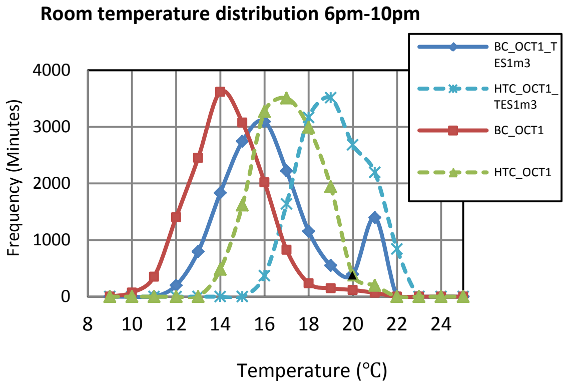

Figure 5. Minutely recorded room temperature distribution for January and February (60days) for the Base Case and Hi TM Case TRNSYS models with Occupancy Type 1 (OCT1), and with and without TES of $1m^3$ tank volume ($TES1m^3$).

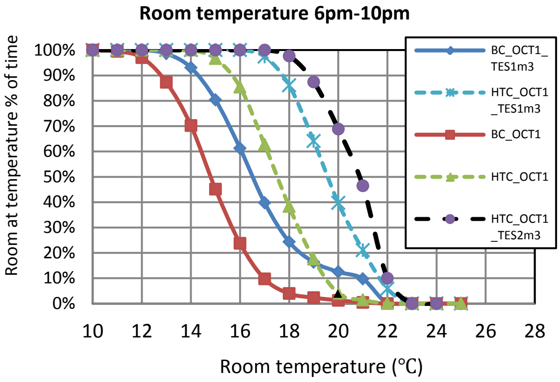

Figure 6. Room temperature duration as percentage of the demand shifting time, for January and February (60days) for the Base Case and Hi TM Case TRNSYS models, with Occupancy Type 1 (OCT1) and with and without TES of $1m^3$ tank volume ($TES1m^3$), and for Hi TM Case with Occupancy Type 1 and TES tank volume of $2m^3$.

In the Hi TM Case, the mean room temperature was over 17°C without TES and over 19°C with TES ($1m^2$) (see figure 5). The temperature remains at 18°C or higher for 86% of the time with TES and 38% of the time without TES (see figure 6), indicating a considerable improvement compared to that of the Base Case.

Increasing the TES tank volume to $2m^3$ increased the average Hi TM Case room temperature close to 20°C. The temperature remained at 18°C or higher for 98% of the demand shifting time period (see figure 6).

DISCUSSION

There is good correlation between the space temperature transients and the range of heat energy demands observed using the two applications, providing confidence that the models operated with a reasonable level of accuracy. The heat demand and the minimum room temperatures varied congruently with the external ambient temperature.

Ensuring good thermal performance is beneficial in terms of energy efficiency and energy saving. The simulations indicated a 15% overall reduction in heating energy resulting from the retrofits implemented in the Hi TM Case. More importantly, the results indicated a 46% reduction in the energy needed to be stored and demand shifted, which will ensure the same room temperature during the demand shift period. This is a factor that could impact the adaptation and feasibility of domestic scale TES, given the space restrictions in UK dwellings, and the potential cost implications.

The rate of space temperature increase during the heating up period is very similar for the two model cases. However, the rate of temperature drop in the

Hi TM Case, during the heating off period, is considerably less than the Base Case (figure 3). This is due to the improved building thermal performance and reduced infiltration resulting from the retrofits in the Hi TM Case.

There was relatively small impact on the space heating energy demand and the room temperature due to the differences in the type 1 and type 2 occupancy schedules, especially in the Base Case model with an inferior building thermal performance. However, with better building thermal performance, as in the Hi TM Case, the room temperature became more sensitive to the occupancy profiles. In the Hi TM Case, a marginal increase in the space temperature was observed with occupancy type 1, due to the additional internal gains from the extra occupiers during the demand shift period. DHW consumption is directly linked to the occupancy schedule, increasing the overall dwelling heat demand for occupancy type 1.

The room temperature between 6pm and 10pm in the Base Case model stays below 18°C for virtually the entire duration (Figure 5). It improves marginally with the use of the TES system, but remains short of that achieved in the Hi TM Case without TES (Figure 6). This demonstrated the importance of improving the thermal performance of the building, in order to ensure higher space temperature, which is critical to maintaining adequate thermal comfort level during the demand shift periods. In the Hi TM Case without TES, the room temperature remained at 18°C or higher for 38% of the time, whilst it increased to 86% when a 1m^3 hot water tank TES system was used. This demonstrated that a 4-hour heat demand shift is achievable without significant reduction in room temperature, using a 1m^3 hot water storage tank, supplying 7.3kWh of heat energy.

In the Base Case model, doubling the size of TES had very little impact in reducing the number of hours the room remained below 18°C. However, in the Hi TM Case, it reduced significantly from 80.4 hours to 25.6 hours. This indicates that a better building thermal performance is necessary to ensure effective utilisation of the TES capacity.

Further investigation is on-going as part of the author's research programme, exploring the potential imlications of parameter such as building size, type and location, wider range of building performance characteristics and internal gains, and larger and more variable building occupancy. Utilisation of different heat storage technologies such as latent and thermochemical storage are also on going, which is an important area of further research into domestic heat demand management and shifting.

This study has shown that a 4-hour heat demand shift is possible without significantly compromising the space temperature, and therefore the thermal comfort. However, a good building thermal performance is a pre-requisite, which is essential for ensuring the effectiveness of the TES. Furthermore, the building thermal performance will have a large role in deciding the practicality and uptake of domestic scale TES for heat demand shifting, in terms of size and cost. For a building with Hi TM Case level of thermal performance and occupancy type 1, a 2m^3 and 95°C hot water storage tank has been shown to be adequate, for ensuring a space temperature of 18°C for 98% of a 4-hour heat demand shift period. In reality, it will be mostly impractical and costly to have 2m^3 hot water tank in UK domestic buildings. To overcome this, latent heat storage using Phase Change Materials (PCM) can be used, which can store 5 to 14 times more heat per unit volume compared to that of sensible heat storage with water (Pinel et al., 2011). However, lower thermal conductivity of PCMs make them less suitable for applications where rapid heat transfer rate is needed (Huang et al., 2011), as would be the case in a dwelling with high heat loss (i.e. the Base Case). This can be avoided by reducing the heat loss rate (i.e. the Hi TM Case), enabling the use of smaller PCM based TES systems, with less complicated heat exchange and transport mechanism, therefore making them cheaper, cost effective and more practical for application in typical domestic buildings in the UK.

Further research following this study is investigating how TES impact and efficacy varies with different building size, type location and larger and more variable occupancy scenarios. A further research area is understanding the adverse impact on the electricity supply and distribution, which could result as a consequence of a wide-scale adaptation of TES in domestic buildings. For example, shifting heating load of the period 6pm-10pm to an off-peak time does not remove the initial peak demand occurring at 4pm (see figure 4), which could become unsustainable, in terms of generation capacity and distribution, if replicated throughout all the UK domestic buildings. In addition, the demand could peak unsustainably at 7am when the heating systems switch on for the morning heating period. Further, the current off-peak period (12am to 7am) may become the new peak period if the heat demand within the morning heating period and 6pm-10pm shifts to 12am to 7pm throughout all of the UK building stock. A solution to this might be to store heat in the TES during all times of low electricity demand from the grid. In addition, the release of the stored heat into the space could be combined with heating from the grid on demand, spreading the stored heat use over both of the heating periods

(7am-9am and 4pm-10pm) and replenishing the store when the grid load is low. This would mean shifting bulk of the heat demand to off-peak times and spreading the remaining demand over an extended demand shift period, resulting in a flattened heating load curve. The models developed in this study, with further enhancement, will enable exploration and understanding these scenarios, which is essential for formulating a viable future heat demand management strategy.

CONCLUSION

A 1990's two bedroom detached building with a standard and an improved building fabric parameter sets were modelled in IES-VE and TRNSYS. Simulations were carried out with two typical occupancy schedules, and the thermal transient responses and the heat energy consumption were analysed. Hot water tank based sensible TES system models were used to shift the heat demand from the period 6pm-10pm to an off-peak period of 12am-7am. The results indicated that a 4-hour heat demand shift is possible without significantly degrading thermal comfort. A 2m^3 hot water tank, storing water at 95°C, would maintain the room temperature at 18°C or higher during 98% of the demand shift period. A 1m^3 hot water storage tank would ensure 18°C or higher room temperature for 86% of the demand shift period. However, this is only achievable in buildings with high thermal mass and performance, without which the effectiveness of the TES system is not realized. Therefore, good building thermal performance is a pre-requisite for ensuring effective heat demand shifting using domestic scale TES.

ACKNOWLEDGEMENT

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APPENDIX A.

Table 4. Building fabric construction details used in the IES-VE Base Case and Hi TM Case models.

Parameter	**Base Case**	**High TM Case**
Ground Floor	0.01 Synthetic carpet 0.05 Rubber underlay 0.02 Timber flooring 0.30 Air gap 0.15 Cast concrete 0.15 Stone chipping 0.75 London clay U-Value = 1.39W/m^{2}K	0.01 Synthetic carpet 0.05 Rubber underlay 0.02 Timber flooring 0.10 Air gap **0.20 Light weight concrete** 0.15 Cast concrete 0.15 Stone chipping 0.75 London clay U-Value = 0.97W/m^{2}K
External Wall	0.100 Facing brick outer 0.058 Cavity insulation 0.150 Block inner skin 0.015 Plaster finish U-Value: 0.72 W/m^{2}K	0.100 Facing brick outer 0.058 Cavity insulation 0.150 Block inner skin 0.015 Plaster finish **0.05 EPS Slabs** **0.15 Gypsum plaster** U-Value = 0.33 W/m^{2}K
Internal Partition Walls	0.150 Gypsum plasterboard 0.100 Cavity 0.150 Gypsum plasterboard U-value = 1.59W/m^{2}K	**0.015 Gypsum plasterboard** **0.050 EPS slabs** 0.150 plaster on both sides 0.100 Cavity 0.150 plaster on both sides **0.050 EPS slabs** **0.0150 Gypsum plasterboard** U-value = 0.277W/m^{2}K
Roof	0.025 Slate tiles 0.01 Ashfelt U-value = 4.87W/m^{2}K	0.025 Slate tiles 0.01 Ashfelt U-value = 4.87W/m^{2}K
External Windows PVC	Double glazed 0.006 Pilkington glass 0.012 Cavity 0.006 Pilkington glass U-value = 1.98 W/m^{2}K	**Triple glazed** 0.006 Pilkington glass 0.012 Cavity 0.006 Pilkington glass 0.012 Cavity 0.006 Pilkington glass U-value = 1.41 W/m^{2}K
Internal Doors	0.04 plywood U-value = 2.29 W/m^{2}K	0.047 plywood U-value = 2.29 W/m^{2}K
External Doors	0.047 Oak door U-value = 2.55 W/m^{2}K	0.047 Oak door U-value = 2.55 W/m^{2}K
FF floor/GF ceiling	0.01 Synthetic carpet 0.05 Rubber underlay 0.02 Timber flooring 0.300 Cavity 0.150 Gypsum plasterboard U-value = 1.28 W/m^{2}K	0.01 Synthetic carpet 0.05 Rubber underlay 0.02 Timber flooring 0.300 Cavity 0.150 Gypsum plasterboard **0.150 Gypsum plasterboard** U-value = 1.08 W/m^{2}K
Loft floor/FF ceiling	0.170 Insulation 0.150 Gypsum plasterboard U-value = 0.22 W/m^{2}K	**0.270 Insulation** 0.150 Gypsum plasterboard **0.150 Gypsum plasterboard** U-value = 0.136 W/m^{2}K