DYNAMIC SIMULATION OF THERMAL CAPACITY AND CHARGING/ DISCHARGING PERFORMANCE FOR SENSIBLE HEAT STORAGE IN BUILDING WALL MASS

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ABSTRACT

The potential for utilization of the building mass thermal capacity for demand side management in the residential sector is addressed. A three apartment residential houses made of massive brick, equipped with a heat pump is modeled and its thermal behavior is simulated. It is shown that thermal storage capacity of the building can indeed contribute considerably to residential demand side management activities. Even after heating periods as short as two hours the heating demand for the following four hours can be reduced by almost 20 %. The slow temperature increase within the thermal mass and the heat conduction into deeper wall layers are thereby the main limiting factors.

INTRODUCTION

Hand in hand with the increasing installation of renewable non dispatchable energy generation, the challenge of matching electricity production and consumption arises. Heating in residential and commercial buildings accounts for up to 30 % of Germanys end energy consumption (BMWi, 2011) and could therefore potentially play a role in providing flexibility to balance fluctuating electricity availability. Within the scope of the Dual Demand Side Management (2DSM) concept (Molitor, C. et al., 2012) a holistic approach is developed to manage the energy demand (i.e. electrical and thermal) on city quarter level.

One of the focus areas within 2DSM is the analysis of thermal energy storage in buildings, intending to store excess electrical as thermal energy whenever available (i.e. through heat pumps) and reduce the buildings' demand for electricity in periods of peak load while substituting fossil fuels usually used for heating purposes. Besides of the well-developed thermal storage technology based on hot water tanks the inherent thermal storage capacity of buildings, attributable to the mass and thermal capacity of the used construction materials, is analyzed. This thermal capacity is available in every building at no cost and besides of integration of a suitable heating system it requires no structural alteration to the existing building. This makes the approach particularly attractive for the massive buildings in the existing building stock.

The existing pricing schemes for electricity in Germany are either not time dependent or provide a lower price for electricity consumption at night (STAWAG, 2013). This was for example widely used to operate electrical night storage heating systems, by loading a solid thermal mass or heating a water tank. However, heating the building itself would be in conflict with the thermal comfort of the residents, who generally prefer lower temperatures while sleeping (Peeters, L., 2009). Nevertheless, it is known that during summer in non-residential buildings the lower electricity price was used to pre-cool the building, reducing the power demand for air conditioning during daytime (Artmann, N., 2007; Kolokotroni, M., 1998). Since it is expected that the rising share of renewable electricity generation will lead to dynamic pricing schemes, only dependent on actual availability and demand, low price phases can occur at any time throughout the day. Thus, pre-heating or even overheating a residential building to load its thermal wall mass while it is not occupied could provide additional storage capacity, especially in winter time.

The existing considerations of the impact of differentiated heating phases in buildings were either oriented towards cooling or towards the oscillating effect of periodic temperature reduction at night or during absence of residents (Braun, J., 1990; Kolokotroni, M., 1998; Artmann, N., 2007). In contrast, this analysis examines in detail the effects of one single heating pulse brought into the building. Based on that pulse an assessment of the amount of energy, which can be stored and reclaimed from the buildings mass, is performed. Furthermore, it is examined how the availability of that capacity varies with changing ambient temperature and different timeframes for the heating periods of the building.

The basis for this approach is a simulation of thermal building behavior in Dymola/ Modelica (Modelica Association et al., 2012) combined with a detailed simulation of the electric grid in Neplan (BCP Busarello + Cott + Partner AG, 2012). The simulations are coupled and exchange required variables for every simulated time step, thus allowing to balance energy demand and availability.

In the next section the approach is presented explaining the chosen simulation scenario and the modelled object of analysis. Afterwards the used thermal building model and the modelled heating system are presented and the suitability for the performed simulations is shown based on two validation scenarios. In the next section the simulation results are presented followed by the discussion of the outcomes and a concluding summary of the found thermal building behaviour.

APPROACH

The analysis of the thermal capacity is based on the thermal model of an existing three apartment house build in 1964 and located within the project region of 2DSM in Bottrop, Germany. For this exemplary building it is evaluated how much thermal energy can be stored in the wall mass, by lifting the set temperature of the heat pump based heating system by few degrees for a short period of time. Therefore, the house is modeled in Modelica, based on our institutes' library of building components. The dynamic simulation of the thermal behavior is than performed in Dymola. In the following the simulation scenario is introduced and the key data of the analyzed building are presented.

Simulation scenario

Thermal behavior of a building is a very complex mechanism, which is strongly influenced by the thermal capacity of the building mass. However, within the regular operation of the building the resulting thermal effects that are influenced by the stored heat are hard to distinguish. Usually, only distinct sudden changes in ambient temperature reveal the extent of that capacity. To isolate the effect of thermal storage in building wall mass from other thermal effects within the building a special simulation scenario is created and some basic assumptions are made.

The amount of radiation entering the thermal zone through the windows is very volatile and can bring a huge amount of energy into the building within a short time. In passive solar design, it is assumed that on a sunny day each square meter of window area on the south facade can bring up to 1 kWh of thermal energy into the building (Eicker U., 2012). Thus, taking this effect into account would make it impossible to isolate the thermal storage effects, which in comparison would cause rather small heat flows. Therefore the effect of long wave solar radiation is excluded.

Furthermore, it is assumed that except for the heating and supply system the building is empty, meaning that neither furniture nor other components with a thermal mass are considered. The choice of interior construction, furnishing, flooring etc. would allow for countless combinations of components with significant thermal mass and influence upon thermal resistance if positioned in contact with wall and floor layers. Therefore, to evaluate the general potential of thermal storage within the wall mass such components are omitted.

The initial air temperature within the building is set to 20 °C. To enable the usage of the total thermal comfort band for the heat storage process that initial air temperature was chosen at the lowest still acceptable comfort limits according to DIN V 18599 – 10 (DIN, 2011) and (Peeters, L., 2009). For the base scenario the ambient temperature and the wind speed are assumed to be constant during the simulation period at 0 °C and 4 m/s respectively, thus corresponding approx. to an average winter day in Germany (DWD, 2012). The temperature of the soil under the building is assumed to be constant at 10 °C (DIN, 2008 /2). Only such stable ambient conditions allow inducing a constant heat flow from the building to the outside. This makes it possible to recognize the changes in heat loss caused by the heat storing activities. Variations of ambient temperature, however, will be additionally performed to compare the storage potential at various conditions.

The simulation is then run under constant thermal conditions for one week making sure that a steady state with constant wall temperatures is reached. Afterwards an overheating phase of the building is started. Within that phase the building's heating system will be set to lift the indoor temperature to higher temperatures for a given time frame. In accordance with the concept of using excess renewable electricity from short-term production peaks, the overheating phase in the base scenario will be set to two hours. Following the overheating phase the temperature set point is reduced to the base value and the simulation is continued for another week under stable conditions. Within that cool down phase special attention will be given to the time frame of one day directly after overheating, since it is intended to observe short term heat storage results.

Analysis of first dynamic simulations results have shown that after overheating an additional hour is required before the cool down phase starts. Within that time the heat stored in the distribution system and the air volume is also transferred into the buildings thermal mass. Therefore, overheating time is balanced as heating time and one additional hour. The cool down is than measured for the subsequent 24 hours.

Keeping indoor comfort in mind it is observed which temperatures are reached by the chosen heating system and which overheating timeframes are suitable to realize considerable storage effects. Furthermore, the storage effect is analyzed in detail, examining how much reduction of heating demand is achieved in the cool down phase. Finally, the storage efficiency of the wall mass is evaluated.

Object of analysis

The analyzed building comprises approx. 350 m of heated living area divided into three apartments. The building material is assumed to be massive brick with gypsum plaster on the inside and lime plaster on the outside. Ceilings and floor slab are made of concrete with a screed layer on top and an additional layer of mineral wool in the floor slab. The roof is made of rafter, peat fiber and a layer of mineral wool, with lime plaster on the inside and roof tile on top. The properties of the main materials are given in table 1.

Table 1
Properties of main materials

component	main material	thickness	λ	capacity	surface
		d: $[m]$	$[\frac{W}{m\,K}]$	c: $[\frac{J}{kg\,K}]$	A: $[m^2]$
inner walls (bearing)	massive brick	0.24	0.81	900	186.875
inner walls (other)	massive brick	0.15	0.81	900	536.25
inner ceilings	concrete	0.2	2	1000	759
outer walls	massive brick	0.365	0.81	900	256.5
floor slab	concrete	0.25	2	1000	126.5
roof	peat fiber rafter	0,045 0,14	0,09 0,14	1200 1600	123.2
inner plaster	gypsum	0.015	0.4	1000	1482.325
outer plaster	lime	0.02	0.8	1000	379.7
isolation (roof/ floor slab)	mineral wool	0.04	0.04	1030	249.7
screed	screed	0.05	1.4	1000	524.625
windows	glas	0.04	U-Value: 1,3		123.2
air volume	air	V≈1200 m	0.0262	1007	

As a reference value, the total static thermal capacity of the building is calculated to approx. 175 kWh/K. However, that assumes that all layers of the building will be heated equally by 1 K. This static value can be seen as a benchmark as to which part of the total thermal building capacity is being used in a given scenario. Still, a credible capacity can be only reached through dynamic analysis.

According to the calculations in DIN EN 12831 the simulated building has a design heat load of approx. 25 kW (DIN, 2003 /2). Within this simulation the building is equipped with a heating system composed of an air-water heat pump (HP) with 30 kW nominal- and 40 kW peak-power. Typically a HP heating system is not designed to cover the total thermal demand as a standalone system and is usually combined with a peak-load boiler. However, in this case the HP is dimensioned for standalone operation, to adapt the system with the intended process of storing excess renewable electricity generation within the buildings thermal mass. Furthermore, a traditional radiator system was chosen, since this is the most widespread technology for heat delivery within residential buildings.

It is assumed that within the overheating and cool down no ventilation activities are performed. Nevertheless, air infiltration of the building, which is calculated according to DIN EN 12831, is taken into account (DIN, 2003 /2). Assuming an n_{50} value of 3 /h air infiltration is approx. 0.1 /h.

MODELLING

Thermal Building Model

For the building model all thermal components with different materials properties or ambient conditions are modelled separately. However, all thermal masses with identical structure and surrounding conditions are aggregated. That allows to represent the thermal model with nine thermal components within the building and two external thermal boundary conditions which are presented in table 2.

Table 2
Thermal components of the model

thermal component	thermal connections
inner walls (bearing)	convection & thermal radiation
other inner walls	convection & thermal radiation
inner ceilings	convection & thermal radiation
outer walls	convection & thermal radiation
floor slab	convection & thermal radiation
roof	convection & thermal radiation
windows	convection & thermal radiation
radiators	convection & thermal radiation
inside air volume	convection
outside air	convection (wind speed of 4 m/ s)
soil under the building	thermal conduction

All elements of the building's thermal mass and the radiators are connected with the indoor air volume through convection and with each other through thermal radiation. The building connects to the environment through convection at outer walls and roof, each assuming a wind speed of 4 m/s. Furthermore, the floor slab of the building connects through thermal conduction with the soil under the building. The coefficient of heat transfer α is dynamically calculated within the simulation (DIN, 2008; Glück, B., 1999). On the inside of the building this results in α values of 1.5 – 3.0 $\mathrm{W/(m^2 \cdot K)}$, while on the outside α is constantly 20 $\mathrm{W/(m^2 \cdot K)}$.

For every type of heat transfer between the building's thermal mass, the air volume and the environment the heat flow is determined. Additionally, for the overheating and cool down phase heat flow balances are computed to determine which amount of the heating energy could be stored and later reclaimed.

$$Q_{wall.i} = \sum_t \left(\dot{Q}_{conv,i} + \dot{Q}_{rad,i}\right) \quad (1)$$

To get more insight into the thermal activation process of the thermal mass every element of the building material was discretised into layers of 5 mm thickness. Dynamic heat conduction and capacity are calculated separately for every layer, thus allowing for detailed insight into the temperature profiles and the resulting storage capacity within the thermal mass.

Heating system

A hydraulic radiator based heating system is modelled. This type of heating system is commonly used in Europe and will be the most important case available for the described management of energy storage in building structures.

The supply system consists of a monovalent air/water HP unit and pumps for the HP and the consumer circuit as well as simple pressure loss models to represent the connecting piping network. In this simple HP model table based manufacturer data is used to model the HP's characteristic. This model derives the condenser's thermal power and the unit's electrical power from the condenser and evaporator temperature and a load factor. The HP's thermal power output is continuously controllable so that a given set point temperature can be reached. The flow temperature set point depends on the outside air temperature which is constant during an experiment as previously described.

The consumer part consists of similar radiators with thermostatic valves. Radiators are discretized in vertical direction. Each section consists of a water volume and a metallic wall which is sized according to manufacturer data. The model is based on the work of Tritschler (1999) and shows a good dynamic behaviour. The consumer system is designed for temperatures $T_{flow}/T_{return}/T_{room\ air}$ = 70/50/20 °C. Additionally, a safety factor of 1.3 for the radiator size is assumed. According to the radiator size the appropriate thermostatic valve is selected to achieve a valve authority of about 0.5 and the proportionality range is 2 K. The set point temperature of the thermostatic valve will be changed to raise the room air temperature during the experiments as explained earlier in the section "simulation scenario".

VALIDATION

A dynamic validation of the transient thermal behaviour without solar gains is performed according to the 'Exercise 1' of the EMPA (the Swiss Federal Laboratories for Material Testing and Research) test arrangement. This test was developed for evaluating the performance of building energy simulation codes (Manz, H. et al., 2006). The EMPA experimental setup consists of an outdoor test cell that is designed for calorimetric measurements. This setup delivers accurate experimental data that can be used for validation of building energy simulations. This mainly includes the test cells' heat input, the air change rate, the thermo physical and geometrical properties, and the thermal performance of the cell.

For the validation the test cells' structure is implemented in our model and the thermal performance of the cell is simulated and compared with the provided experimental data. The comparison results are shown in the lower diagram in figure 1 along with the underlying heat input profile.

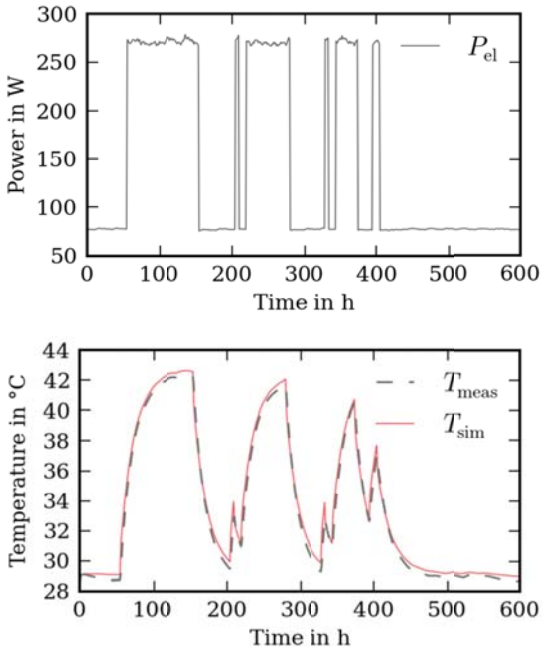

Figure 1 a) Heat input profile (top) b) Comparison between the simulated and the measured mean cell air temperature (bottom)

The results are evaluated by calculating an average absolute difference and a root mean squared difference D_{rms}. The values are 0.28 K and 0.4 K respectively. The average absolute difference indicates the overall magnitude of the difference between the experiment and the simulation results. In the root mean squared difference, larger deviations are stronger weighted:

$$D_{rms} = \sqrt{\frac{1}{n}\sum_{i=n}^{n} D_i^2} \quad (2)$$

The results show that the simulation model successfully reproduces the experiment profile. Thus, the results of the thermal model are precise enough to guarantee accurate reproduction of thermal behaviour of the building wall mass.

Having validated the dynamic behaviour of the model now the thermal capacity of the building model is evaluated through the dynamic simulation of a single cool down process. For every layer of the entire building mass the initial temperature is set to 25 °C while all other temperatures are set to 20 °C. Simulation is than run until all layers of the building reach 20 °C and the released energy is determined. This value is compared with the calculated static thermal mass introduced in the approach section. Based on this calculation, the building's thermal capacity for an 5 K temperature spread amounts to:

$$175\ \mathrm{kWh/K} \cdot 5\ \mathrm{K} = 875\ \mathrm{kWh} \quad (3)$$

The simulation of the cool down process showed that the building has released 880 kWh to the environment.

The deviation of approx. 0.5 %. can be traced back to marginal differences in the material properties used in the analytical and simulation assessments. Hence, the static capacity of the model reproduces the reality accurately.

SIMULATION RESULTS

First, the thermal behaviour of the modelled building in steady state is analysed. With the given conditions of 0 °C ambient and 20 °C indoor air temperature the buildings heat losses and equally the heating demand are approx. 10 750 W, of these 9 780 W due to convection and 970 W due to air infiltration. This results in an energy consumption of approx. 1807 kWh per week. Thus, according to the static capacity calculation presented before, even heating the entire building mass by one degree only provides enough energy for approx. 16 hours.

$$\frac{(175\ \text{kWh/K}\cdot 1\ \text{K})}{10.755\ \text{kW}} = 16.3\ \text{h} \qquad (4)$$

Still, this neglects that heat stored on the outer layers of the building is unloaded much faster than those 10.75 kW, which have to pass all wall layers. Performed dynamic simulation shows that in fact charging the entire building mass by one degree only provides enough energy for 12 hours without heating.

Overheating phase

Due to the used proportional controller, the simulated indoor air temperature is almost more than 1 K higher than the set temperature. To reduce this offset the set temperature is reduced until in steady state an indoor air temperature of approx. 20 °C is reached. The resulting simulation condition is an indoor air temperature of 19.8 °C and operative temperature of 19 °C. Within the overheating phase air temperature is supposed to reach 25 °C, however due to the short overheating phase, only 24.5 °C is reached. This results in an operative temperature of 22 °C. Once the overheating is finished, it takes another hour for the air mass to cool down to the initial state. The average temperature within the whole phase of overheating and one-hour stabilization phase is approx. 22.7 °C (figure 2).

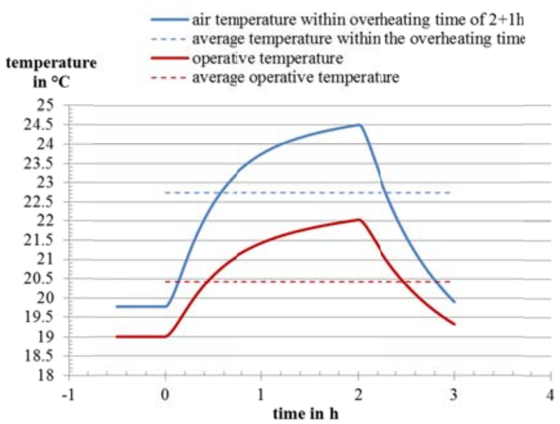

Figure 2 Air and operative temperatures

Accountable for the storage of energy within the building is the temperature rise, which is reached in the wall mass. Influenced by the presented air temperature rise the following changes in wall mass temperatures are reached in the simulation. The outer wall temperature (figure 3) changes within the first 0.11 m from the inside, which is one fourth of the total wall thickness. The average temperature rise within these first layers is approx. 0.4 K. The temperatures of inner walls change along the whole thickness, while the average temperature rise is 0.4 K for the load bearing walls and 0.6 K for the non-bearing walls (figure 4). Also, figure 4 shows, that the stored head is quickly transferred into deeper wall layers, resulting in lower wall surface temperatures and slower discharging of the stored energy.

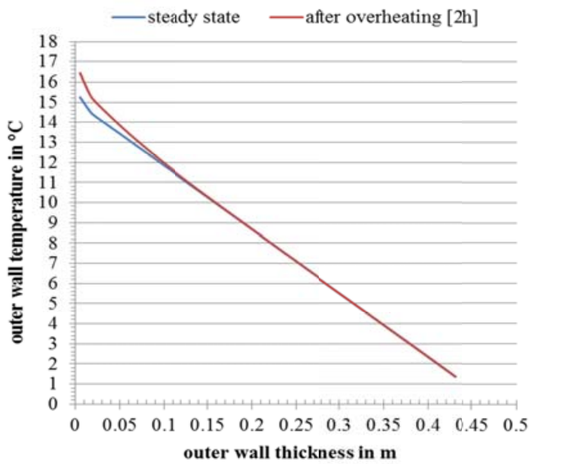

Figure 3 Temperature profile within the outer wall

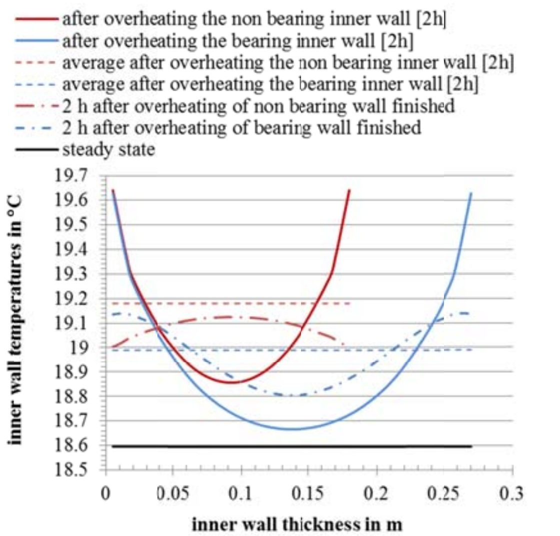

Figure 4 Temperature profiles within inner walls

Cool down and thermal capacity

Within the simulation of the base scenario the heating system generates 79 kWh. One hour after the overheating the total energy input is either consumed by the regular heat loss or stored in the buildings wall mass (figure 5).

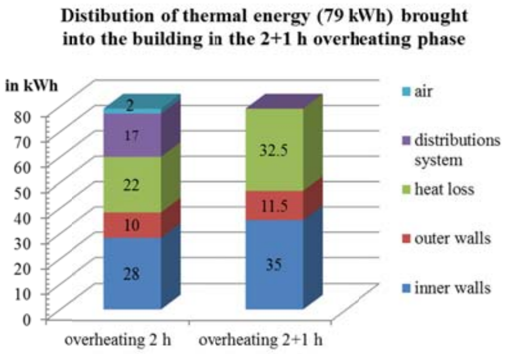

Figure 5 Heat distribution after overheating

The following cool down process shows that the energy flow from the wall mass cannot uphold the desired room temperature. Still it can support the heating system with a considerable amount of energy. For the first two hours of the cool down phase the wall mass supplies over 25 % of the total energy demand for the building. For the time scope of four hours still almost 20 % are provided. After 24 hours the wall mass unloaded approx. 66 % of the stored energy while providing on average 10 % of the energy demand for the whole day (figure 6).

After the first 24 hours, the outer wall is not providing a considerable amount of energy anymore. The 6 kWh difference between the loaded energy of 11.5 kWh and the reclaimed 5.5 kWh is the additional heat loss due to overheating the building. Accordingly in the simulated week with an overheating pulse the HP needed to generate 6 kWh more heat as compared to a week in steady state.

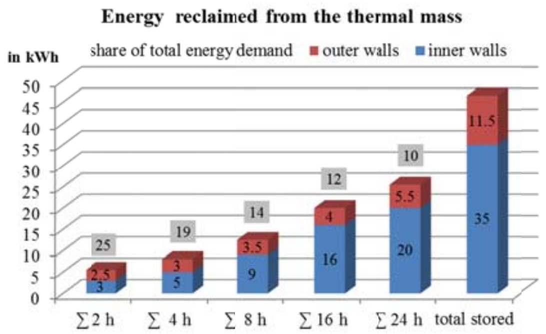

Figure 6 Cool down of the thermal mass

Since the stored heat is conducted into deeper wall layers it takes another 2.5 days until 90 % of the stored energy are uncharged. However, resulting heat flows are very small and not sufficient for a planned demand shift. Nevertheless, besides of the loss of 6 kWh, by the end of the second simulation week all other energy is reclaimed from the wall mass. Thus, 38.5 out of 44.5 kWh were recovered, which corresponds to a storage efficiency of approx. 87 %.

In order to test the sensitivity of the thermal storage process upon changing conditions, the same analysis was performed for changing ambient temperatures (table 3) and for different overheating times (table 4).

Also, the temperature profiles of the inner walls for an overheating time of 6 hours are given in figure 7.

Table 3
Thermal behavior of the building for different ambient temperatures

		ambient temperature		
		-5 °C	0 °C	5 °C
inner wall in kWh		27.5	35	38.5
outer wall in kWh		9	11.5	13
total in kWh		36.5	46.5	51.5
share of total heating energy demand in %	for 2h	15	25	26.5
	for 4h	12	19	24
	for 8h	9.5	14	19.5
	for 16h	7.5	12	15.5
	for 24h	6	10	13
recovered energy within 24 h in kWh / %		20 / 68	25.5 / 63	26.5 / 55
total energy stored & recovered in kWh		29.5	40.5	48
recovered energy as share of daily energy demand in		11%	16%	19%
		≈ 3 h	≈ 4 h	≈ 4.5 h
efficiency		≈ 80 %	≈ 87 %	≈ 93 %

Table 4
Thermal behavior of the building for different overheating times

		overheating time		
		2h	3h	6h
inner wall in kWh		35	54.5	113.5
outer wall in kWh		11.5	17.5	35
total in kWh		46.5	72	148.5
share of total heating energy demand in %	for 2h	25	30	45
	for 4h	19	25	43
	for 8h	14	21	38
	for 16h	12	17	32
	for 24h	10	15	28
recovered energy within 24 h in kWh / %		25.5 / 63	38 / 61	74 / 59
total energy stored & recovered in kWh		40.5	62.5	126
recovered energy as share of daily energy demand in		16%	24%	49%
		≈ 4 h	≈ 6 h	≈ 12 h
efficiency		≈ 87 %	≈ 86 %	≈ 85 %

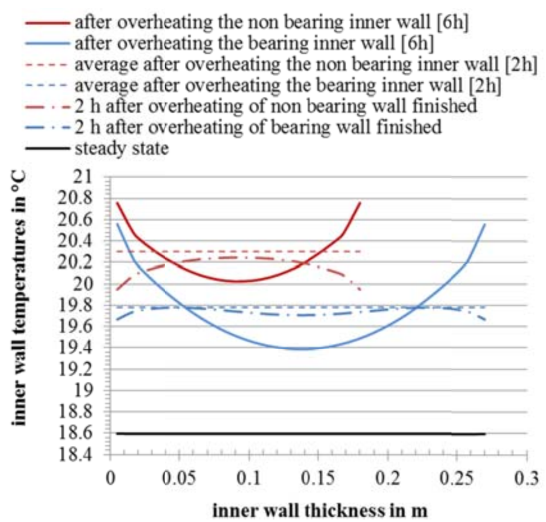

Figure 7 Temperature profiles within inner walls

DISCUSSION

Temperatures

The chosen minimum temperature of 20 °C results in an operative temperature of approx. 19 °C which according to (Peeters, L., 2009) is still acceptable for approx. 65 % of the occupants for an ambient temperature of 0 °C. Furthermore, an overheating phase would potentially be used to preheat the building before the residents come home. Taking this into account the low initial temperature corresponds well to a temperature setback for the time the building is unoccupied.

The reached upper temperature of 24.5 °C corresponds to an operative temperature of 22 °C, which is acceptable for more than 90 % of occupants (Peeters, L., 2009). Even if the desired 25 °C is reached, operative temperatures stay at a comfortable level. However overheating temperatures should not become much higher due to the increasing difference between air and operative temperature, which is usually recognized as uncomfortable by occupants.

Due to the rise of wall temperatures after the overheating phase the operative temperature decreases slower than the air temperature. Therefore, when the initial air temperature is reached again, the operative temperature is still at a level acceptable for more than 80 % of the occupants.

Storage in thermal mass

Already the static analysis for that un-insulated massive brick building shows that even if theoretically charging the total thermal mass of the building by one degree it delivers only enough energy to compensate the heat losses for 16 hours.

Nevertheless, even in the base scenario with only two hours overheating time an energy amount corresponding to the building's total heat demand for approx. four hours could be stored. For an overheating time of 6 hours even energy corresponding to almost a half day's energy demand could be stored. This is mainly influenced by the much stronger temperature increase within the inner walls. However, due to heat conduction into deeper wall layers and the slow temperature increase of the heated building mass, the walls cannot deliver the stored heat at the required rate.

Thus it can be seen that while the magnitude of energy, which can be stored in building mass, is considerable the rate of heat transfer is not sufficient to substitute the heating system. Rather the stored energy can reduce the residual heating load for a given timeframe. For such application, however, the building mass delivers good performance. After just an overheating time of 2 hours the buildings thermal demand is reduced by almost 20 % for a timeframe of four hours at an ambient temperature of 0 °C. For comparison, it would require a 350 l water buffer tank with a temperature difference of approx. 20 °C to store the same amount of energy. The energy released by the wall mass within the next 24 hours after overheating still covers 10 % of the total 24h energy demand of the building. For overheating times of up to 6 h the capacity could be almost tripled. Still, longer overheating times cause heat transfer into deeper layers of the inner wall mass, thus leading to longer discharging times and less controllable Demand Side Management (DSM). Storage efficiency was 87 % for the base scenario and going only slightly down for longer overheating times due to higher heat losses with raised indoor temperature.

For varying ambient temperatures the storage performance changes distinctly. Due to higher heat losses at lower ambient temperatures the installed system fails to reach the desired overheating temperature. With an ambient temperature of -5 °C this reduces the thermal storage capacity by over 20 % as compared to the base scenario. Also the storage efficiency goes down, since the larger temperature spread between inside and outside causes heat stored in the outer wall to be lost before it can be discharged. For even lower ambient temperatures the heating system could not provide enough heat to charge the walls considerably.

For higher temperature, lower heat losses to the ambient allow for a larger storage capacity and higher efficiencies. However, the due to the lower heat losses indoor temperature rises quicker and falls slower thus, bringing more energy into deeper layers of the wall mass. This results in extended discharging times of the wall mass. For an ambient temperature of 5 °C already 13 % less energy is discharged on the first day after overheating. In simulations with higher ambient temperatures the heat pump control reduced the flow temperature to such extent that desired overheating temperatures could not be reached anymore. Thus, such ambient temperature controlled mechanism would require an override if storage in thermal mass is used.

CONCLUSIONS

It is shown that even in old un-insulated buildings thermal energy storage within the wall mass has potential to support residential DSM activities. Even for short overheating periods energy amounts equivalent to a typical hot-water buffer tank capacity can be stored. However, due to heat conduction into deeper wall layers and the slow temperature increase of the building mass, the loaded walls cannot substitute the heating system. Still they reduce the buildings energy demand distinctly. Extrapolating the capacity of the ideally modelled building to the whole project region of 2DSM in Bottrop with approx. 950 apartments, thermal energy off 5MWh could be stored within two hours and recovered within five hours after the overheating phase.

Better storage capacities can be reached with longer overheating phases and higher ambient temperatures. However, stored energy is then discharged very slowly and integration into dynamic DSM would be hard to implement and control. Good DSM performance is reached with shorter overheating periods at cold weather conditions. Thereby less heat is transferred into deeper wall layers and more of the stored energy is consumed within an assessable timeframe.

It is also shown, that such storage activities would be supported by some changes in the buildings heating system and control. Thus, installation of heating systems exceeding the design heat load of the building increase the storage potential, especially in cold ambient conditions. Furthermore, control systems lowering the flow temperature with increasing ambient temperatures would require an overrun function, otherwise this function limits the storage potential significantly.

In further research it needs to be evaluated how the potential storage capacity would change for different building materials. Also the storage effect for other distribution systems e.g. floor heating requires further evaluation. Finally, once the general potential is shown, additional dynamic effects of furnishing upon the storage capacity can be analyzed in the future.

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