Heat Pumps, Photovoltaics and Energy Storage in Buildings – Load Characteristics and Flexibility Options on District Level

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Abstract

A comprehensive simulation study of (future) energy-efficient districts including building, HVAC system and energy storage is performed in order to investigate the potential and limits of storage and flexibility in buildings on the district level. Based on three existing examples of energy-efficient districts, building and district models are developed. In future decarbonized districts, the heat demand will be significantly decreased and will be provided by electric energy to a large extent: new buildings built in nZE standard, deep renovated existing buildings as well integration of heat pumps in buildings will lead to a strongly seasonal varying electricity demand. This assessment includes a detailed investigation of the PV own-consumption as well as the external (price) signal-driven energy storage in buildings. The use of the thermal mass of buildings as storage as well as the additional integration of onsite (thermal/electric) storage allows to increase the PV own consumption and further reduce the electric energy of the district, while the influence on the peak power is limited.

Keywords: Decarbonization of the Building Stock, Energy Efficient District; Energy Storage; Energy Flexibility; PV and Heat Pump; Energy Storage; Urban Planning; Energy Policy

1. Introduction

a. Energy Flexibility in Buildings

The use of heat pumps (HP) in buildings for space heating and or domestic hot water (DHW) preparation is without any doubt in most cases the best and often the only option for the decarbonization of the building stock (Wemhöner et al. 2019, Biermayr et al. 2021). The decarbonization of existing districts remains as a major future challenge (Abbasi et al. 2021). With the increasing decarbonization of the electricity mix, the use of HPs will be significantly more competitive than any other technical option. The decarbonization of the electricity system is challenging and requires the integration of renewables and also the integration of electrical and thermal energy storage in the energy system and in buildings (Kurnitski et al. 2011, Ochs et al. 2021). With the electrification of buildings (and mobility) and the integration of PV, buildings will represent an important part of the electricity system, representing both a load and a source and the impact on the electric system becomes increasingly relevant.

Energy flexibility (of buildings) has been intensively studied within the last decades. The main objective is improving the grid stability, which faces challenges with increasing share of renewables on the one hand and electrification of buildings and mobility on the other hand. Li et al. (2021) recently presented a comprehensive review of energy flexibility options in residential buildings. Demand side management is mainly used for peak power reduction, but also possible CO_2 emission savings and cost reduction potential was investigated on building and district level.

Typically, energy flexibility options are distinguished in “shift” and “shed“ (IEA HPT Annex 67). In this context “shift” means that energy consumption is increased before a peak occurs such that during usual peak times the building load can be decreased (i.e. overheating, followed by a period of reduced consumption). “Shed” instead would just cut the peak, which would lead to a reduced indoor temperature during the usual peak period. Hence, assuming violation of the thermal comfort (TC) is not acceptable, in buildings “shed” is not an option.

b. Research gap and novelty of this work.

Several studies on energy flexibility can be found and many of them are summarized within the IEA EBC Annex 67 project and follow-up projects collaborate within Annex 83. The main drawback of existing studies is that they typically lack a to analyze a complete year but concentrate on certain periods. Secondly the lack to analyze the load curve (LC) of the building stock and its future development with massive integration of PV in buildings. This

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work includes two important aspects. Firstly, a simplified building stock model (using “future” Tyrol as an example) is investigated and secondly, the entire year is analyzed showing the influence on the required grid capacity from the grid perspective and the influence on the electricity peak. For this purpose, at first, for a selection of real case studies the electric load curve resulting from space heating (SH) and domestic hot water (DHW) preparation with a HP and considering auxiliary energies as well as appliances is presented, secondly the building and building stock simulation model is presented and the introduced simplifications are justified. Then, in a sensitivity analysis, the influence on the storage efficiency, storage capacity and storage duration is analyzed. Finally, the building stock simulation results are presented and discussed, see Fig. 1.

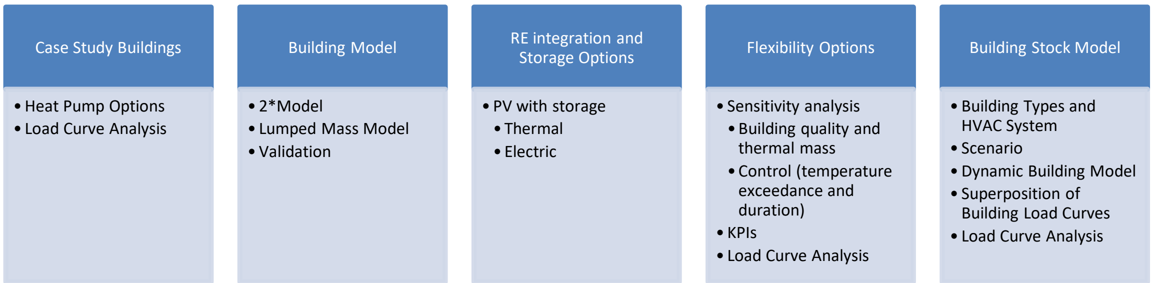


Fig. 1: Structure and method of this work

2. Case Studies

Case Studies of buildings with HP and PV are introduced (Fig. 2) in order to be able to analyse the potential of energy flexibility on building level.

Energy flexibility requires buildings with electric heating system (i.e. HP) for DHW and or SH, and. Three examples of realized buildings and districts are analyzed and used as case studies in this work:

- “Campagne Areal” (NHT and IIG, Innsbruck) around 1000 apartments in 16 buildings acc. to the Passive House (PH) Standard is supplied with DH and central ground water (GW) HPs for SH (Dermentzis et al. 2021(a)).
- In the project “Rum 27” (NHT, Innsbruck) new multi-apartment buildings are connected to District Heating (DH) and, to achieve the PH Plus Standard have a large PV system. In order to increase the PV own consumption, equipped with so-called apartment-wise booster HPs for DHW (Ochs, et al. 2022).
- The two nZE multi apartment buildings “Innsbruck Vögelebichl” (NHT, Innsbruck) represent typical new buildings and are equipped with GW-HP, solar thermal and PV (Dermentzis et al. 2021(b)).

Campagne (NHT), Passive House with District Heating for DHW and GW-HP for SH and PV

Rum 27 (NHT, renderwerk.at), Passive House Plus with district heating and booster HP for DHW and PV

Vögelebichl (NHT), Passive House Plus with GW-HP and ST and PV

Fig. 2: Example of very efficient apartment buildings (PH Standard) with different HP systems and PV

These three examples of buildings in Passive House quality can be seen as representative prototypes of buildings with very high efficiency and lowest possible grid impact. The resulting load curves of a building simulation with simplified building models representing the case study multi apartment buildings (MAB) each in PH quality (15 kWh/(m² a)) are compared in Fig. 3. The small MAB has on annual level more PV production than total electricity consumption (NZEB) and has a higher grid load peak power in summer (PV excess) than in winter. The peak power (hourly average in specific value) is similar for all three buildings and is in the range of 10 W/m² including auxiliary energy and appliances. Obviously, with increasing number of storeys, the possible PV contribution significantly reduces and NZEB is only possible up to typically 4 storeys. Passive House quality and a very efficient HP-based heating system is required to reach NZEB (see also Ochs et al. (2014)). Hence, in terms of energy, in the majority of cases buildings will represent a greater load then source. However, in terms of peak power, PV excess electricity can be more relevant for the grid. Onsite PV and energy storage in buildings influences the load characteristic and the flexibility potential of the building stock.

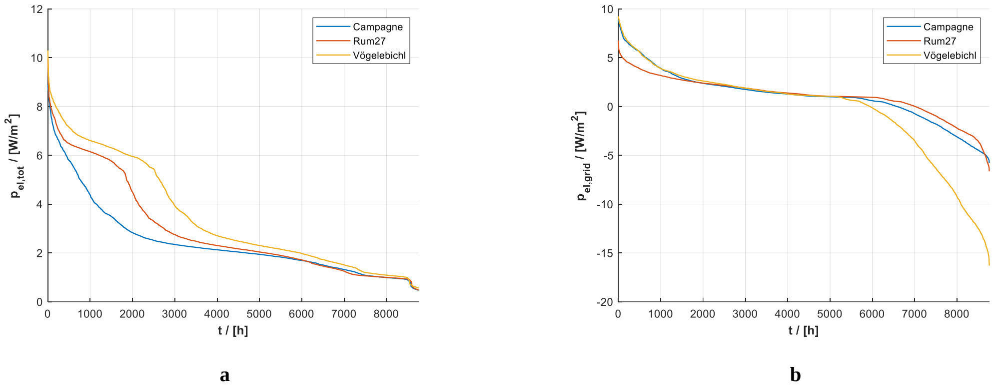


Fig. 3: Specific electric load curve (a) total electricity demand and (b) grid electricity demand of a large (10 storey) MAB with GW-HP for SH and PV, a medium (7 storey) MAB with booster-HP for DHW and PV and a small (4 storey) MAB with GW-HP for SH and DHW and PV, climate of Innsbruck.

3. PV, Energy Storage and Energy Flexibility

a. Energy Flexible Buildings

Through energy storage, energy flexibility in buildings has the potential to provide additional capacity for energy grids, and integrate RE sources in energy systems. Furthermore, there is a potential to reduce costly extensions or upgrades of energy distribution grids. The main challenge is providing thermal comfort, reducing thermal losses while ensuring an economic benefit for the building owner/operator and the utility, see (IEA EBC, Annex 67). In times of availability of abundant and cheap renewable electricity buildings can be (slightly) overheated (activation of the thermal mass) or available storage capacities (thermal/electric) can be charged such that in peak power times or when renewable energies are scarce, the load can be reduced. A flexible external signal-driven control is required for such an operation.

The thermal mass of the building and or additional thermal or electric storage can be charged prior to either expected peak load (i.e. low ambient temperature) or high energy price (i.e. low RE availability) periods. It can be expected that peak periods and high price periods frequently coincide but this is not necessarily the case. If low RE availability (in winter with low PV and hydro power and in no wind periods) coincides with low temperature and thus high demand coincide, electricity price can be expected to peak. Contrariwise, periods with high RE availability (excess electricity from wind power and PV) would lead to low electricity prices and this would be pronounced in periods with low loads e.g. high solar radiation and thus high solar gains.

b. Energy Storage Options

In buildings several options for storing energy are available. Typically, a small DHW store will be present, which covers the daily DHW demand (night/day). Optionally, a SH buffer can be present, which is typically dimensioned to prevent on/off operation of the HP. The set point temperature of the buffer storage can be increased to increase its storage capacity. In addition, the thermal mass of the building can be activated by increasing the set point from typically 20 °C (standard assumption for calculations) or 22.5 °C (a more realistic average) to maximum 25 °C (or maybe 26 °C).

Floor heating (FH) or thermal activated building systems (TABS) will not be present in the majority of the buildings with respect to the building stock, instead radiators are the predominant heat emissions system. The flow temperature depends on the building quality and size of the radiators. Using (fan supported) convectors the flow temperature can be further reduced, which leads to lower distribution losses and to better performance of the in future predominantly used heat pumps.

Finally, batteries can be used to store surplus electricity. If present, a typical capacity is 1 kWh of battery capacity per 1 kWp of installed PV. Increasingly, as a rule of thumb batteries are dimensioned to cover the electric load of a building on an average summer day.

Table 1 gives an overview of building-integrated storage and potential storage capacities. In combination with an HP, with an average Coefficient of Performance (COP) of 3, the thermal storage capacity can be approximately converted to electric storage capacity. For DHW the daily electric storage potential is 2.3 kWh. For a typical Single Family House (SFH) the daily electricity consumption (appliances, lighting, etc.) is ranging between 6 kWh/d in summer and 8 kWh/d in winter.

Tab. 1: Example of energy storage in a SFH (150 m²), type and storage capacity (acc. to Ochs et al. 2021).

Energy	**Electric**	**Thermal**		
Type	Battery	Building Mass	SH buffer	DHW storage
Typical Size	ca. 1 kWh/kW_p	200 Wh/K/m²	1000 l	100 to 150 l
Storage Capacity	$5\ kWh_{el} \dots 7\ kWh_{el}$	$28\ kWh_{th}/d$ $\Delta T = 1$ K	$23\ kh_{th}$ 50/30 °C	$7\ kWh_{th}$ 50/10 °C
Converted capacity (electric)		$9.3\ kWh_{el}$	$7.7\ kWh_{el}$	$2.3\ kWh_{el}$

c. Theoretical Savings through Energy Flexibility

Assuming a perfect prediction of the RE availability and the load curve (LC), an external signal could be used to overheat the building stock in times of low CO2-emissions and/or low energy prices and thus reduce the load in the following high energy price period.

In order to activate the thermal mass of the buildings or charging thermal storage the set point temperature can be increased, e.g. by $\Delta T_{SP} = 3.5$ K for the indoor temperature and/or by $\Delta T_{SP} = 10$ K for the DHW storage temperature.

$$T_{SP} = T_{SP} + \Delta T_{SP} \cdot (signal == 1) \qquad \text{(eq. 1)}$$

Through this (additional) activation of the onsite (thermal or electric) storage capacity, peaks in the LC could be theoretically shifted to non-peak times (so-called peak shaving) or additional energy consumption can be generated in low energy demand periods thus leading to a reduced energy demand in the subsequent period. While in the first case the purpose is reducing peaks in the grid electricity, in the second case additional peaks could still occur, but shifted to later times. In any case, if under-temperature is excluded, activation of flexible storage options will increase the average building and or storage temperature and as a consequence, the total energy demand (E_{flex}) will also increase with respect to the reference case (E_{ref}) because of storage losses (E_{loss}).

$$E_{flex} = E_{ref} + E_{loss} \qquad \text{(eq. 2)}$$

Thus, flexibility options will always increase the energy demand, but the additional energy demand and some of the reference energy demand ($E_{ref} \cdot a$) might be provided at lower cost or with higher share of RE and thus with lower CO_2 emissions. The losses depend on the type of storage and the storage duration. In case of the thermal mass of the building the envelope quality (EQ) and the thermal mass (TM) of the building influence the thermal losses.

4. Building and Building Stock Model

a. Dynamic Building Model

The simplified dynamic simulation model of the building includes the HVAC systems, i.e. HP or Direct Electric (DE), DHW and appliances profiles as well as storage options (thermal, electric) and PV integration. A simple dynamic 1-zone lumped capacity model developed in Matlab (ode15s solver) is used (see Ochs, et al. 2021) and compared against a 2* model with and without floor heating, see Fig. 4. Different building typologies and energy levels are implemented. The models were compared against each other and against the validated building simulation model carnotUIBK (see Magni et al. 2022).

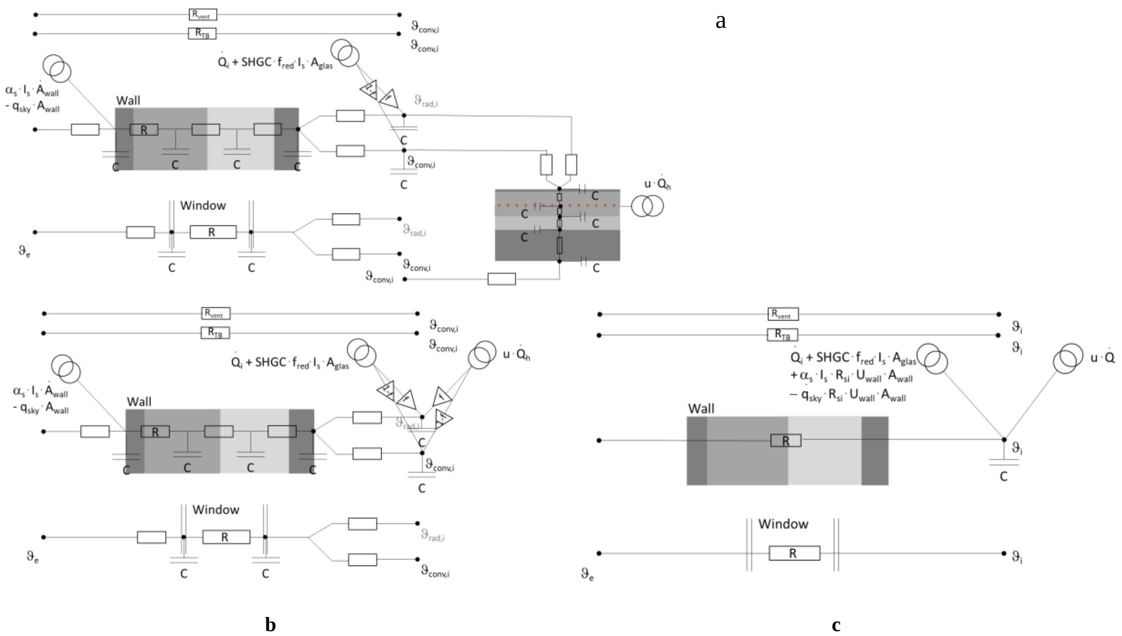


Fig. 4 (a) 2* model with 1 wall with 4 nodes, floor heating and 1 window with 2 nodes (13 ODEs), (b) 2* model without floor heating (8 ODEs) and (c) lumped capacity model (1 ODE)

b. District and Building Stock Model

The building stock electric load curve is determined by superposing the load curves of different building types. For each building type with the different HVAC configurations the load curve is simulated with the reduced order lumped capacity one zone building model with different options of PV and storage integration as well as external-signal based overheating. Each building with its representative energy demand and equipped with either an HP or a DE heating system represents a partly flexible load for the electricity grid. Buildings heated with biomass or connected to DH system represent an appliance- (and auxiliary-) based load only, which is not flexible unless electric storage is implemented (i.e. battery). The scenario under investigation assumes a total phase-out of fossil heating systems (i.e. no gas and oil boiler). The schematic representation of the building stock is shown in Fig. 5. Further details about the buildings can be found in Ochs et al. (2021).

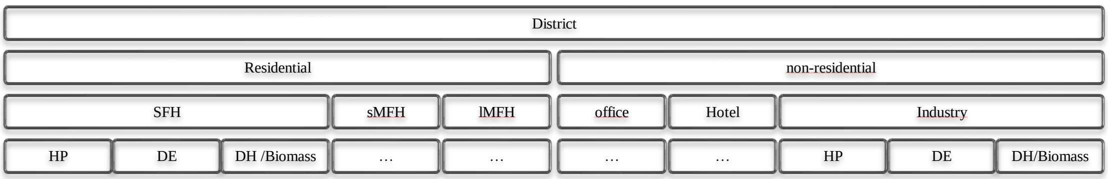


Fig. 5: Scheme of the district/building stock model with different building types (i.e. SFH: Single Family House, sMFH/lMFH: small/large Multi Family House, office, Hotel and Industry) and HVAC systems (i.e. HP: Heat Pump, DE: Direct Electric, DH: District Heating, and Biomass).

c. PV potential in building stock

Assuming PV will be installed on every roof, and given the roof area and restrictions in terms of shaded roof area and competing roof use (chimney, window, ventilation system, etc.) the following potential PV installation is assumed (Tab. 2).

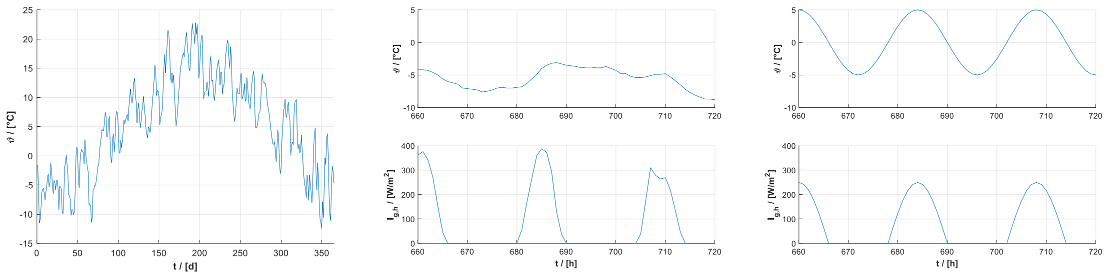
Tab. 2: PV potential and typical battery size in buildings, scenario for Tyrol 2050.

		SFH	s-MFH	l-MFH	Office	Industry	Hotel
Treated area	m²	150.8	334.4	1822.0	1153.8	1009.8	1024.6
No of storeys	-	2	4	10	5	5	5
PV	kW_p	5	9	18	25	21	22
No of Buildings	-	106579	67592	5063	10584	7461	9571

The total roof installed PV sums up approx. 18 MW_p . Remark: The actual total PV potential is significantly higher as only the heated buildings are considered and unheated buildings such as garages, stores and halls, etc. present an additional space for PV that can be integrated in the buildings energy system.

d. Climate

The climate has a significant influence on the energy flexibility. In times of low ambient temperature and low solar radiation, the overheated building will be subject to relevant thermal losses, while in times of moderated temperatures or high solar gains, the storage period is expected to be longer. For this simulation study, the climate of Innsbruck in hourly resolution is used (Meteonorm). Additionally, a synthetic climate is used to investigate the influence of the building envelope quality and thermal mass on the storage duration and storage efficiency. The ambient temperature of Innsbruck in daily resolution is shown in Fig. 6 (a), in Fig 6 (b) a period of 2.5 days in winter is shown. There are four periods of few days with very low temperature at the beginning of the year and two at the end of the year, with the lowest temperature in December and the longest cold temperature period in February. Fig. 6 (c) shows the synthetic climate used for the sensitivity analysis.



a b c

Fig. 6 (a) Daily average temperature of Innsbruck, (b) hourly temperatures and global horizontal radiation for a period of 2.5 days end of January and (c) synthetic climate in hourly resolution for a period of 2.5 days.

5. KPIs

Building time constant: If the thermal mass of the building is concentrated to one node, the building can be expressed by its time constant

$$\tau = \frac{(m \cdot c)_{eff}}{\sum UA + \rho \cdot c \cdot V \cdot n_{eff}} \qquad \text{(eq. 3)}$$

Storage Duration: The storage duration is the time between the point of time when the building is heated again after the external signal driven heating (which is equal to undershoot of the SP temperature) and the point of time when the external signal is set back to zero ($signal == 0$)

$$\Delta\tau = t(heat\ on) - t(signal == 0) \qquad \text{(eq. 4)}$$

Thermal Storage Capacity: The storage capacity is the difference in energy

$$Q_{out} = Q_{ref}(t(heat\ on)) - Q_{ref}(t(signal == 0)) \quad \text{(eq. 5)}$$

Thermal Storage Efficiency: The thermal storage efficiency is the ratio of heat output and input.

$$\eta_{th} = Q_{out}/Q_{in} \quad \text{(eq. 6)}$$

The heat input Q_{in} is the additional heat delivered to the building during the phase when the external signal is equal to one. It is calculated by the heat delivered to the building in that phase minus the heat delivered in that phase without overheating ($Q_{in,ref}$).

Electric Storage Efficiency: The electric storage efficiency is the ratio of electric output and electric input. The electric efficiency depends on the thermal efficiency and on the HP performance.

$$\eta_{el} = W_{out}/W_{in} \quad \text{(eq. 7)}$$

The electric efficiency can be higher or lower than the thermal efficiency. It depends on the temperature level the HP is operated during overheating and would be operated in the reference case (i.e. without overheating). A simple and clear example is an air-to-water HP for DHW preparation. When a HP is only operated during daytime with in average a couple of K higher air temperatures than during nighttime, the HP's COP would be higher leading to an increased electric storage efficiency with roughly the same thermal efficiency.

6. Results and Discussion

a. Lumped mass building model

The simplified lumped mass model used for the building stock model was compared against the more detailed 2* model with and without floor heating, see section above. The dynamic behavior with respect to the indoor (i.e. operative) temperature on hourly resolution cannot be predicted very accurately with the simplified lumped capacity model but the trend with respect to the time constant of the building is correct and the accuracy is sufficiently good with respect to the load and for the purpose of this work. This conclusion is in agreement with the results presented by Magni et al. (2021). The inertia of a floor heating system (see Fig. 7) leads to a different dynamic behavior also with respect to the heating power. However, with respect to the electric load curve, even a floor heating system in combination with a buffer storage and a HP can be predicted sufficiently well with the simplified lumped mass model.

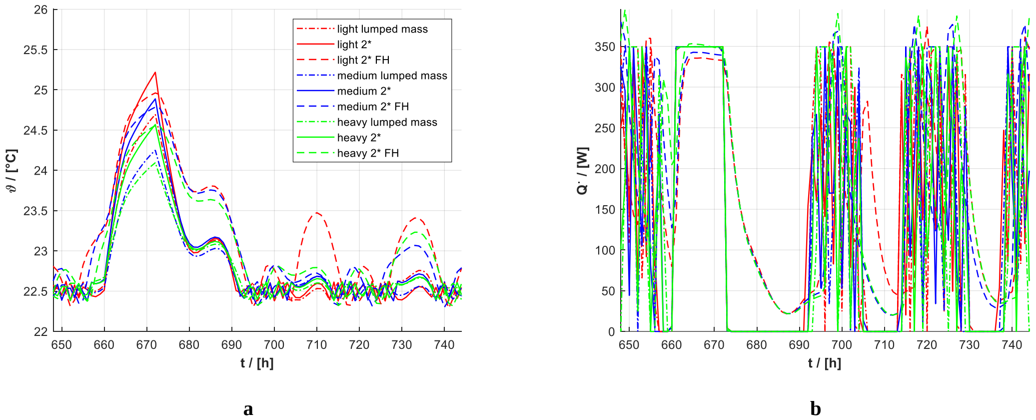


Fig. 7 (a) temperature and (b) heating load of a signal driven overheating (synthetic climate) with different thermal mass of the building (light, medium, heavy).

b. Single Building – Influence of Building Quality and Thermal Mass

Exemplarily, Fig. 8 and 9 show the temperature development of the lumped mass building model with three different envelope qualities (EQ) and two variants of the thermal mass of the building (medium or high thermal mass (TM)) with an external signal-based overheating to 26 °C and 24 °C, respectively.

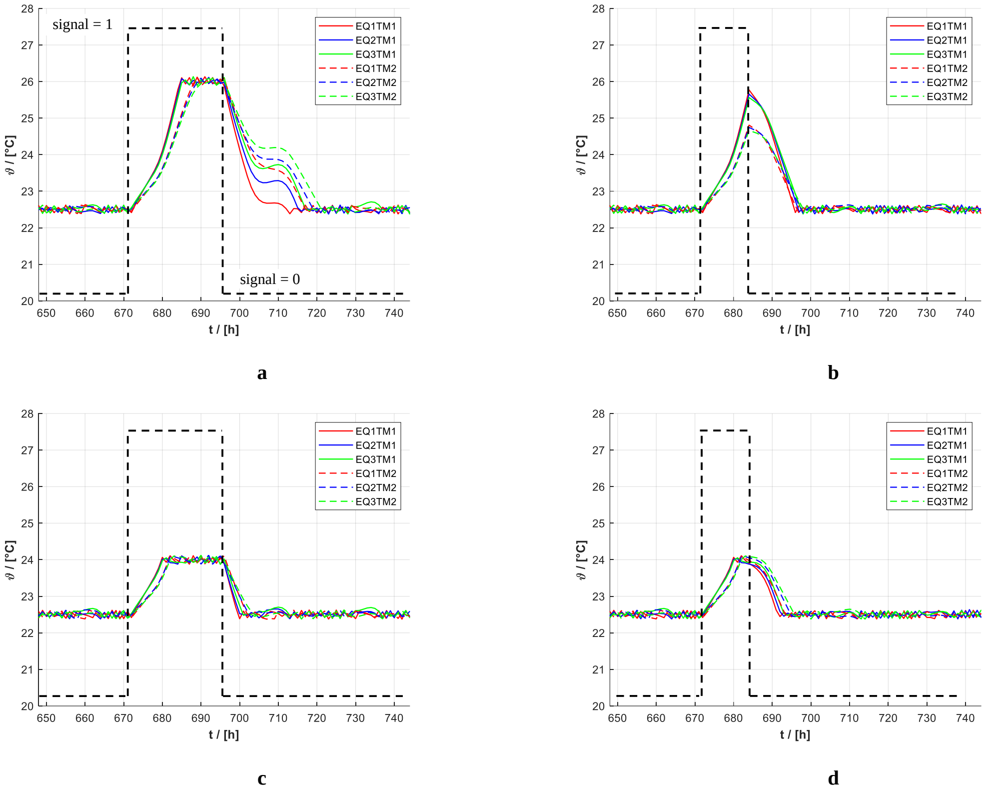


Fig. 8: (external) signal based overheating of the building starting from hour 672 ((a), (c) 24 h (b), (d) 12 h) depending on the thermal mass (i.e. TM1: medium and TM2 high thermal mass), building quality (i.e. EQ1: low, EQ2: medium and EQ3: high envelope quality) and SP ((a) and (b) + 1.5 K (c) and (d) + 3.5 K); 2*1TZ building model, with synthetic climate

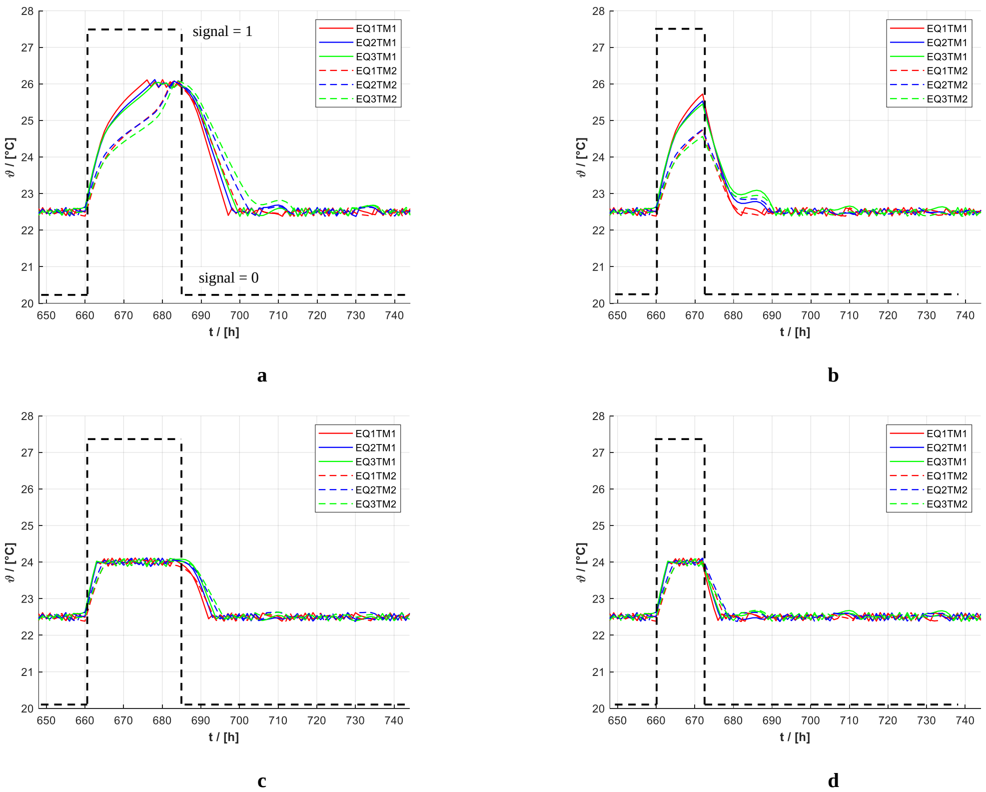
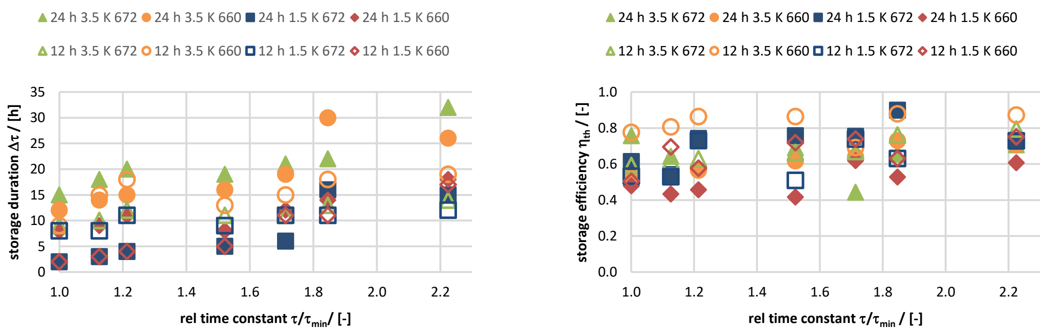


Fig. 9: (external) signal based overheating of the building starting from hour 660 ((a), (c) 24 h (b), (d) 12 h) depending on the thermal mass, building quality and SP ((a) and (b) + 1.5 K (c) and (d) + 3.5 K); 2*1TZ building model, with synthetic climate.

The maximum storage duration ($\Delta\tau$) depends on the building's envelope quality (EQ), the thermal mass (TM), i.e. its time constant τ, the SP temperature exceedance as well as on the climate (external temperature and solar radiation), i.e. on the time of the year. In cold winter times with low temperature, more energy could be theoretically stored in a building, but also the thermal losses are higher. Contrariwise, in the interim season, losses are low, but also the storage potential is low, as only little heat is required at that time at all. As shown in Fig. 8 and 9 for an external signal of 12 h and 24 h the maximum storage period for the building with high envelope quality and high thermal mass does reach 32 h at maximum. The storage duration and the storage efficiency are reported in Fig 10 (a) and (b).



a

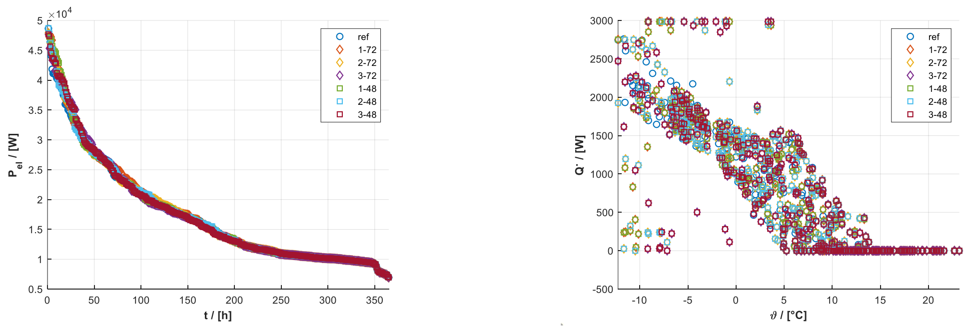
b

Fig. 10: (a) Storage duration ($\Delta\tau$) and (b) thermal storage efficiency (η_{th}) as a function of the relative time constant of the building (τ/τ_{min}) for different overheating duration (12 h or 24 h), temperature (1.5 K and 3.5 K) and starting point (hour 660 or 672).

The efficiency is higher for short heating-up periods with higher overheating temperature. Long overheating periods with low temperature difference lead to short storage periods and poor efficiencies. The storage duration can significantly increase when the next day with increasing temperature and solar gains is reached (as in case of e.g. 24 h, 3.5 K, 660 where dt = 30 h at τ/τ_{min} = 1.85 instead of 19 h at τ/τ_{min} = 1.7 or 32 h instead of 22 h for the case 24 h, 3.5 K, 672 when the relative time constant is increased from 1.85 to 2.22).

c. Single Building – Load Duration Curve

For the example of the SFH the effect of external signal-based overheating is shown in Fig. 11 for the heating sorted heating load (a) and the load vs. ambient temperature curve (b). Peaks at low ambient temperature periods can be reduced and are shifted to times with higher ambient temperature. But this succeeds only for some peak power days and overall the peak power of the building is not reduced.



a

b

Fig. 11. (a) Sorted total electric load duration curve (daily sum) with and without external signal-based overheating and (b) thermal load vs. ambient temperature in daily average for the SFH with SH of 47 kWh/(m² a); for different overheating temperature (1, 2 or 3 K and different overheating period 48 or 72 h) in comparison the the reference without overheating (ref).

In Fig. 12 for a selected period at the end of the year, the daily electric energies are shown and how (with respect to the reference without external signal-based overheating) the load is shifted by maximum 2 days. The daily maximum peak cannot be reduced when two peak periods follow with short time lag.

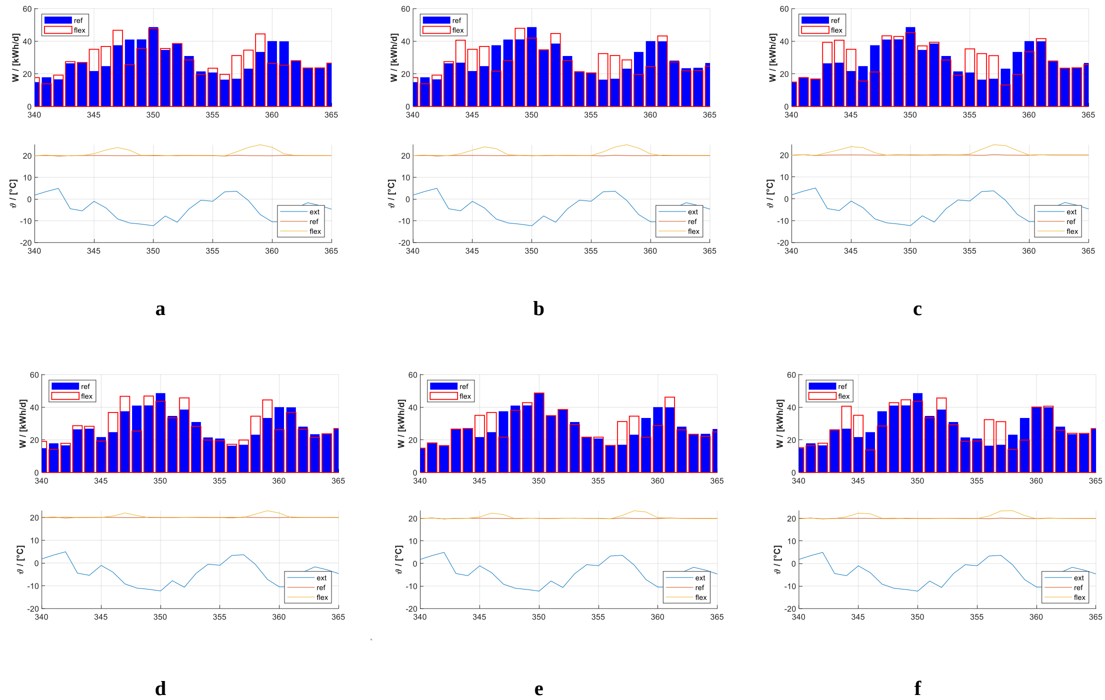


Fig. 12. Daily sum of the electric energy (from day 340 to day 365 of the year) for the SFH for overheating of (a) 1 d in advance and 72 h duration (b) 2 d in advance and 72 h duration (c) 3 d in advance and 72 h duration (d) 1 d in advance and 48 h duration (e) 2 d in advance and 48 h duration (f) 3 d in advance and 48 h duration.

d. Building Stock – Load Duration Curve

The building stock load duration curve is shown in Fig. 13. The peaks occur in times of low ambient temperatures. Based on the previous results, it can be concluded that a shift of more than 24 h cannot be achieved and cold periods are typically longer than 24 h. Peaks can occur with only a short time-lag, e.g. peak at day 352. Hence, the theoretic peak reduction potential is limited to approx. 85 % to 90 %. If in a winter period the average load curve is in the range of 80 % with respect to the peak and a peak situation is predicted in advance, the load must be increased to shave the peak. Thus, in this period the average load must increase from 80 % to e.g. 90 %. Practically, due to non-ideal prediction and non-ideal behavior, the peak power reduction might not occur at all or the peak might be only shifted by max. 24 h.

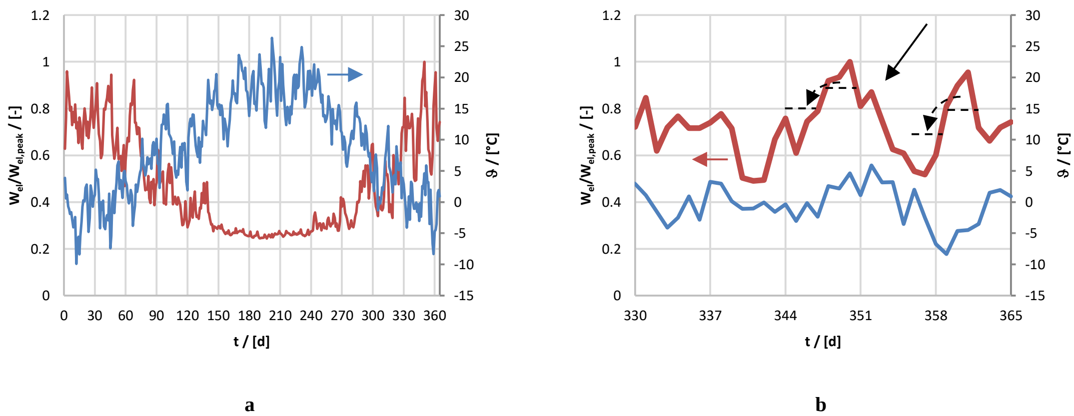
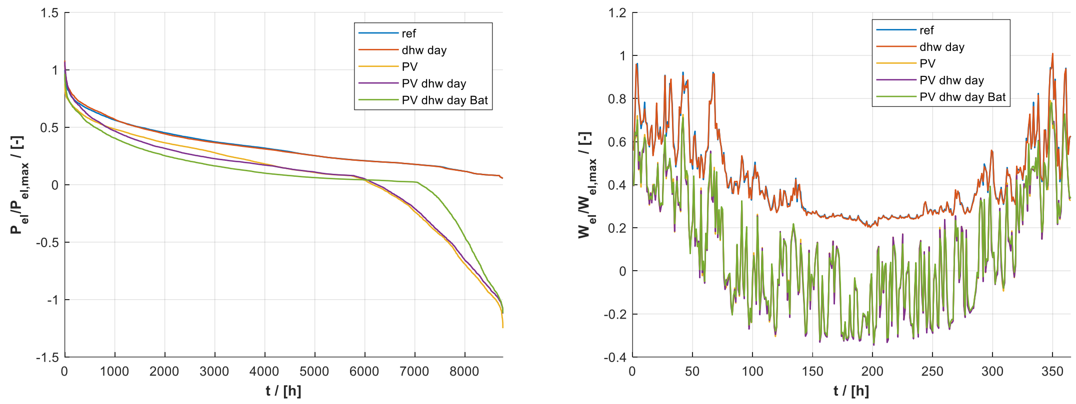


Fig. 13. Building stock electric load curve (based on scenario Tyrol 20250, Ebenbichler et al. 2020) normalized (a) hourly power and (b) daily energy with a section of few days in Winter; total electric energy demand: 1995 GWh, hourly Peak Power: 739 MW.

Fig. 14 shows the load duration curve for the building stock model (a) sorted hourly powers and (b) daily energies with different variants: reference, with DHW preparation during daytime, with and without PV, with battery (1.35 kWh/kW$_p$). While PV has relevant influence on the load curve, in particular in summer, the integration of storage is only of low relevance for the load curve and the peak powers.



a b

Fig. 14. Building stock load curve (based on scenario Tyrol 20250, Ebenbichler et al. 2020); (a) normalized hourly electric power (b) daily energies; total electric energy demand: 1995 GWh, hourly Peak Power: 739 MW; ref: reference without PV and storage, dhw day: ref. with day time domestic hot water storage charging, PV: with PV; PV dhw day: with PV and day time domestic hot water storage charging; PV dhw day bat with additional battery (ca. 1.35 kWh//kWp (in average).

7. Conclusions

Energy storage in buildings can be used to shift the load from peak times to few hours later, thus theoretically reducing the stress on the electric grid. On building level, thermal and electric energy storage is possible (thermal building mass, space heating (SH) buffer, DHW storage or battery, typically in combination with PV and potentially electric cars). Possibilities and limits of load shifting in buildings using the thermal mass and/or thermal or electric storage were discussed. The developed building and building stock/district models allow to evaluate the possibility to shift load through the activation of the thermal mass of the building, thermal energy storage (for SH and DHW) and batteries depending on the building energy level, the HVAC system and onsite PV.

The storage efficiency and storage duration depend on the one hand on the envelope quality of the building and its thermal mass and on the other hand on the control (overheating temperature) and the time of the year (i.e. ambient conditions). The storage duration when overheating the building thermal mass is limited to max. 48 h in the optimistic case (highly efficient building with high thermal mass and floor heating) and is significantly less as concerns the future building stock with an average space heating demand of 45 kWh/(m² a) and in the winter months with low ambient temperature. Hence, the effective storage duration is of the same order of magnitude as a typical battery charging/discharging cycle. The thermal storage efficiency varies strongly between 40 % and 90 %. On the annual perspective and from the grid point of view neither external signal-based overheating nor battery charging have a relevant influence on the peak powers. A load shift from night to day is possible and can make sense regarding renewable integration (CO_2 emission reduction, reduced energy consumption at high price periods) but the requirements on the grid capacity and the provision of peak power plants is hardly influenced.

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