Output Factsheet

Output title: T5.1 Pilot-deployed modular energy management platform

Summary of the output

The output shows how the developed 3Smart tool is applied to 5 diverse pilot sites in 5 countries of the Danube region (HR, SI, AT, BA, HU). It is completed with showing performance of the 3Smart modules on different pilots. Also in this revised output are added now operational logs and seasonal analyses from all pilots.

The Croatian pilot consists of two buildings in Zagreb, one of UNIZGFER and another of HEP, and of the pilot electricity distribution grid of HEP around these two buildings.

The Slovenian pilot consists of a Primary school building and Sports centre of IDRIJA, with the electricity grid of ElektroP around it.

The Austrian pilot consists of two buildings of the municipality Strem, which are the primary school and the retirement and care centre. In addition, the electricity distribution grid of EnergyG is also part of the pilot.

Bosnia and Herzegovina pilot consists of a business building in property of EPHZHB in Tomislavgrad and of the pilot electricity distribution grid of EPHZHB around the building.

The Hungarian pilot consists of a buildings complex of EON in Debrecen and of the pilot electricity distribution grid of EON around the building.

The five individual reports for different pilots show how the 3Smart tool is organized on pilots, how it operates the buildings and the grids, and show also the seasonal analyses of pilots operation for characteristic days with assessed economical benefits. They are used in Output T4.2 for performing cost-benefit analyses of pilots installations exactly regarding the part of adding-up the 3Smart platform to the automation systems.

Contribution to EUSDR actions and/or targets

The output contributes to Priority Area 2 "To encourage more sustainable energy" of the EUSDR within which the following actions are required: „To explore the possibility to have an increased energy production originating from local renewable energy sources to increase the energy autonomy", „To promote energy efficiency and use of renewable energy in buildings and heating systems", „To facilitate networking and cooperation between national authorities in order to promote awareness and increase the use of renewable energies".

The performed pilots show that it is viable to unlock demand response capacities of buildings as largest consumers of energy. It is very important for enabling higher renewable energy integration since the energy system regulation needs to be brought at least in part on the side of consumers within the process of energy system decarbonization.

Performed testing, if applicable

The piloting of the 3Smart tool is performed on 5 3Smart pilots and elaborated in this output – both organization of the modules of the tool and their individual and cumulative performance is shown, including financial benefits.

Integration and use of the output by the target group

Main target groups for the usage of the platform outputs are building owners or managers, infrastructure companies, and national regulators.

Building owners can learn how to better use the infrastructure they manage to reduce their operating costs and also help the proliferation of demand response services locally which then also streams secondary benefits of renewable energy capacities increase.

A similar position is for infrastructure operators – it shows how the infrastructure operation costs can be lowered via demand response and optimization.

Geographical coverage and transferability

The 3smart EMS platform piloting was conducted in 5 countries in the Danube region, with results showing that it can bring benefits in all these configurations. This proves that its concept and results are transnationally relevant and transferrable to different local contexts and different infrastructure setups.

Durability

The platform validity is not constrained with time and should become more and more relevant as the energy efficiency and demand response regulations get mature over time to trace the path of energy systems decarbonization in Europe and across the globe.

The output will evidence how the tool can be organized for different setups and which benefits it can bring.

Synergies with other projects/ initiatives and / or alignment with current EU policies/ directives/ regulations, if applicable (max. 1500 characters)

The platform has a synergy effect with Clean Energy for all Europeans package – it shows how buildings and grids can be smartly managed and how they can interact through demand response. Its testing is also very important for the coming decades of the energy system full decarbonizaton in the Danube region and the EU, so it is in line with the European Green Deal of the European Commission as well as with numerous directives and national plans that will stem out of it.

There is a clear synergy of this developed tool with the Interreg Central Europe project Store4HUC (Integration and smart management of energy storages at historical urban sites) which inherits the developed procedures for economical assessment of various combinations of PV and battery systems to decide which configuration is economically optimal, plan its optimal operation and run it. Also a synergy can be assessed with H2020 project REWAISE (Resilient water innovation for smart economy), that is about to start, where demand response and coordination in the water cycle will be developed and tested.

Output integration in the current political/ economic/ social/ technological/ environmental/ legal/ regulatory framework

The output evidences the possibilities of buildings energy management and also the possibilities for their participation in demand response service provision. The output should also be considered in environmental context showing that smart energy management can lower energy consumption not necessarily on the cost of users comfort.

The output with its seasonal analyses performed for pilots also gives clear figures about possible savings achievable and demand response potentials of buildings to energy regulators, giving them the benefit-side insight for further policies shaping in the area of energy management and demand response.

Project Deliverable Report

Smart Building – Smart Grid – Smart City

http://www.interreg-danube.eu/3smart

DELIVERABLE D7.1.3

Operational logs and their seasonal analysis – Croatian pilot

Project Acronym	3Smart
Grant Agreement No.	DTP1-502-3.2-3Smart
Funding Scheme	Interreg Danube Transnational Programme
Project Start Date	1 January 2017
Project Duration	36 months
Work Package	7
Task	7.1
Date of delivery	**Contractual:** 31 December 2019 **Actual:** 31 December 2019
Code name	**Version:** 1.0 Final ☒ Final draft ☐ Draft ☐
Type of deliverable	Report
Security	Public
Deliverable participants	UNIZGFER, HEP
Authors (Partners)	Mario Vašak, Tomislav Capuder, Anita Martinčević, Nikola Hure, Hrvoje Novak, Danko Marušić, Paula Perović, Marko Kovačević (UNIZGFER), Leon Leposša, Martin Bolfek (HEP)
Contact person	Mario Vašak (UNIZGFER)
Abstract (for dissemination)	This document provides operational logs of the 3Smart system for characteristic days in seasons of heating and cooling. These logs are compared with the conventional control system operation in the same conditions to be able to quantify achievable benefits through interaction of building-side and grid-side 3Smart modules which implements optimization of building and grid operational costs. The operational logs include also the optimal building bid for flexibility in the given pricing conditions.
Keyword List	building-side energy management system, grid-side management, operational logs, seasonal analysis, benefits, demand response, reservation, activation

Revision history

Revision	Date	Description	Author (Organization)
1.0	31 December 2019	Collected and explained operational logs from the Croatian pilot	Mario Vašak, Anita Martinčević, Nikola Hure, Danko Marušić, Hrvoje Novak, Paula Perović, Tomislav Capuder (UNIZGFER)

Table of Contents

Executive summary

The 3Smart project deals with real-time integrated grid-building energy management including demand response. It considers this key topic for the forthcoming process of decarbonization of the energy system from regulatory, technology and economical aspects.

From the technology side, the project has yielded a modular software tool that is adaptable for application to various buildings and grids configurations. Within the project five pilots are performed where these tools are tested. Each of the pilots encompasses the grid and the buildings perspective. These five pilots are situated in five different countries: Croatia, Slovenia, Austria, Bosnia and Herzegovina and Hungary.

This deliverable provides operational logs of the 3Smart system operation on the Croatian pilot, focussed on particular characteristic days in the heating and cooling season. It provides a comparison with the conventional control performed under the same conditions. In this way it is possible to quantify the benefits achievable exactly due to the 3Smart system operation on the site. Moreover we are able to compute the optimal flexibility bid for the building in given pricing conditions from the grid. The benefits with and without flexibility activation from the grid side are assessed.

1. Introduction

The Croatian pilot consists of two buildings of the two involved Croatian partners in the project – University of Zagreb Faculty of Electrical Engineering and Computing (UNIZGFER) and Hrvatska elektroprivreda d.d. (HEP) – and of the pilot electricity distribution grid of HEP Distribution System Operator around these two buildings.

The pilot setup on the side of the buildings and the grid, including the 3Smart system structure on the pilot, is provided in the deliverable D7.1.2 [1].

This deliverable concerns the operational logs obtained by operation of the 3Smart modules on the setup of the Croatian pilot. The focus here is on the analysis of the essential modules that enable predictive and coordinated behaviour of the entire building connected to the grid operated also with the 3Smart modules. The buildings are analyzed in conditions specific for different season – heating and cooling, on the level of characteristic days.

With these operational logs we are giving answers to the following questions posed for building operation during a certain day which are not easy to be answered without the 3Smart tool adapted for a particular building:

- What is the optimal way of daily building operation in terms of the overall building operational costs:
  - When and how much to heat/cool a specific of several hundreds of zones?
  - When and how much to heat/cool the centrally prepared medium for heating/cooling of zones
  - When and how much to charge/discharge the battery system?
  - From which initial condition should building start at the beginning of the day?
  - What should be the amount of offered flexibility from the building to the grid?
- How much is the optimal way of operation better than usual, conventional one?

In this analysis the 3Smart tool is used to enforce a repeatable day-to-day behaviour in a way that starting building condition (at the day start, at midnight) is enforced to be the same as the ending day condition (at the following midnight). In this way the evaluation of the 3Smart system operation is fair meaning that the 3Smart system does not exploit any initial condition in the building for inducing savings, but leaves the building in the same condition as it was at the beginning of the day – i.e. no energy cumulated in initial conditions is exploited. The computations performed within 3Smart predictive control modules also select the optimal starting building condition for minimum operational costs.

In Chapter 2 the operational logs and seasonal analysis for the UNIZGFER building is presented. Then in Chapter **Pogreška! Izvor reference nije pronađen.** this is also performed for HEP building. In both chapters necessary inputs from the grid side (pricing and flexibility conditions) are provided to be able to generate the operational logs and perform the seasonal analysis.

2. UNIZGFER building operational logs and seasonal analysis

The operational logs and seasonal analysis are performed for two selected typical days of building operation – sunny workday in July as a representative for the cooling season operation of the building and sunny workday in January as a representative of the heating season operation of the building.

2.1 Grid-side and boundary conditions for the building operation – cooling season

The explanation of the operational logs is started by presenting the conditions provided by the grid for a sunny workday in July.

The needed flexibility time windows for the grid within the analysed day are as follows:

- 11:30-11:45;
- 13:00-13:30;
- 14:30-15:00.

The pricing conditions computed by performing the calculations by long-term grid-side modules are as follows:

- reservation price: 0.027 EUR/kW/15 min;
- activation price: 0.109 EUR/kWh;
- penalty price: 0.219 EUR/kWh.

The expected day-ahead electricity pricing is shown in Figure 2.1.

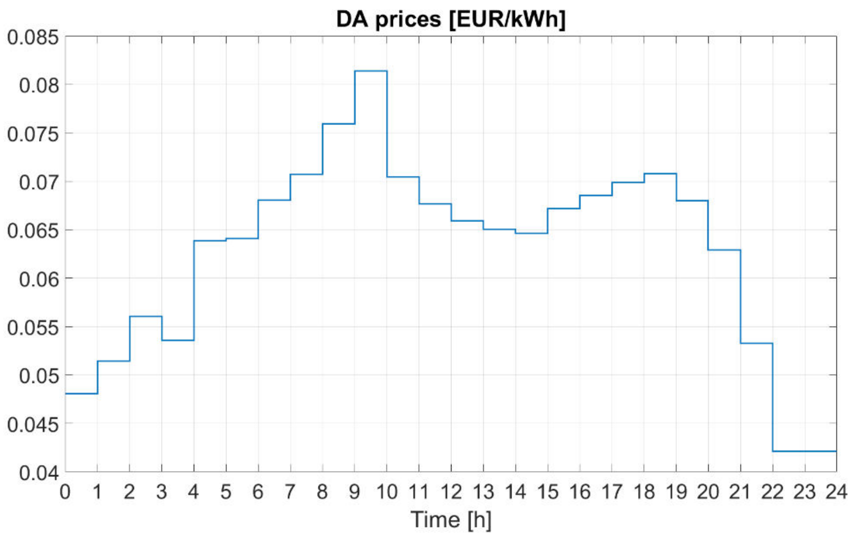

Figure 2.1. Day-ahead electricity pricing for a sunny workday in July.

Additional parameters taken into account are consisted of the relevant meteorological conditions, namely outdoor air temperature profile (shown in Figure 2.2) and direct and diffuse solar irradiance profiles (shown in Figure 2.3), as well as the non-controllable consumptions on the HVAC level (thermal energy consumption profile shown in Figure 2.4) and the microgrid level (electrical energy consumption profile shown in Figure 2.5).

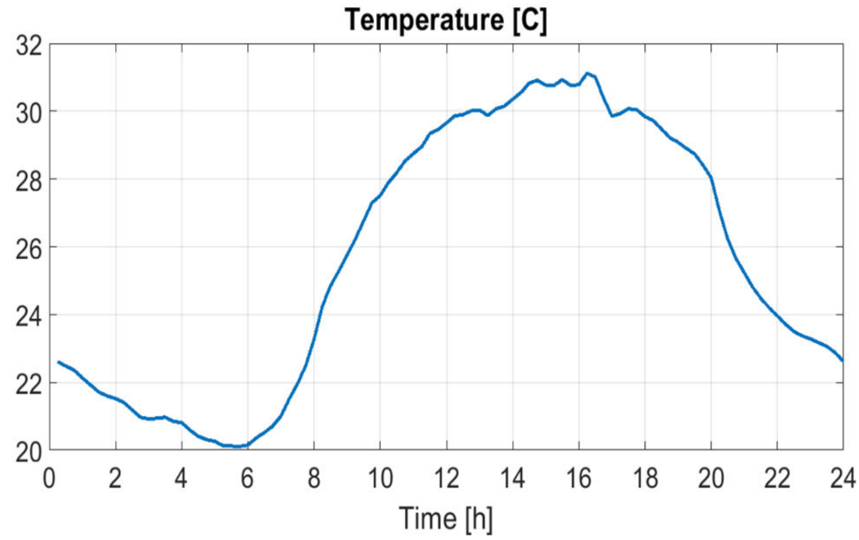

Figure 2.2. Outdoor air temperature for a sunny day in July.

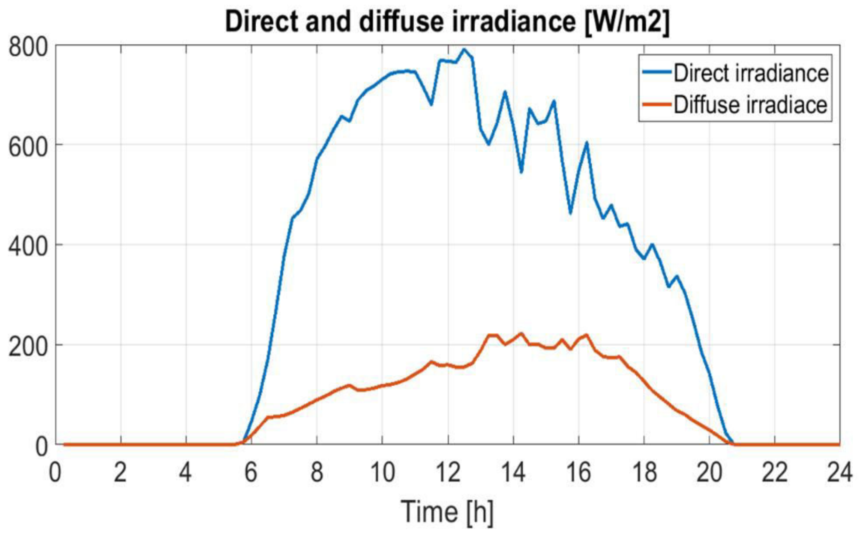

Figure 2.3. Direct (normal) and diffuse (horizontal) solar irradiance for a sunny day in July.

Non-controllable thermal energy consumption on the HVAC level accounts for the consumption of the adjacent faculty building cooled from the same chiller while the non-controllable electrical energy consumption on the microgrid level is consisted of the energy consumption of the office lighting, computers, building elevators as well as refrigerators and electrical air conditioning units in server rooms.

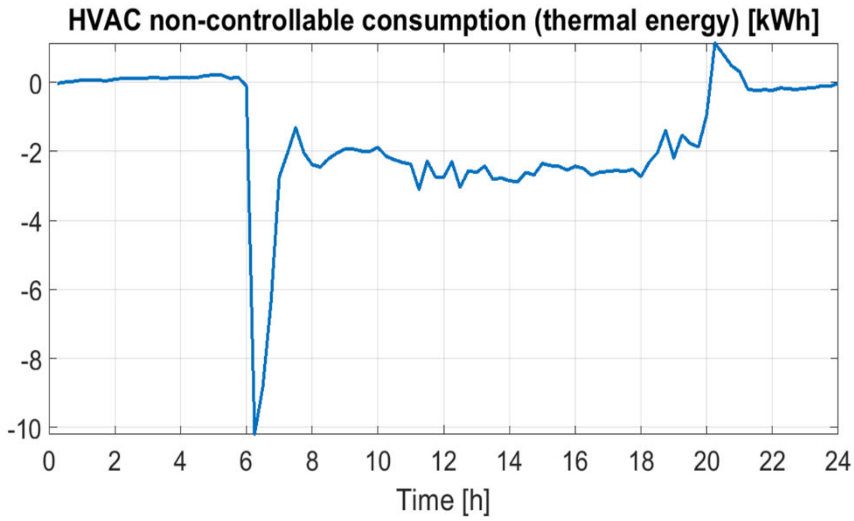

Figure 2.4. Non-controllable consumption of thermal energy on the HVAC level, for a sunny workday in July.

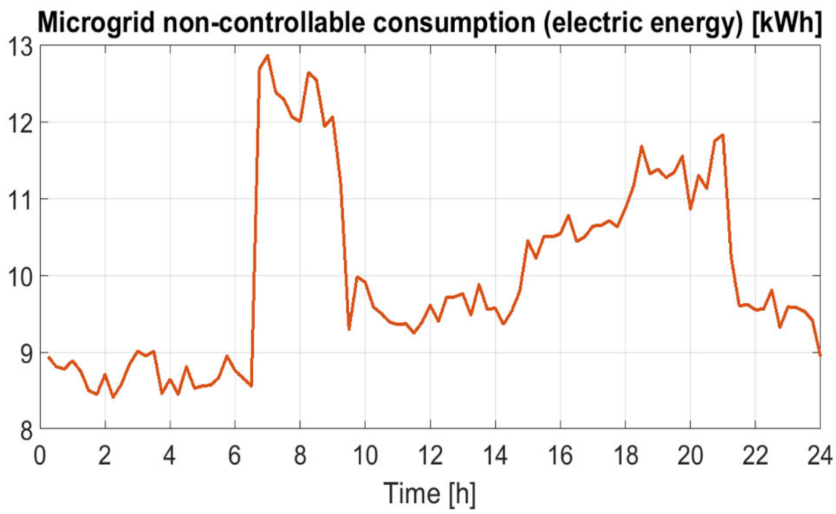

Figure 2.5. Non-controllable electrical energy consumption on the microgrid level, for a sunny workday in July.

2.2 The optimized building operation – cooling season

The presentation of the optimized building behaviour will be given by passing through different levels of the 3Smart system and analysing the optimized behaviours computed. For each level three responses are given corresponding to the three different modes of operation:

- conventional control;
- 3Smart system operation when flexibility is not called (or, without activation);
- 3Smart system operation when flexibility is called.

First the responses on the zone level are analysed. In conventional control on the zone level we consider that in each zone exists a simple hysteresis controller that switches progressively the fan coils fan speeds to higher when the temperature of the room rises more and more above the set point and vice versa when the opposite is the case. This way of operation is actually the state-of-the-art conventional control algorithm for rooms temperature regulation. The lowest fan speed switches on when the reference temperature, set in this analysis to 24°C, is surpassed above by 0.5°C. Conventional control on the zone level is leaned also to conventional control on higher levels, i.e. meaning that for the conventional control response on the zone level the cooling medium is prepared by following the conventional control algorithm on the central HVAC level. In Figure 2.2. one may see a typical temperature profile of one of the 248 zones of the UNIZGFER building. With conventional control (blue line) the air temperature in the zone is kept at about 24.5°C during the operating hours, i.e. some 0.5°C higher than the desired, reference temperature of 24°C. The cooling system is switched off from 20:30 till 06:00 the next day in all the control modes as this is the way how the system operates now. This is suboptimal for the 3Smart system as the flexibility in choosing the time of rooms cooling could bring further benefits (usually COP of the chiller during the night is much better), but for now the on-off operation schedule of the cooling system is outside the influence of the 3Smart system.

The 3Smart operation when flexibility is not called is the optimized building response obtained for the case when building obeys the reserved flexibility, but the grid has not activated the flexibility. This is the nominal scenario according to which the building plans its behaviour and the one from which the building's declaration of consumption for the grid comes. This also means that this declared profile is the basis for determining the building's flexibility reaction. The building in principle intentionally declares more and consumes more exactly in time frames of possible flexibility activation, thus giving itself a higher flexibility margin. This explains why in Figure 2.6 the building plans to intensively cool the rooms yet in the periods of flexibility: just after 11:30, just after 13:00 and just after 14:30 – see the purple line which corresponds to the building behaviour without activation. The building engages both the chiller and the fans of the fan coils in the flexibility period intensively. In order to remain in comfort interval and give more space to intensive cooling, in periods before the flexibility intervals the temperature is kept on the upper bound.

The 3Smart operation when flexibility is called is the optimized building response exhibited to obtain maximum power consumption reduction from the declared consumption profile exactly in the flexibility intervals. One may see in Figure 2.6 (orange line) that the system overcools the space before the flexibility intervals such that in them the cooling system can remain as silent as possible, in extreme case completely switched off, to give the highest consumption difference compared to the declared consumption profile, explained just above. So, in this scenario the zone is kept on 23.5°C which is the lower edge of the flexibility interval such that when the flexibility interval occurs the zone starts to heat up as the cooling is reduced to also reduce the consumption according to the flexibility request.

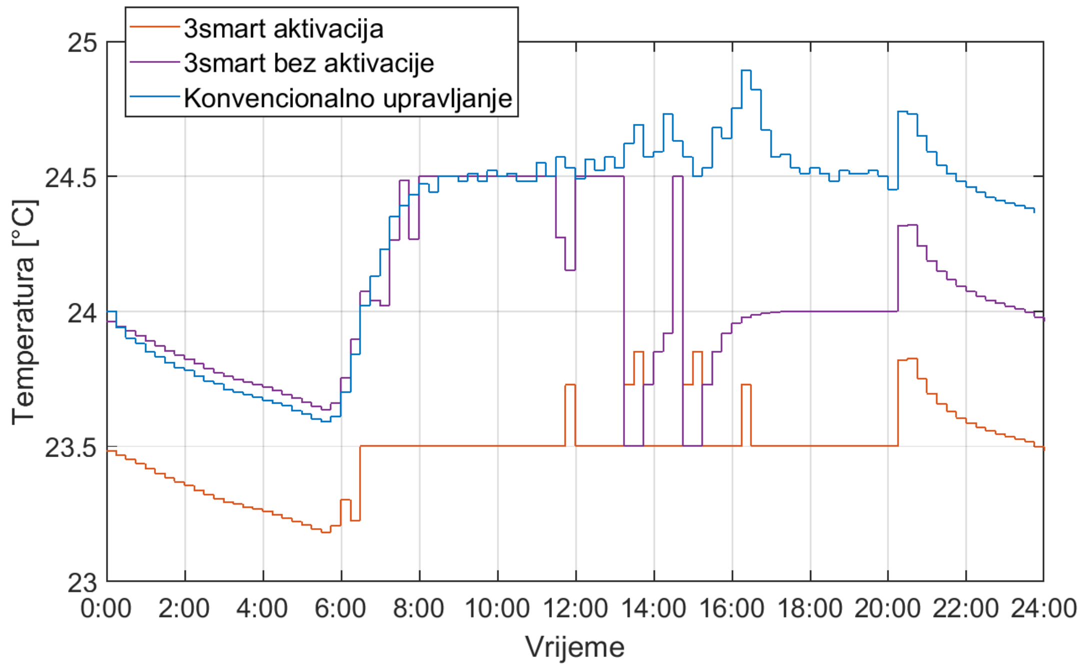

Figure 2.6. A typical response of temperature for a room in UNIZGFER building within the analysed day.

In Figure 2.7 one may see for the same zone as provided in Figure 2.6 the response of cooling energies provided from the fan coil to room air. The lowest cooling energy consumption actually here occurs with the conventional control, but it has also the lowest level of comfort achieved. At the times of flexibility windows one may see the abrupt rise in cooling energy for the case of behaviour without flexibility activation and the abrupt decrease in cooling energy consumption for the case of flexibility activation. This is exhibited, as explained above, to get highest possible flexibility margin from the cooling system.

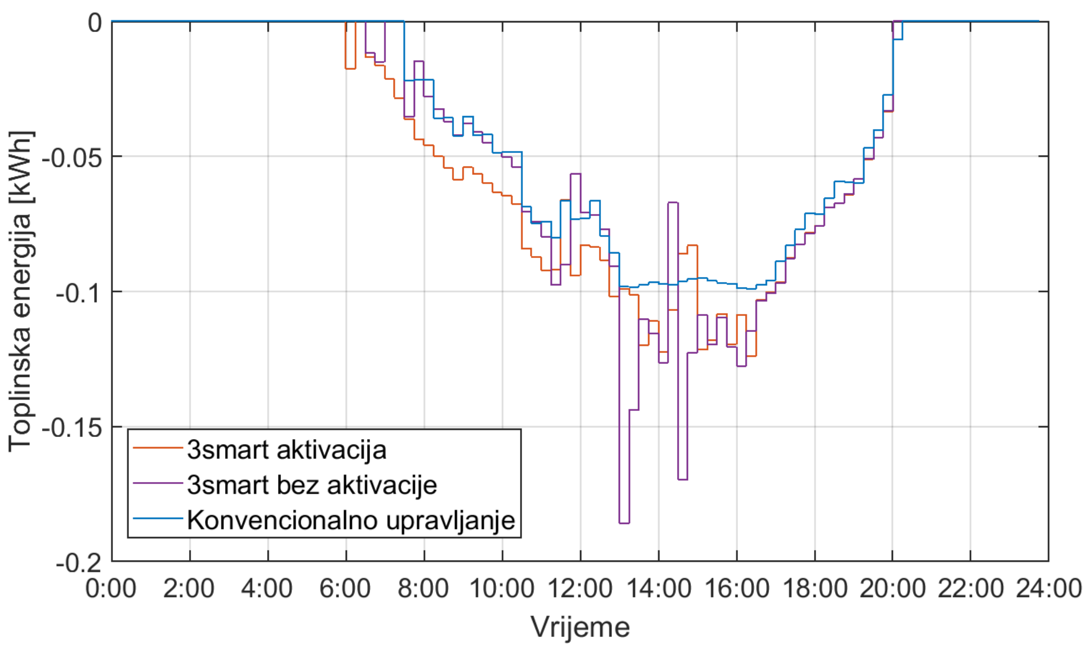

Figure 2.7. Typical cooling needs for one zone.

This becomes even more obvious in Figure 2.8 where the sum of required energies for exertion to rooms air for all the 248 controllable zones is shown.

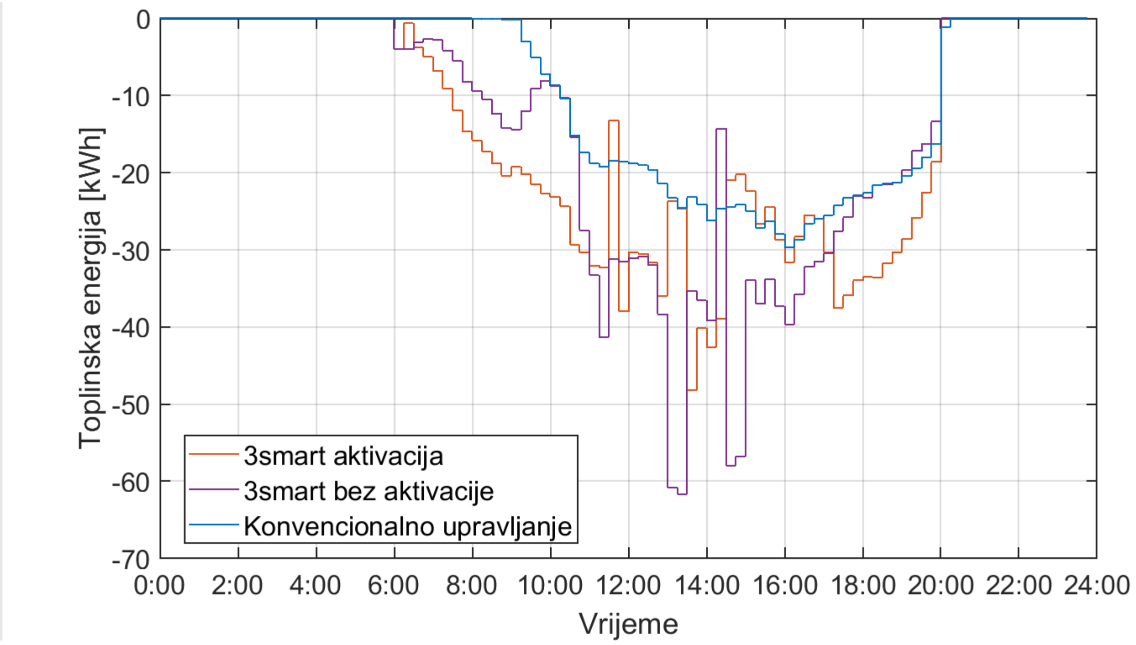

Figure 2.8. Overall cooling energy needs for all the zones (sum of energies that should be exerted in zones air).

On the central HVAC level manipulated variable of the system is the temperature of the medium coming out of the chiller. It must be set above the lower bound of 7°C. Conventional control in UNIZGFER building keeps this temperature permanently on 8°C (blue line in Figure 2.9). For saving reasons, taking into account that enough energy can be extracted to rooms' air with much higher starting temperature, the 3Smart system poses much higher starting temperatures which brings much more beneficial COP of the chiller and reduces the consumption of the overall cooling system significantly, especially considering also the losses in supply ducts.

However, at particular times of the day the temperature of the cooling medium is significantly lowered to provide the needed cooling load to keep the temperatures in all the rooms in the required temperature span. Additionally, these spikes are used for flexibility provision. Figure 2.9 and Figure 2.10 show the behaviour of the supply temperature from the chiller and the behaviour of the electricity consumption profile of the entire HVAC system – meaning the consumption of the chiller and of the fans of fan coils. Figure 2.10 shows a significant possibility of reduction of consumption by using more favourable operating points for chiller operation, in accordance with the cooling needs of all the zones – the temperature of the medium supplied towards the zones is always such that all cooling requests of all the zones can be served. Additionally, one may see a difference between the energy consumption profiles for cooling without activation of flexibility and with activation of flexibility. For the case when flexibility is not activated, consumption before flexibility intervals is reduced and pumped up in the flexibility intervals. For the case of activation, it is vice versa, more is consumed before (recall the pre-cooled spaces achieved, as explained above) and then consumption maximally decreased in the flexibility interval. In this way the flexibility provision potential of the building is maximized. From Figure 2.10 one may see that the flexibility offered is between 2 and 5 kWh in 15 minutes, i.e. the flexibility is between 8 kW (for the first flexibility interval) and 20 kW (for the second and third flexibility interval).

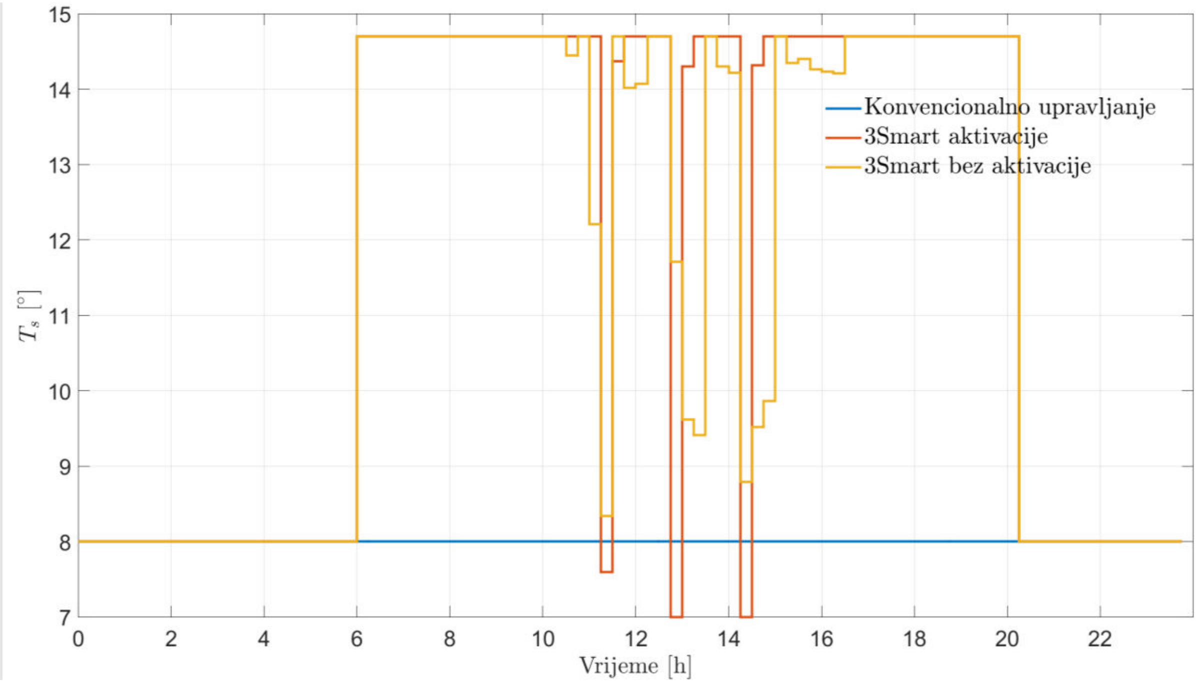

Figure 2.9. Profile of medium temperatures towards the zones.

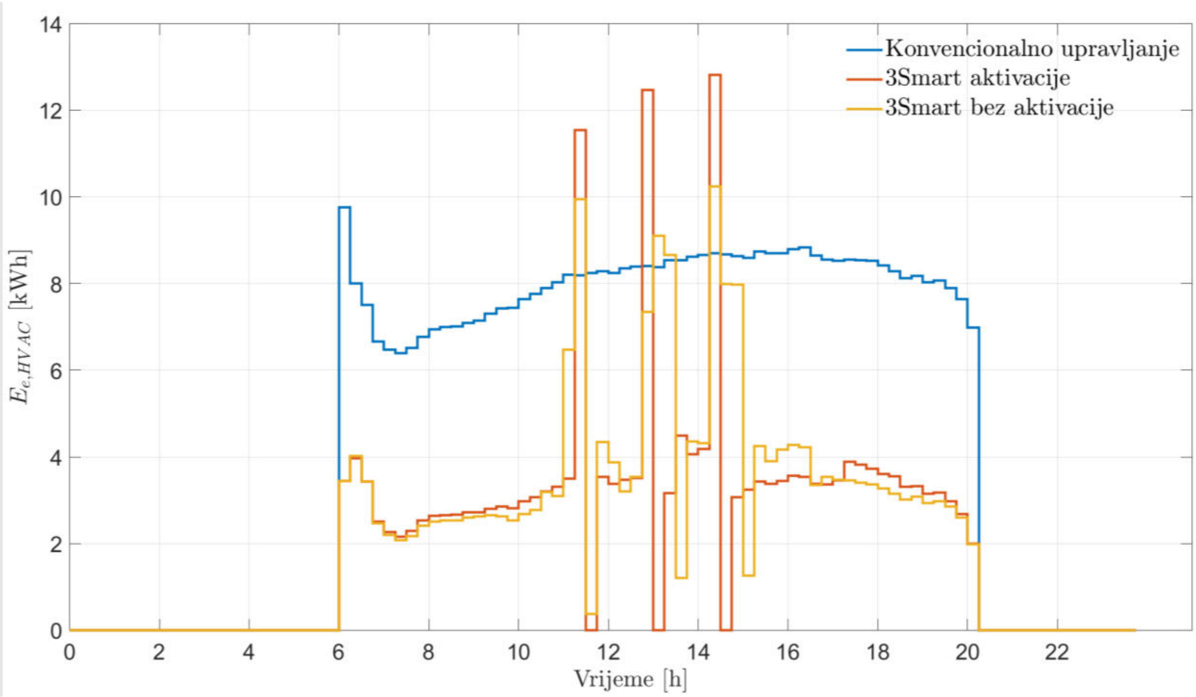

Figure 2.10. Electricity consumption of the HVAC system (chiller + fans of fan coils).

On the microgrid level controllable component is the battery system with whose charging or discharging the overall electricity exchange profile between the building and the grid can be modified. Figure 2.11 shows the operation of the battery system for the conventional control and for the 3Smart operation cases, without and with flexibility activation.

For the case of conventional control (blue line in Figure 2.11), the algorithm applied corresponds to the usual way of closed commercial battery storage systems operation which is actually flattening the energy exchange profile, in order to minimize the peak power payments. In the case of the battery system of the UNIZGFER building, its capacity and power (32 kWh / 10 kW) are rather small, and thus its effect on flattening the overall electricity consumption profile of the building is limited. One may see that the discharge is performed at 06:00 to reduce the power peak related to starting of the chiller machine, and the charging is performed just after turning off the chiller at 20:30 when the consumption of the building significantly drops. The flattening effect on the overall electricity exchange profile with the grid, presented in Figure 2.12 in blue line, is quite limited.

When operated with 3Smart, the microgrid level exploits the demand response opportunities offered by the grid in flexibility intervals and computes the optimal flexibility bid of the building towards the grid for each flexibility interval. The reaction on the microgrid level is consistent with the reactions on the lower level – the microgrid level decides that it pays off also to include the battery system in flexibility provision – thus when flexibility is not called it is planned to charge the battery exactly in the flexibility intervals in order to increase the load to be declared to the grid. But, when flexibility is called, in flexibility intervals actually discharging operation happens. In this way the achieved flexibility for a 10 kW battery system is 10 kW of declared consumption (for charging) minus -10 kW of actual reaction when activation is called (for discharging) and thus amounts 10-(-10)=20 kW.

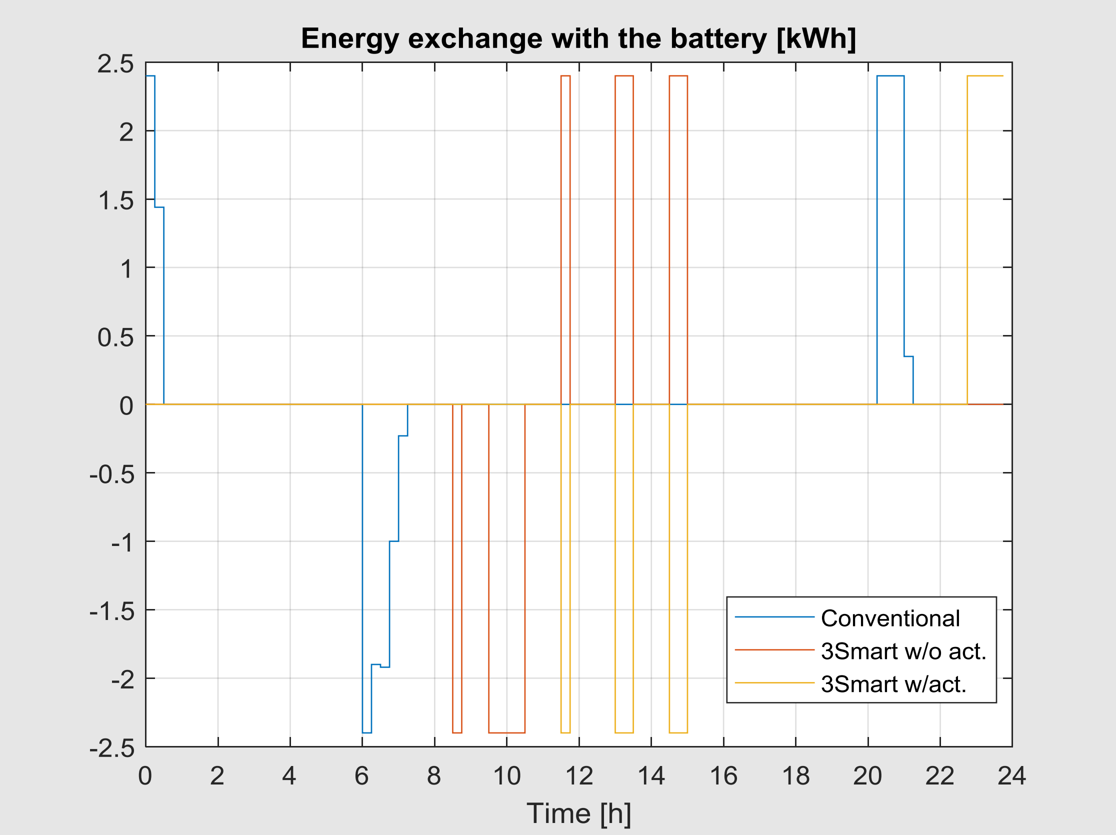

Figure 2.11. Battery system energy exchange.

The overall electricity exchange profile with the grid is given in Figure 2.12. Significantly lower electricity consumption comes dominantly from more efficient cooling with higher supply temperature due to the higher COP of the chiller. Also one may see the available flexibility amounts as the difference between the 3Smart with activation and 3Smart without activation energy exchange profiles.

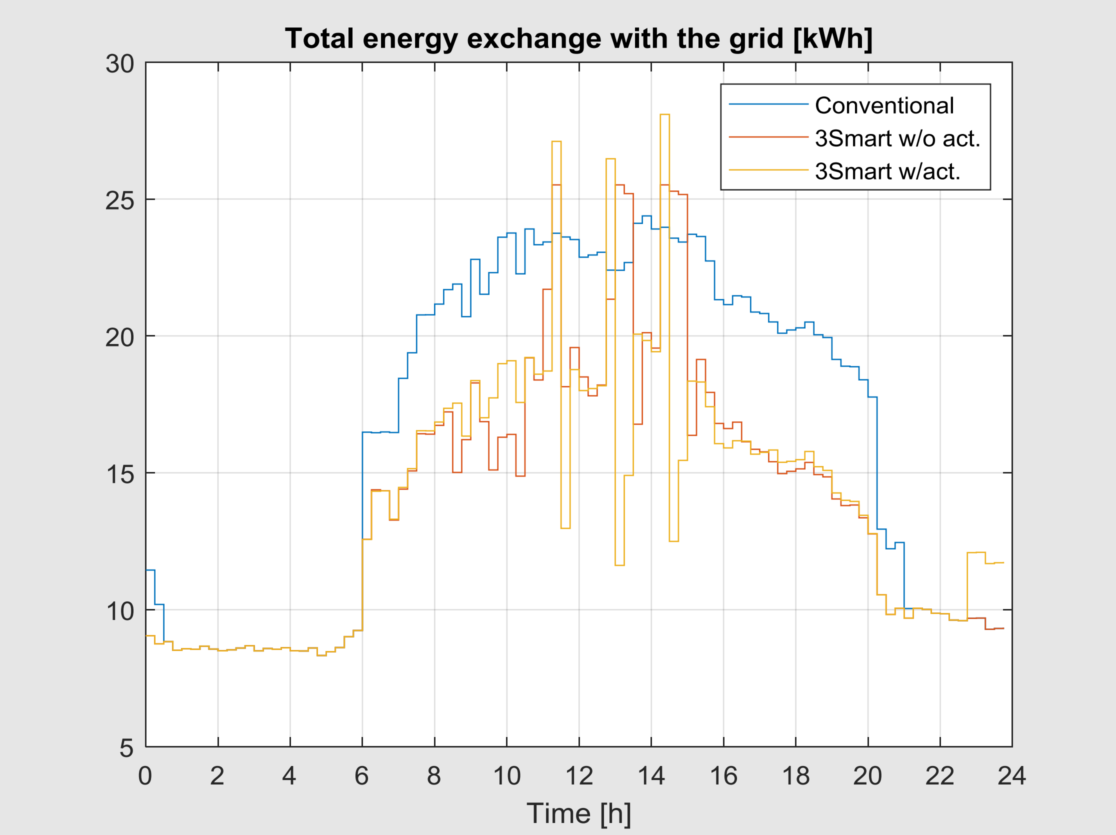

Figure 2.12 Electricity exchange with the grid

The flexibilities offered by the building for specific flexibility intervals are shown in Figure 2.13. The overall operational costs of the building for the sunny workday in July are provided in Figure 2.14.: 105 EUR for conventional control, 65 EUR for 3Smart control without activation of flexibility, and 58 EUR for 3Smart control with activation of flexibility. Average daily gain is thus 43.5 EUR or roughly 43 EUR.

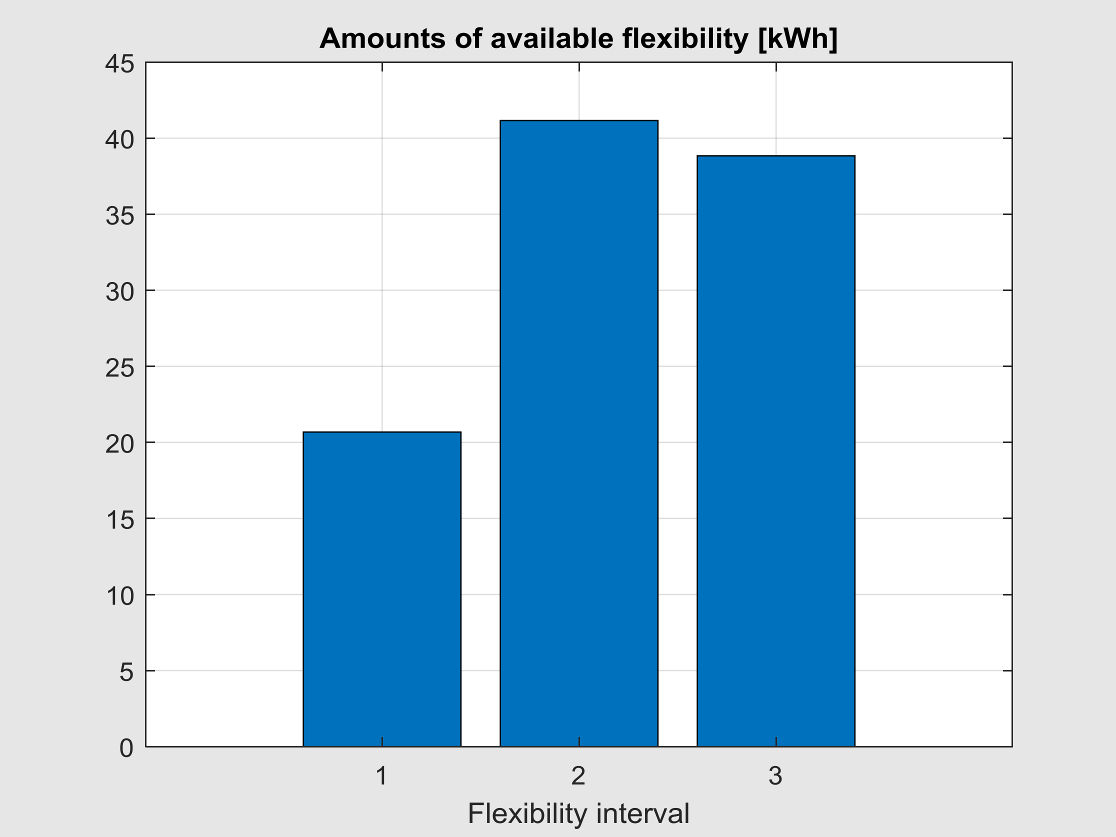

Figure 2.13 Flexibilities offered for the 3 flexibility intervals: 20, 41, 38 kW respectively.

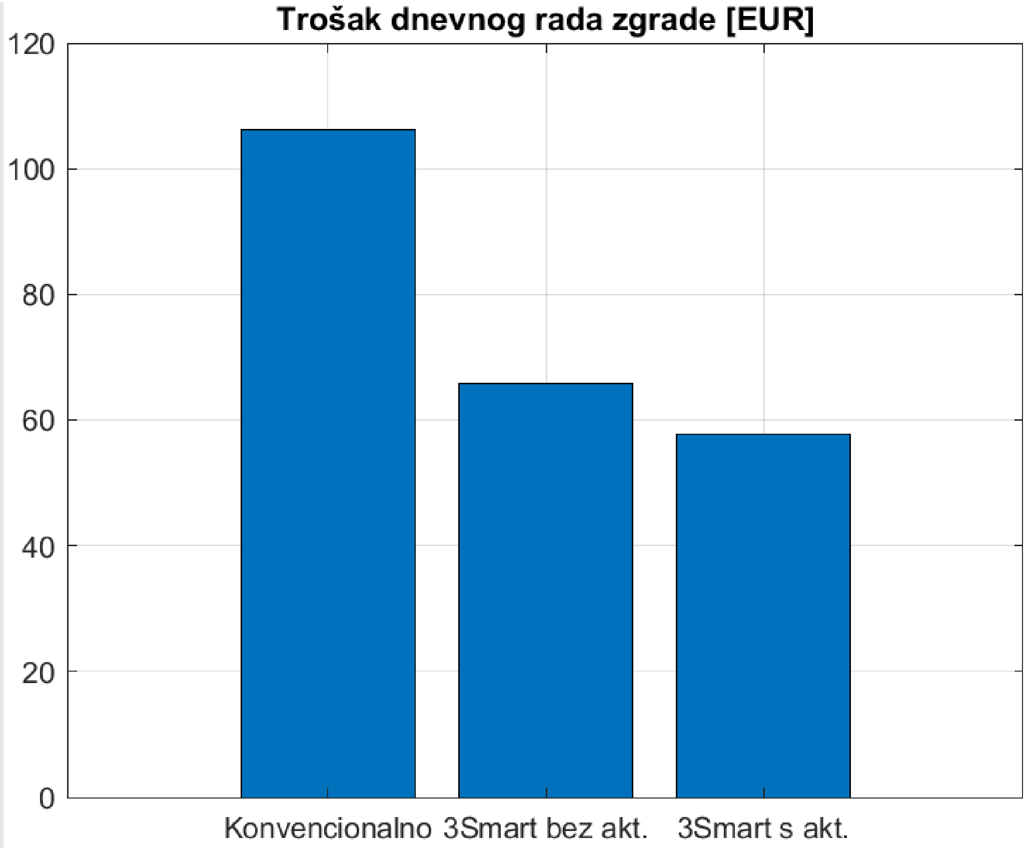

Figure 2.14. Overall building operational costs for the sunny workday in July.

2.3 Grid-side and boundary conditions for the building operation – heating season

The explanation of the operational logs is started by presenting the conditions provided by the grid for a sunny workday in January.

The needed flexibility time window for the grid within the analysed day is as follows:

- 11:30-15:00.

The pricing conditions computed by performing the calculations by long-term grid-side modules are as follows:

- reservation price: 0.0162 EUR/kW/15 min;
- activation price: 0.065 EUR/kWh;
- penalty price: 0.13 EUR/kWh.

The expected day-ahead electricity pricing is shown in Figure 2.15.

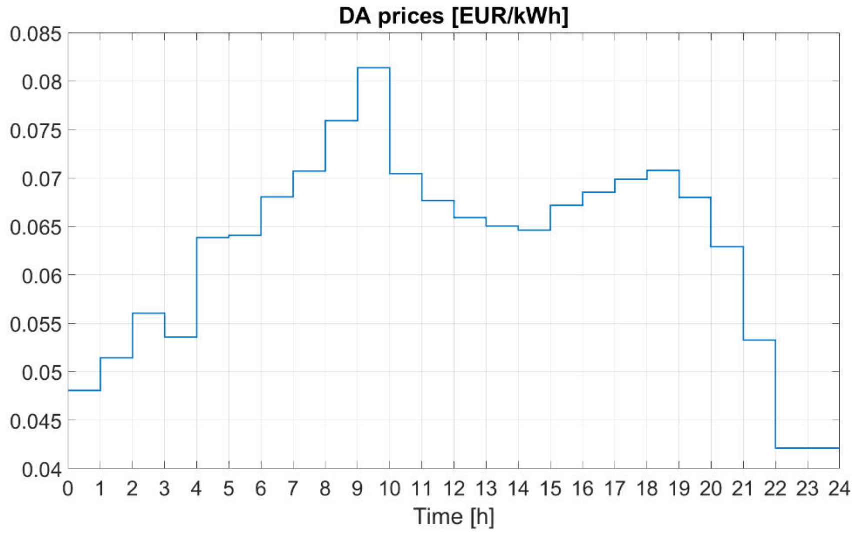

Figure 2.15. Day-ahead electricity pricing for a sunny workday in January.

Additional parameters taken into account are consisted of the relevant meteorological conditions, namely outdoor air temperature profile (shown in Figure 2.16) and direct and diffuse solar irradiance profiles (shown in Figure 2.17), as well as the non-controllable consumptions on the HVAC level (thermal energy consumption profile shown in Figure 2.x) and the microgrid level (electrical energy consumption profile shown in Figure 2.x).

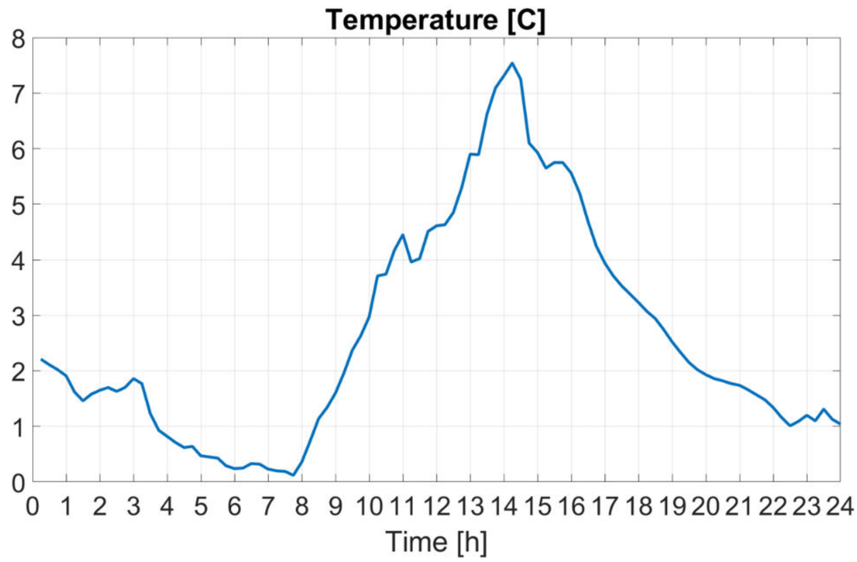

Figure 2.16. Outdoor air temperature for a sunny day in January.

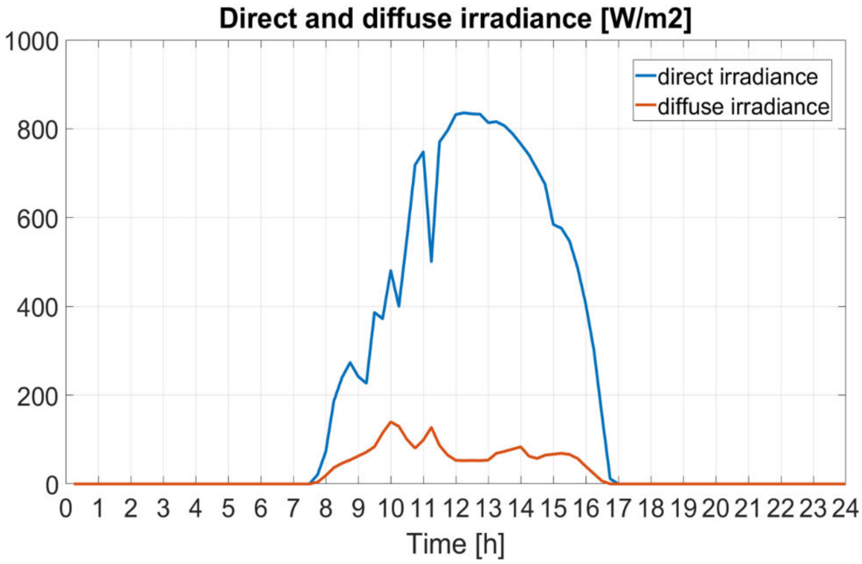

Figure 2.17. Direct (normal) and diffuse (horizontal) solar irradiance for a sunny day in January.

The non-controllable thermal energy consumption on the HVAC level (Figure 2.18) accounts for the consumption of radiators throughout the building in service rooms (kitchens, toilets) and the main stairway. The non-controllable electrical energy consumption on the microgrid level (Figure 2.19) is consisted of the energy consumption of the office lighting, computers, building elevators as well as refrigerators and electrical air conditioning units in server rooms.

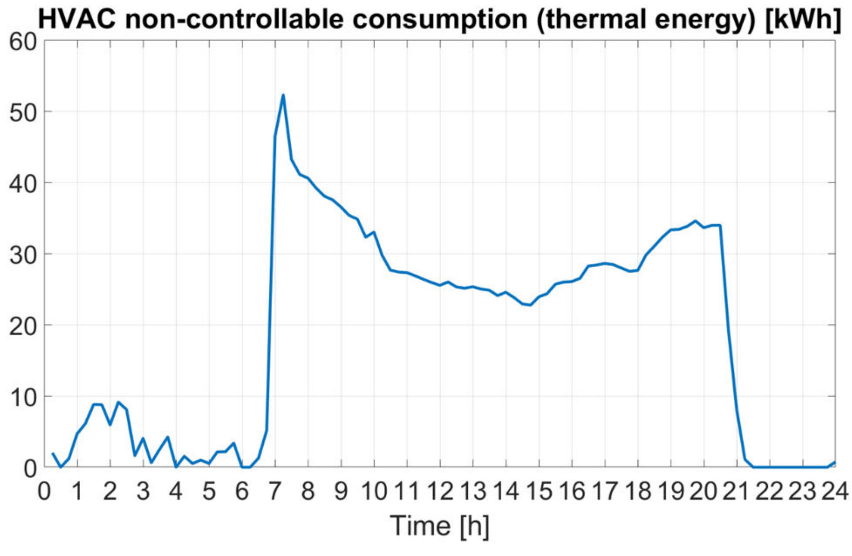

Figure 2.18. Non-controllable consumption of thermal energy on the HVAC level, for a sunny workday in January.

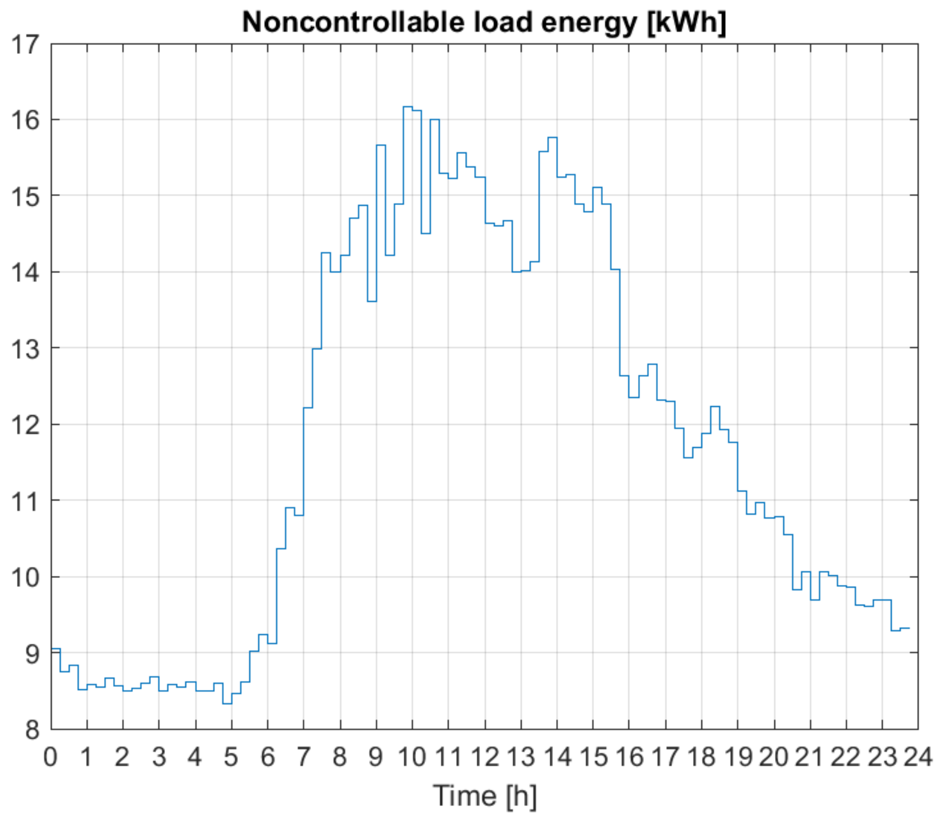

Figure 2.19. Non-controllable electrical energy consumption on the microgrid level, for a sunny workday in January.

2.4 The optimized building operation – heating season

The presentation of the optimized building behaviour will be given by passing through different levels of the 3Smart system and analysing the optimized behaviours computed. For each level three responses are given corresponding to the three different modes of operation:

- conventional control;
- 3Smart system operation when flexibility is not called (or, without activation);
- 3Smart system operation when flexibility is called.

First the responses on the zone level are analysed. In conventional control on the zone level we consider that in each zone exists a simple hysteresis controller that switches progressively the fan coils fan speeds to higher when the temperature of the room falls more and more below the set point and vice versa when the opposite is the case. This way of operation is actually the state-of-the-art conventional control algorithm for rooms temperature regulation in heating. The lowest fan speed switches on when the reference temperature, set in this analysis to 25°C, is surpassed below by 0.5°C. Conventional control on the zone level is leaned also to conventional control on higher levels, i.e. meaning that for the conventional control response on the zone level the cooling medium is prepared by following the conventional control algorithm on the central HVAC level. In Figure 2.20. one may see a typical temperature profile of one of the 248 zones of the UNIZGFER building. With conventional control (blue line) the air temperature in the zone is kept within [24.5,25.5]°C during the operating hours. Heating is available during the entire day, but the temperature is required to be within the comfort limits only within the occupancy periods, i.e. between 06:30 and 20:00.

The 3Smart operation when flexibility is called is the optimized building response exhibited to obtain maximum power consumption reduction from the declared consumption profile exactly in the flexibility intervals. One may see in Figure 2.20 (orange line) that the system overheats the space before the flexibility interval such that in them the heating system can remain as silent as possible, in extreme case completely switched off, to give the highest consumption difference compared to the declared consumption profile. So, in this scenario the zone is kept on 25.5°C which is the higher edge of the flexibility interval such that when the flexibility interval occurs the zone starts to cool down as the heating is reduced to also reduce the consumption according to the flexibility request. In order to well prepare for provision of flexibility, the building is pre-heated during the night such that also its internal states (walls, furniture) are heated up to give then the possibility for the building to slowly cool down almost during the entire flexibility interval and that the heating needs and fan coil fan usage are reduced as much as possible. Thermal energy request, for the room whose temperature response is given in Figure 2.20, is provided in Figure 2.21.

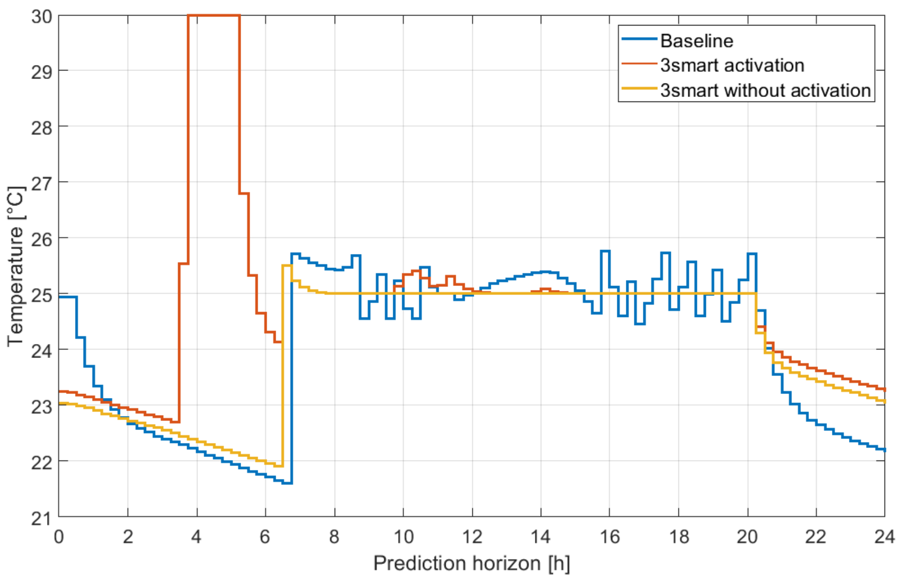

Figure 2.20. A typical response of temperature for a room in UNIZGFER building within the analysed day.

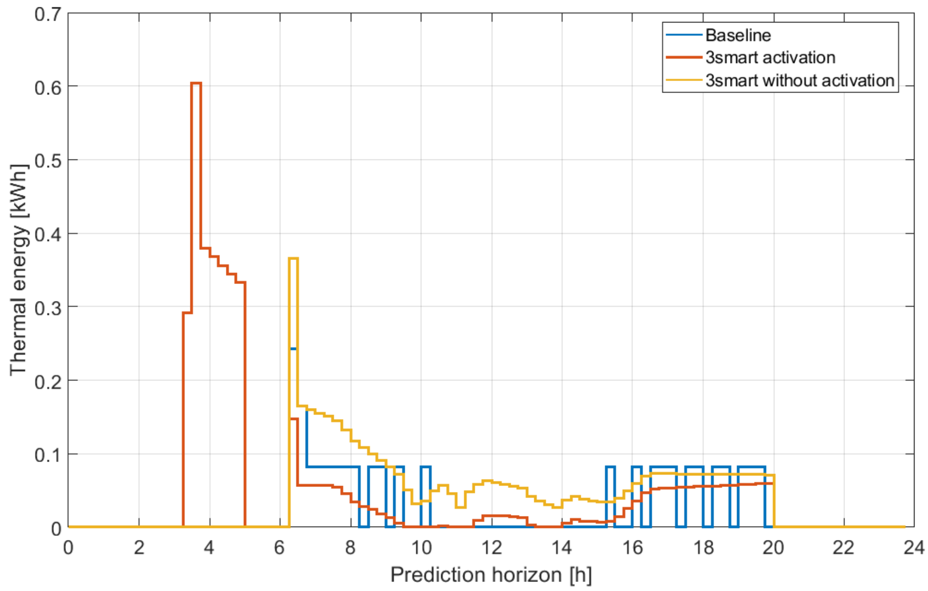

Figure 2.21. Thermal energy exerted to air of the considered room in UNIZGFER building within the analysed day.

Figure 2.22 shows the cumulated thermal energy needs of all 248 controllable zones within the UNIZGFER building. One may observe that the highest energy demand, at the time of the heating system switch on at 06:00 even oversteps the 1 MW heating power limit of the heat exchanger with conventional control. The 3Smart system obeys this limit and uses pre-heating even when flexibility is not called to be able to stay below the heat exchanger limit when heating needs to start for comfort reasons.

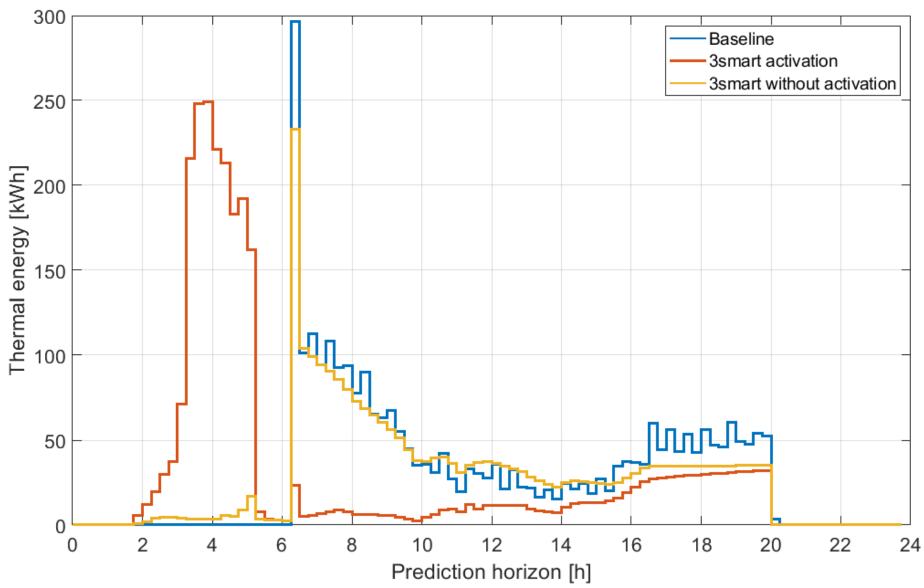

Figure 2.22. Overall heating energy needs for all the zones (sum of energies that should be exerted in zones air).

The central HVAC system level in the heating season on UNIZGFER building decides on the starting supply temperature of the medium and on the starting medium flow through the secondary of the heat exchanger. Baseline in this case is a constant 60°C reference and a stepwise waveform for the supply medium flow, being lower in the non-occupancy period and higher during the occupancy period. The exhibited responses are shown in Figure 2.23 for the supply medium temperature and in Figure 2.24 for the HVAC supply medium flow. One may see the reaction in case of activation where the supply medium temperature is intentionally raised at the times of flexibility. In this way the heating needs of rooms can be attained with lower fan speeds and thus reduced electricity consumptions. Supply medium flow reference is also in the case of activation reduced.

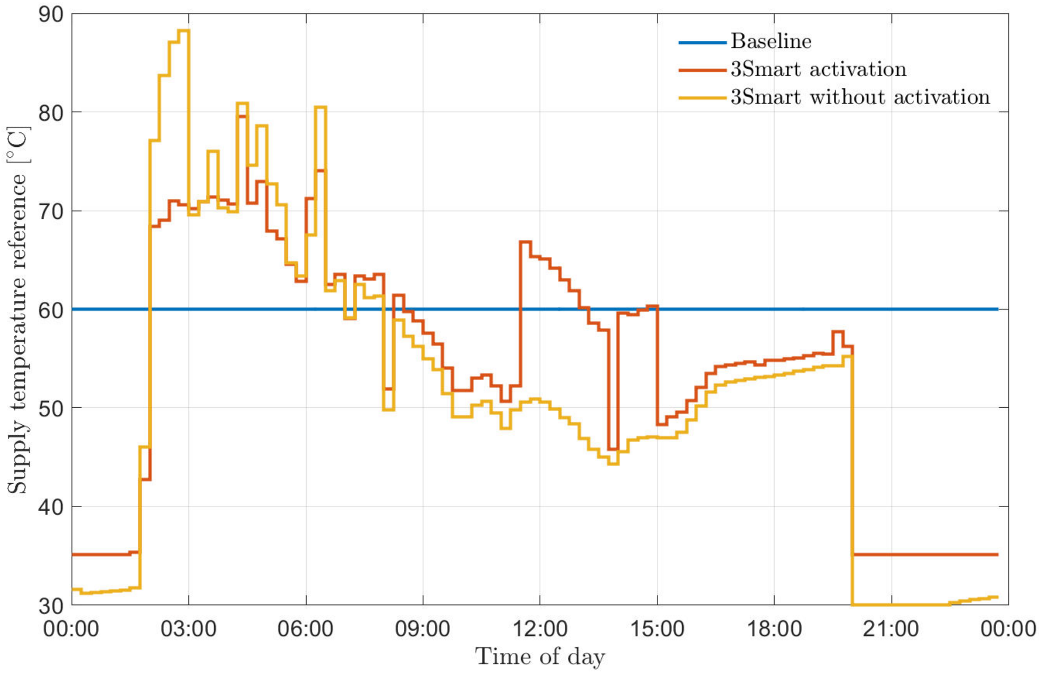

Figure 2.23. HVAC supply medium temperature reference.

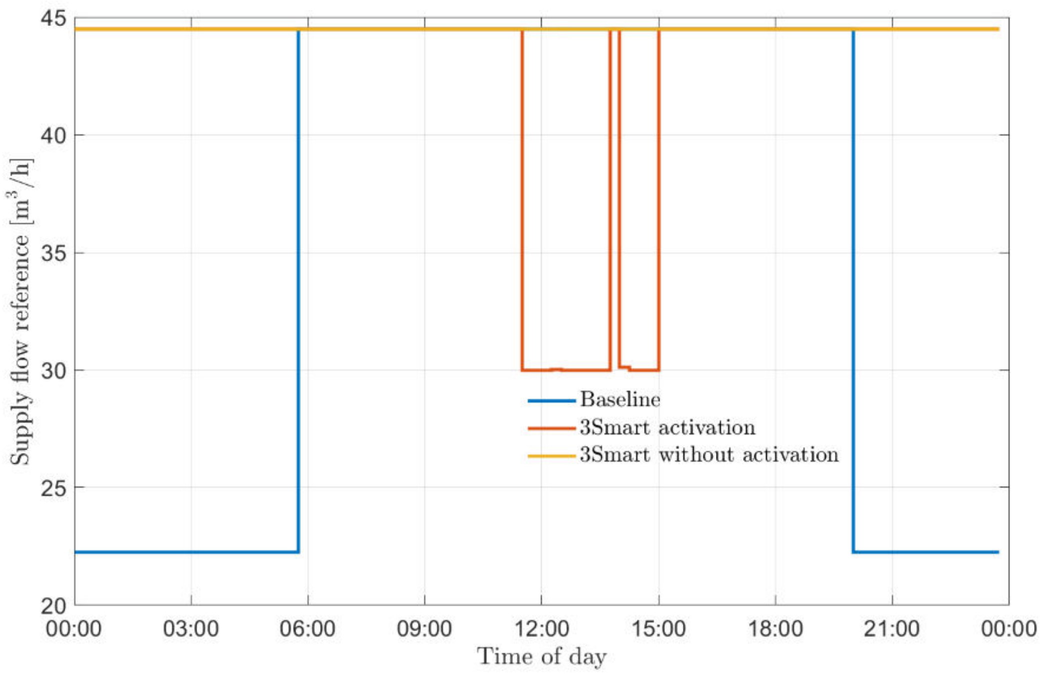

Figure 2.24. HVAC supply medium flow reference.

The overall exhibited electricity consumption profile on the central HVAC system level is shown in Figure 2.25. One may see that in case of activation the electricity consumption is significantly reduced, at the cost of higher electricity and thermal energy usage in the early morning.

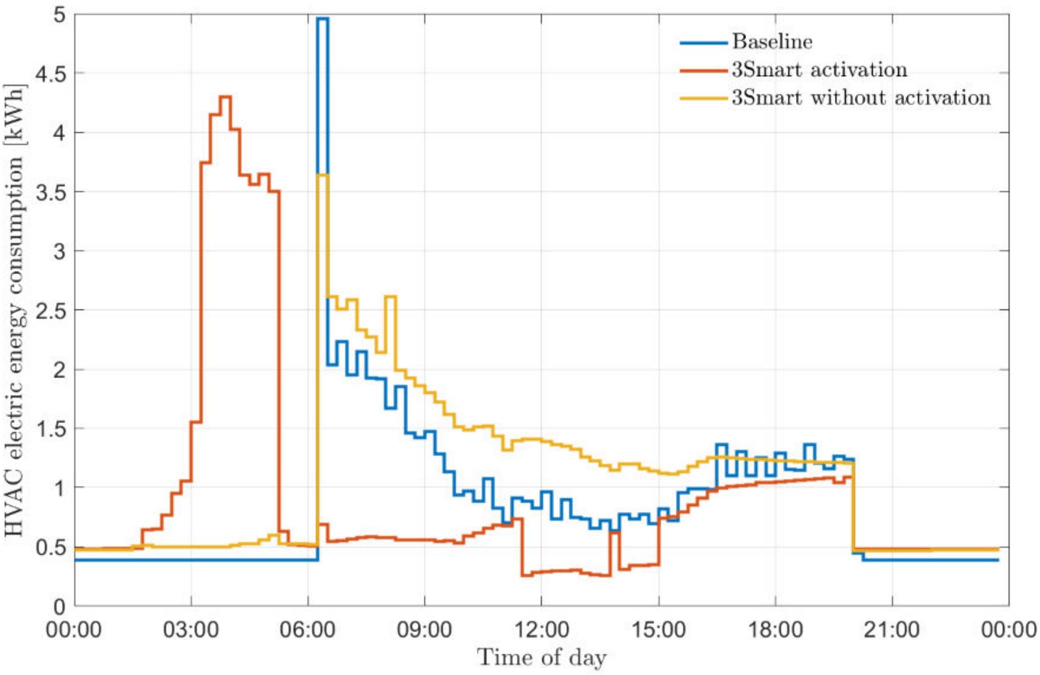

Figure 2.25. HVAC electric energy consumption.

On the microgrid level the battery system without activation is practically not actuated, and for the case of activation it is only used to flatten the reduced consumption such that a constant flexibility can be offered, see Figure 2.26. In the case of conventional control the battery system is used to flatten the electricity demand such that it gets discharged in the morning when there is a significant demand increase due to fan coils fans and circulation pump increased consumption. It gets back charged in the evening when the consumption of the heating system drops.

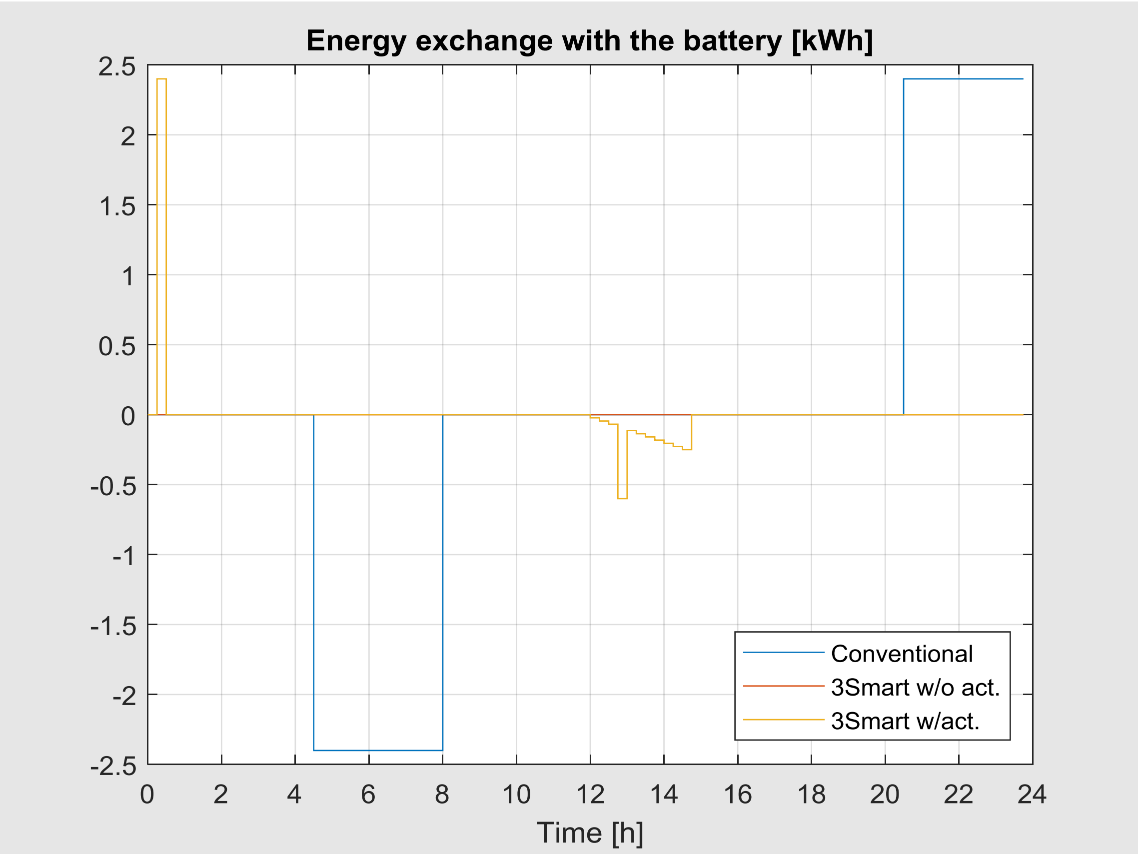

Figure 2.26. Energy exchange with the battery system.

The form of the overall electricity exchange with the grid in the three mentioned cases – conventional control, 3Smart without activation and 3Smart with activation – is shown in Figure 2.27. One may spot the difference between the 3Smart without and with activation showing the flexibility margin the building can provide for demand response. In heating this flexibility is quite limited and amounts only 4.5 kW. It may be observed that it stems from the heating system while the batteries are just used to flatten the power decrease through the flexibility interval.

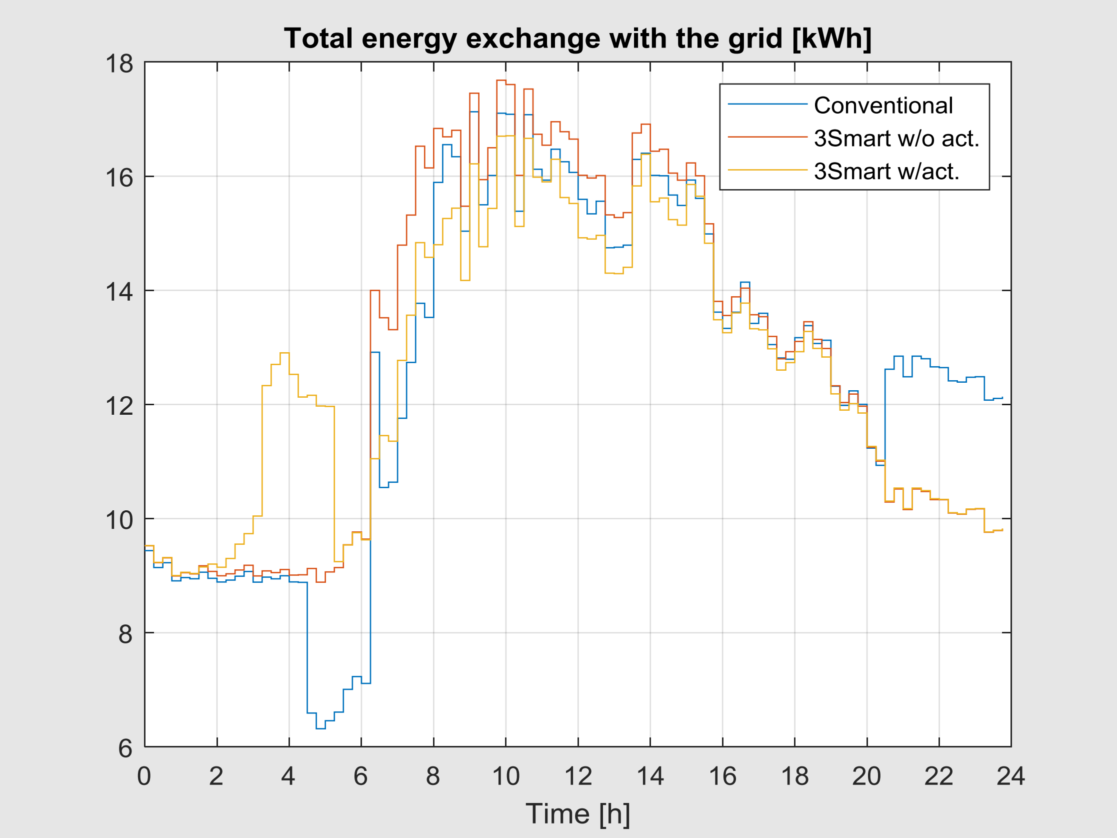

Figure 2.27. Total energy exchange with the grid. Flexibility interval: 11.30-15.00. Flexibility offer: 4.5 kW.

The comparative economical performance assessment of the building operation is provided in Table 2.1. The total daily savings in heating amount at 15 € (7,8%) in average – assessed with presumption flexibility is activated in 50% of cases.

Table 2.1. Costs comparison for a typical January workday.

	Conventional control	**MPC – w/o activation**	**MPC – with activation**
Heating	130.14 €	120.24 €	125.02 €
Electricity, microgrid operation, flexibility	61.54 €	54.51 €	53.64 €
Total	191.68 €	174.75 €	178,66 €

3. HEP building operational logs and seasonal analysis

3.1 Grid-side and boundary conditions for the building operation – cooling season

The explanation of the operational logs is started by presenting the conditions provided by the grid for a sunny workday in July.

The needed flexibility time window for the grid within the analysed day is as follows:

- 11:30-11:45;
- 13:00-13:30;
- 14:30-15:00.

The pricing conditions computed by performing the calculations by long-term grid-side modules are as follows:

- reservation price: 0.027 EUR/kW/15 min;
- activation price: 0.109 EUR/kWh;
- penalty price: 0.219 EUR/kWh.

The expected day-ahead electricity pricing is shown in Figure 3.1.

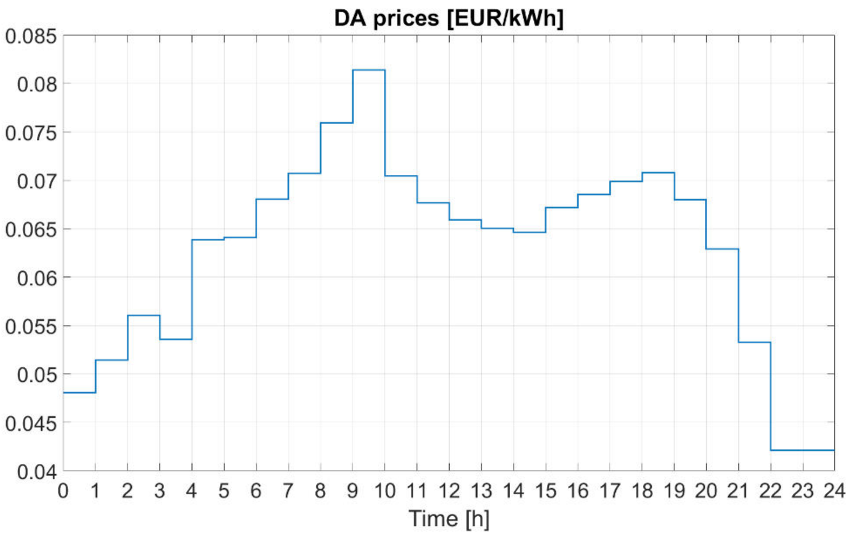

Figure 3.1. Day-ahead electricity pricing for a sunny workday in July.

Additional parameters taken into account are consisted of the relevant meteorological conditions, namely outdoor air temperature profile (shown in Figure 3.2) and direct and diffuse solar irradiance profiles (shown in Figure 3.3), as well as the non-controllable consumptions on the HVAC level (thermal energy consumption profile shown in Figure 3.4) and the microgrid level (electrical energy consumption profile shown in Figure 3.5).

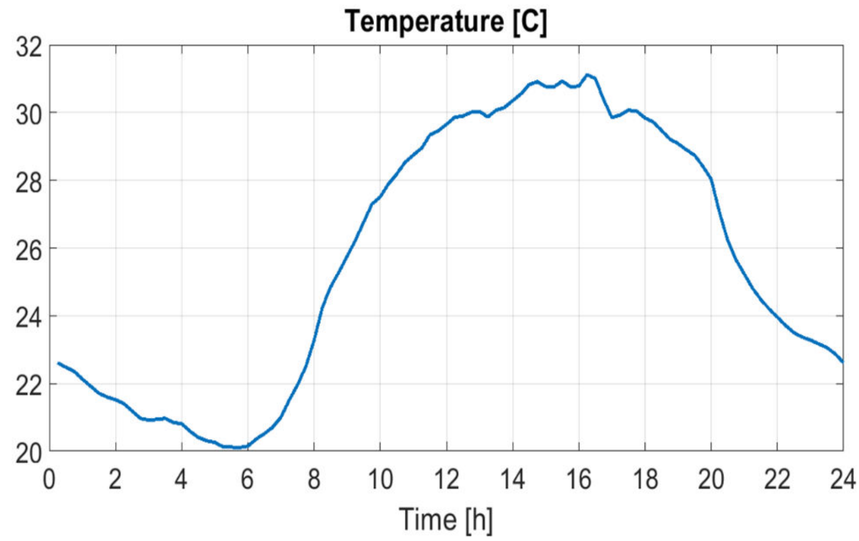

Figure 3.2. Outdoor air temperature for a sunny day in July.

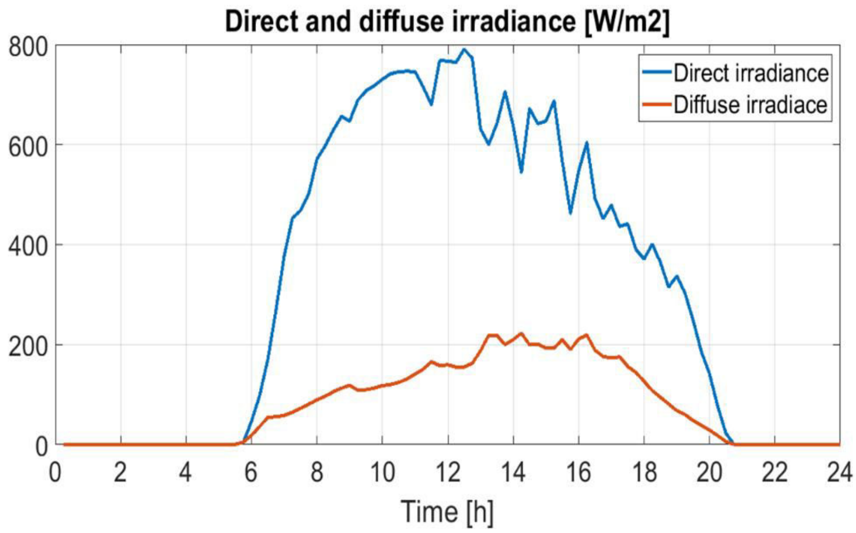

Figure 3.3. Direct (normal) and diffuse (horizontal) solar irradiance for a sunny day in July.

Non-controllable thermal energy consumption on the HVAC level accounts for the consumption of the additional auxiliary buildings cooled from the same chiller while the non-controllable electrical energy consumption on the microgrid level is consisted of the energy consumption of the office lighting, computers, building elevators as well as refrigerators and additional electrical equipment.

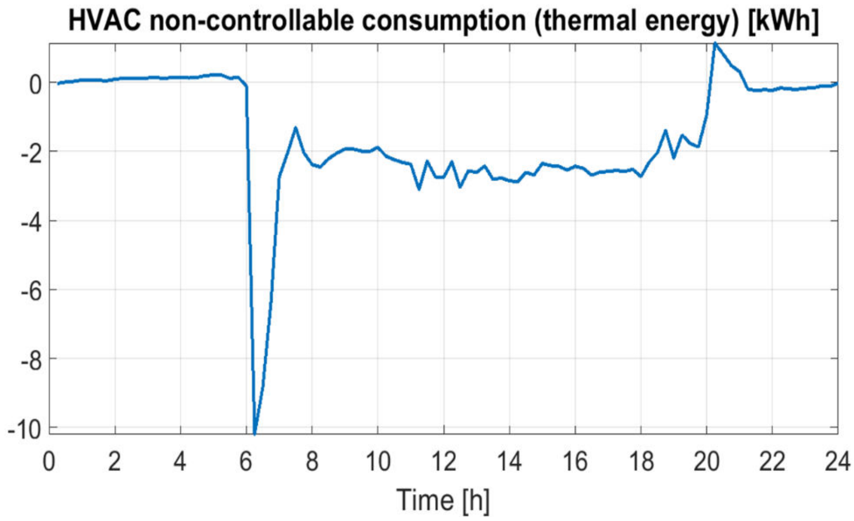

Figure 3.4. Non-controllable consumption of thermal energy on the HVAC level, for a sunny workday in July.

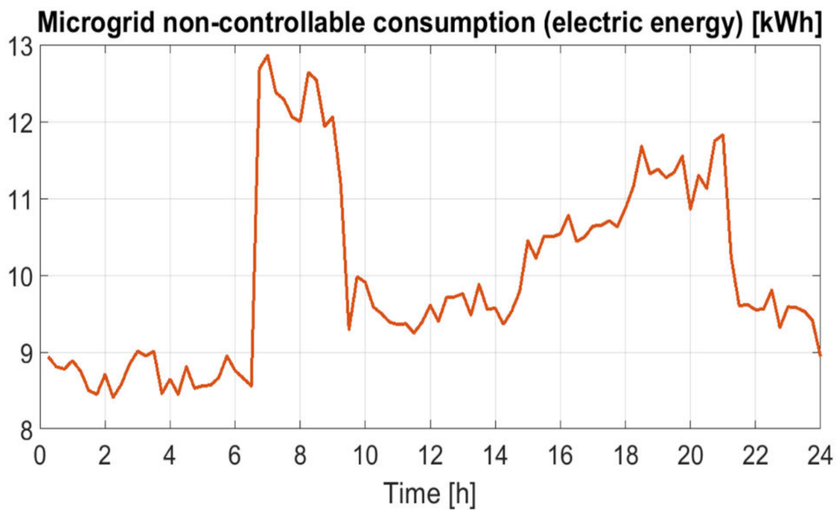

Figure 3.5. Non-controllable electrical energy consumption on the microgrid level, for a sunny workday in July.

3.2 The optimized building operation – cooling season

The presentation of the optimized building behaviour will be given by passing through different levels of the 3Smart system and analysing the optimized behaviours computed. For each level three responses are given corresponding to the three different modes of operation:

- conventional control;
- 3Smart system operation when flexibility is not called (or, without activation);
- 3Smart system operation when flexibility is called.

First the responses on the zone level are analysed. In conventional control on the zone level we consider that in each zone exists a simple hysteresis controller that switches progressively the fan coils fan speeds to higher when the temperature of the room rises more and more above the set point and vice versa when the opposite is the case. This way of operation is actually the state-of-the-art conventional control algorithm for rooms temperature regulation. The lowest fan speed switches on when the reference temperature, set in this analysis to 24°C, is surpassed above by 0.5°C. Conventional control on the zone level is leaned also to conventional control on higher levels, i.e. meaning that for the conventional control response on the zone level the cooling medium is prepared by following the conventional control algorithm on the central HVAC system level. In Figure 3.6 one may see a typical temperature profile of one of the zones of the HEP building. The cooling system is switched off from 06:00 till 18:00 the next day in all the control modes as this is the way how the system operates now. This is suboptimal for the 3Smart system as the flexibility in choosing the time of rooms cooling could bring further benefits (usually COP of the chiller during the night is much better), but for now the on-off operation schedule of the cooling system is outside the influence of the 3Smart system.

The 3Smart operation when flexibility is not called is the optimized building response obtained for the case when building obeys the reserved flexibility, but the grid has not activated the flexibility. This is the nominal scenario according to which the building plans its behaviour and the one from which the building's declaration of consumption for the grid comes. This also means that this declared profile is the basis for determining the building's flexibility reaction. The building in principle intentionally declares more and consumes more exactly in time frames of possible flexibility activation, thus giving itself a higher flexibility margin. On the other hand, with activation the building tries to reduce its consumption in flexibility intervals as much as possible to enlarge the flexibility margin. This explains why in Figure 2.6 the building plans to intensively cool the rooms just before the periods of flexibility and then reduced cooling in the flexibility interval which causes the temperature to rise from the lower to the upper comfort margin. One may see in Figure 3.6 (red line) that the system overcools the space before the flexibility intervals such that in them the cooling system can remain as silent as possible, in extreme case completely switched off, to give the highest consumption difference compared to the declared consumption profile. So, in this scenario the zone is kept on 23.5°C which is the lower edge of the flexibility interval such that when the flexibility interval occurs the zone starts to heat up as the cooling is reduced to also reduce the consumption according to the flexibility request.

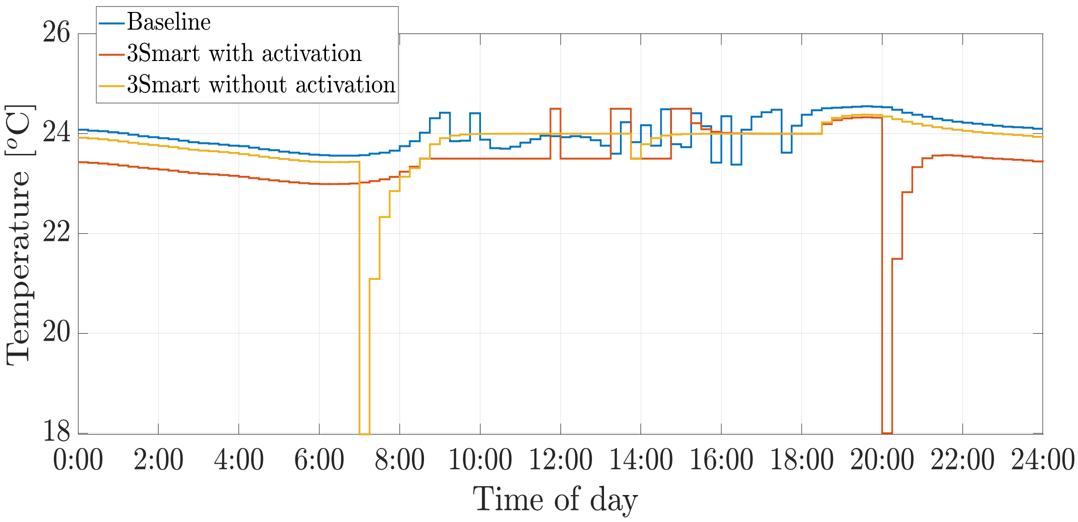

Figure 3.6. A typical response of temperature for a room in HEP building within the analysed day.

Figure 3.7 shows the behaviour of the cooling energy provided to room air, for the room with temperature response shown in Figure 3.6. Before the flexibility provision there is an intentionally introduced interval of extensive cooling, and the maximum reduction that still enables to remain within the comfort range in the flexibility interval.

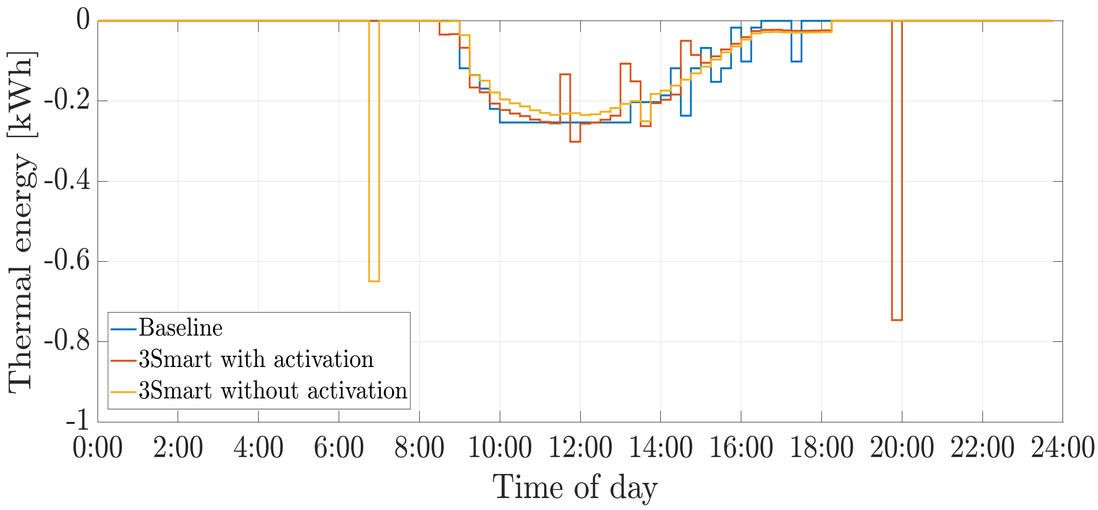

Figure 3.7. Typical cooling needs for one zone.

Figure 3.8 shows the cumulated cooling demands of all the zones, and again the pattern from a single room, shown in Figure 3.7, can be observed. One may spot an intensive precooling in the morning to yield the comfort on time and use lower outside air temperature for a better COP of the heat pump. The zone level has decided that in interaction with the central HVAC level.

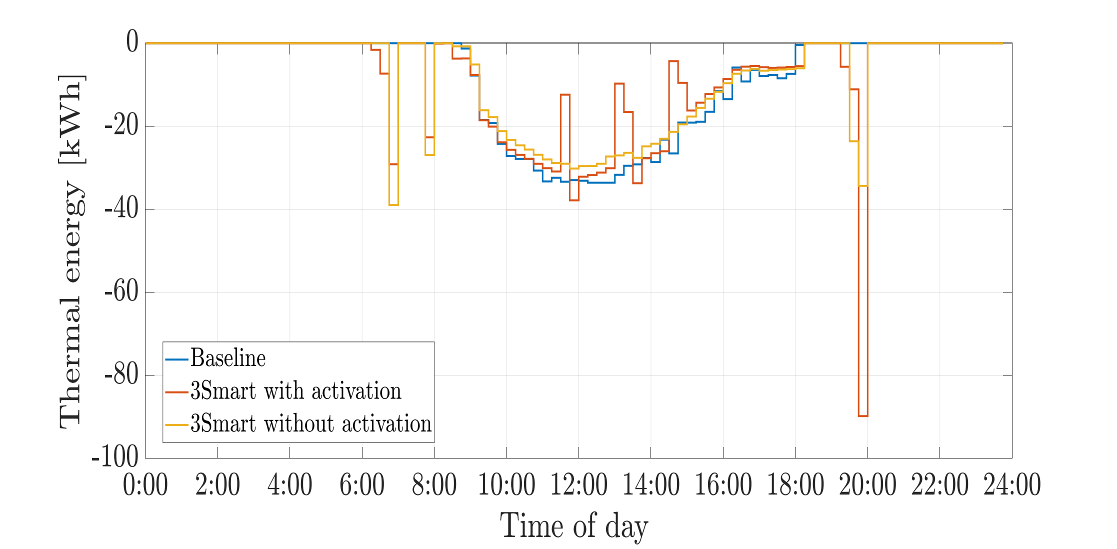

Figure 3.8. Overall cooling energy needs for all the zones (sum of energies that should be exerted in zones air).

The central HVAC system level is responsible for deciding the starting temperature of the cooling medium. The supply medium temperature behaviour as calculated with 3Smart for the case of activation and no activation of flexibility is provided in Figure 3.9. Also conventional control is shown where the starting medium temperature is decided based on the current outdoor temperature, as provided in Figure 3.2. Also here intensive pre-cooling in the morning is visible with 3Smart to attain lower temperature states in rooms, including the higher inertia state of walls and furniture, that then enables less intensive cooling during the day.

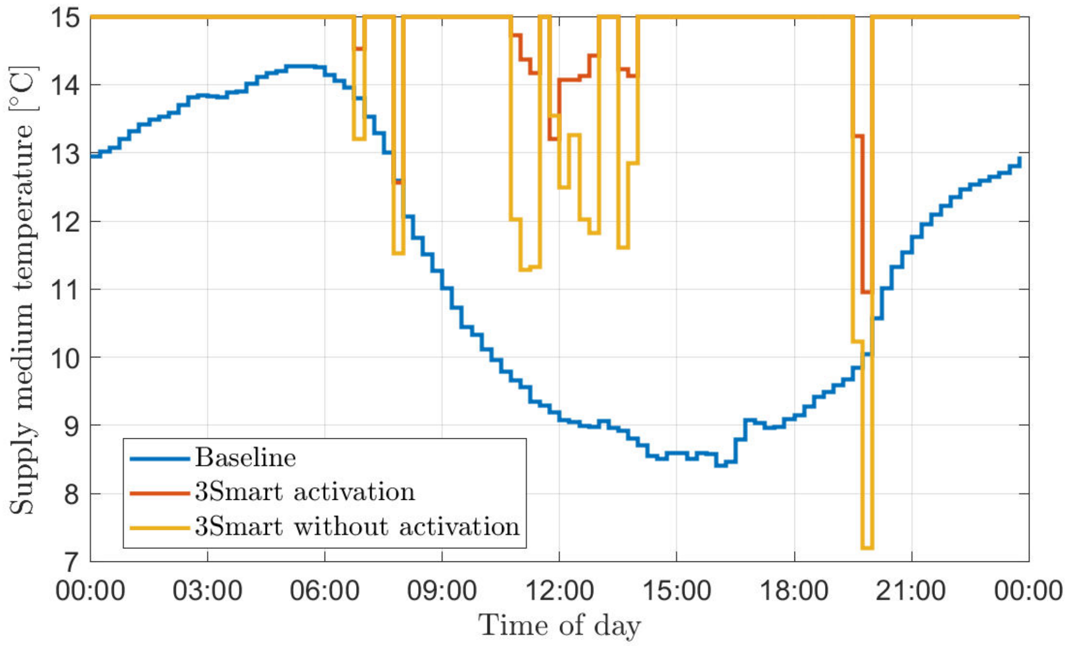

Figure 3.9. Supply medium temperature at the output of the chiller towards the building.

Also here intensive pre-cooling in the morning is visible with 3Smart to attain lower temperature states in rooms, including the higher inertia state of walls and furniture, that then enables less intensive cooling during the day.

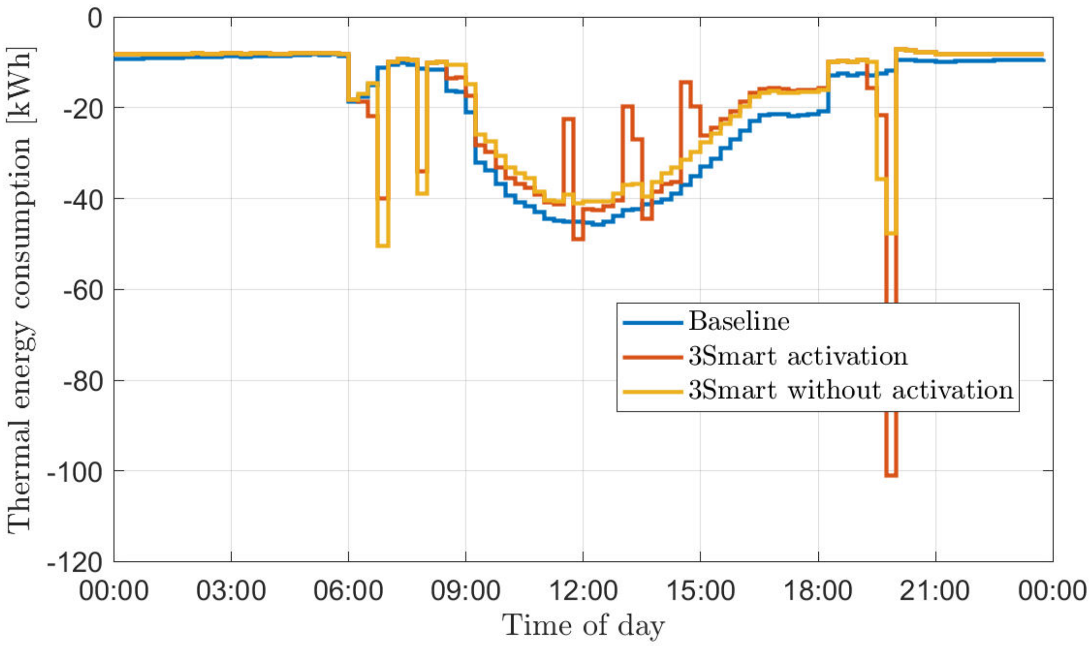

Figure 3.10. Water-side thermal energy consumption of the central HVAC system.

In Figure 3.11 the entre electrical energy consumption of the indoor climate system is shown. Here it is clearly visible that in each flexibility interval the consumption without activation is first dropping just before the interval, then intentionally increased in the flexibility interval to enlarge the flexibility margin. The behaviour with activation is the opposite – just before the interval the electricity consumption (I.e. cooling) is intensified and then during the flexibility interval maximally decreased. This results in a significant flexibility margin enabled by cooling and it is a source for revenues and reducing operative expenditure of the building.

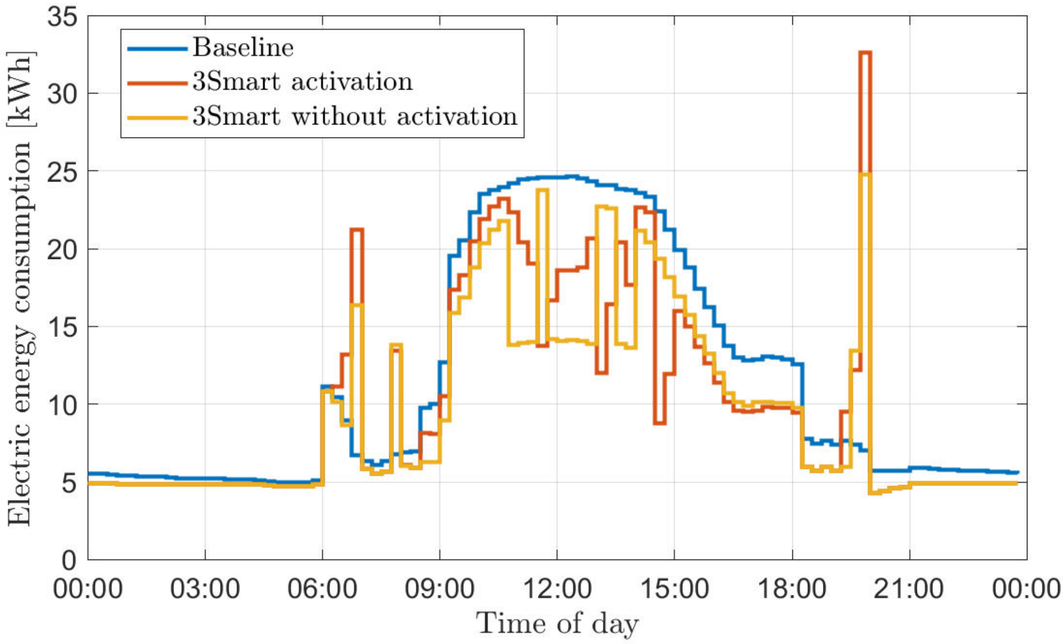

Figure 3.11. Electric energy consumption of fan coil units and central HVAC system.

The microgrid level of the HEP building deals with battery system control and with the synchronization of lower electricity consumption levels to obtain minimum operational costs of the building. It also considers the degradation costs of the battery system. For the considered prices of flexibility provision, 3Smart decides not to engage batteries. The battery energy exchange is provided in Figure 3.12. Conventional controls of the battery system intends to flatten the building electricity consumption profile as this is the usual way of commercial battery systems operation and incurs thus the profile is provided.

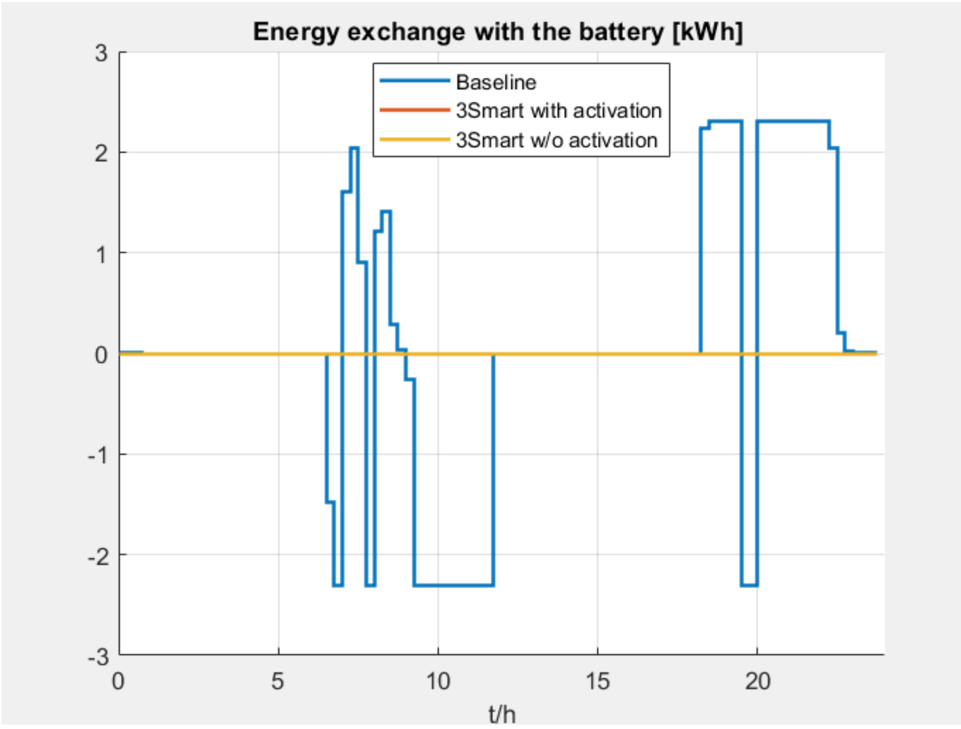

Figure 3.12. Energy exchange with the battery system.

The total building electricity exchange with the grid is shown in Figure 3.13. Here also non-controllable building consumption is accounted together with battery operation and the cooling system operation.

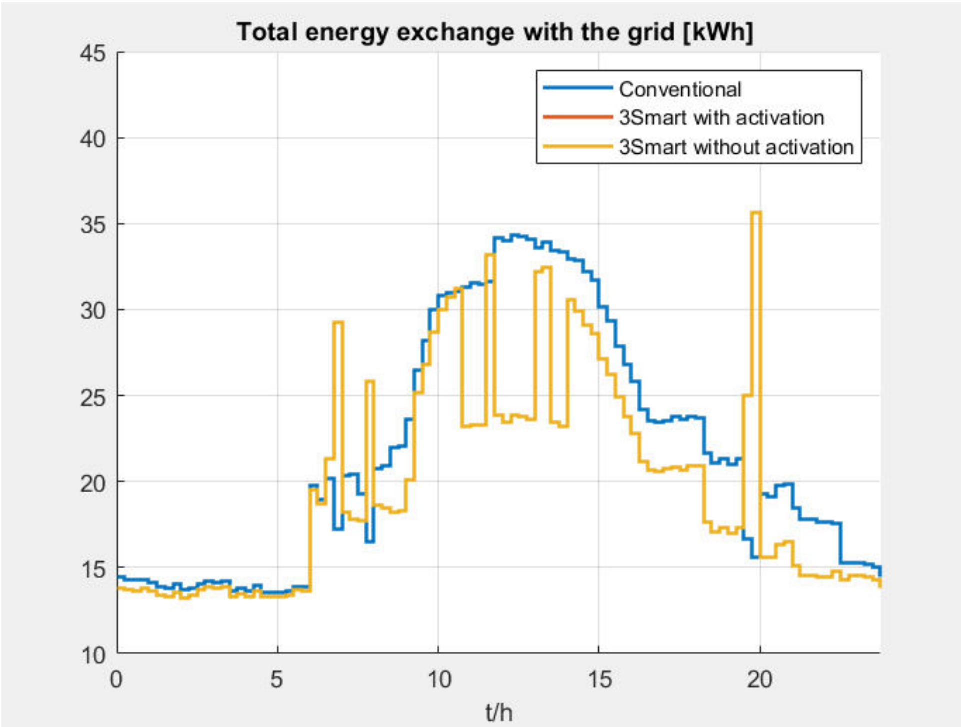

Figure 3.13. Energy exchange with the grid.

The overall gains with respect to HEP building operational cost for the analysed day is shown in Figure 3.14 where building operational costs are provided for conventional operation and for 3Smart operation with and without flexibility activation. The microgrid level at the end decides not to engage flexibility as it calculates that there will be no extra earning for the building through participation in demand response under given conditions. The daily gain of the building operation can be assessed as 28.5 EUR.

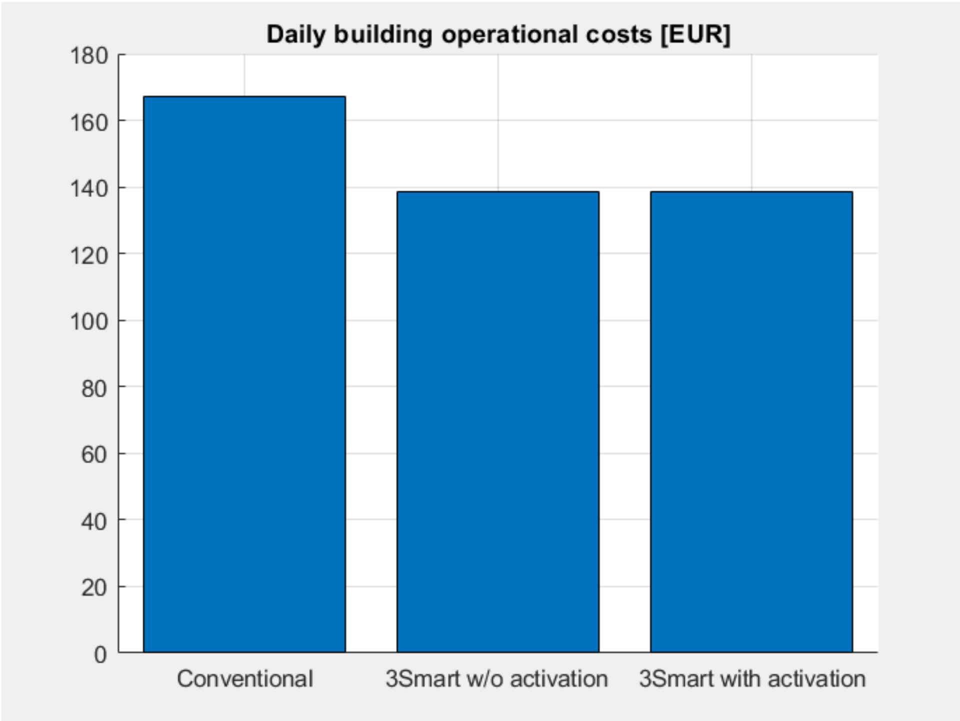

Figure 3.14. Daily building operational costs of HEP building for the analysed day in the cooling season.

3.3 Grid-side and boundary conditions for the building operation – heating season

The explanation of the operational logs is started by presenting the conditions provided by the grid for a sunny workday in January.

The needed flexibility time window for the grid within the analysed day is as follows:

- 11:30-15:00.

The pricing conditions computed by performing the calculations by long-term grid-side modules are as follows:

- reservation price: 0.0162 EUR/kW/15 min;
- activation price: 0.065 EUR/kWh;

- penalty price: 0.13 EUR/kWh.

The expected day-ahead electricity pricing is shown in Figure 3.15.

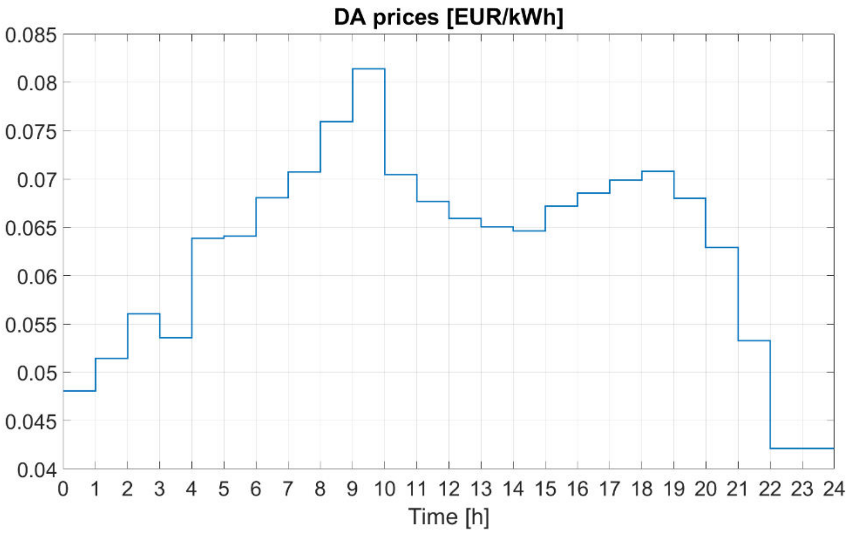

Figure 3.15. Day-ahead electricity pricing for a sunny workday in January.

Additional parameters taken into account are consisted of the relevant meteorological conditions, namely outdoor air temperature profile (shown in Figure 3.16) and direct and diffuse solar irradiance profiles (shown in Figure 3.17), as well as the non-controllable consumptions on the HVAC level (thermal energy consumption profile shown in Figure 3.18) and the microgrid level (electrical energy consumption profile shown in Figure 3.19).

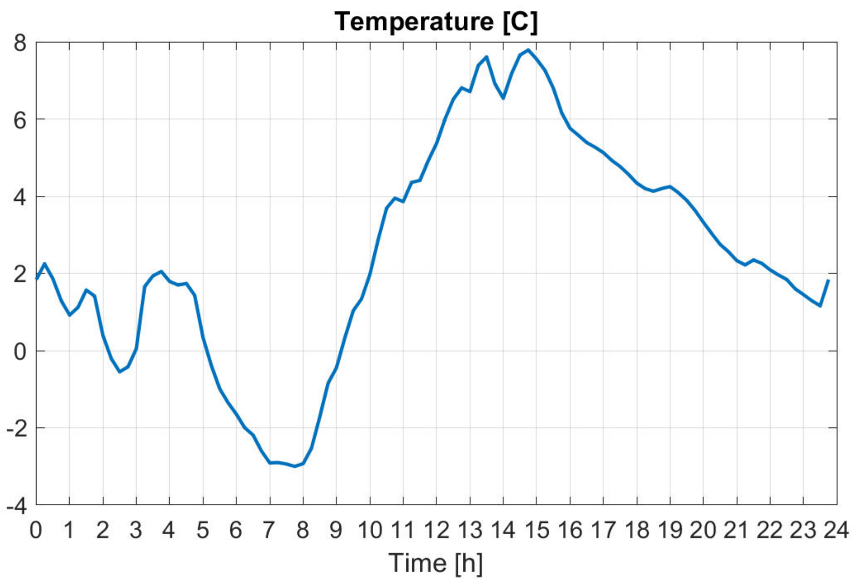

Figure 3.16. Outdoor air temperature for a sunny day in January.

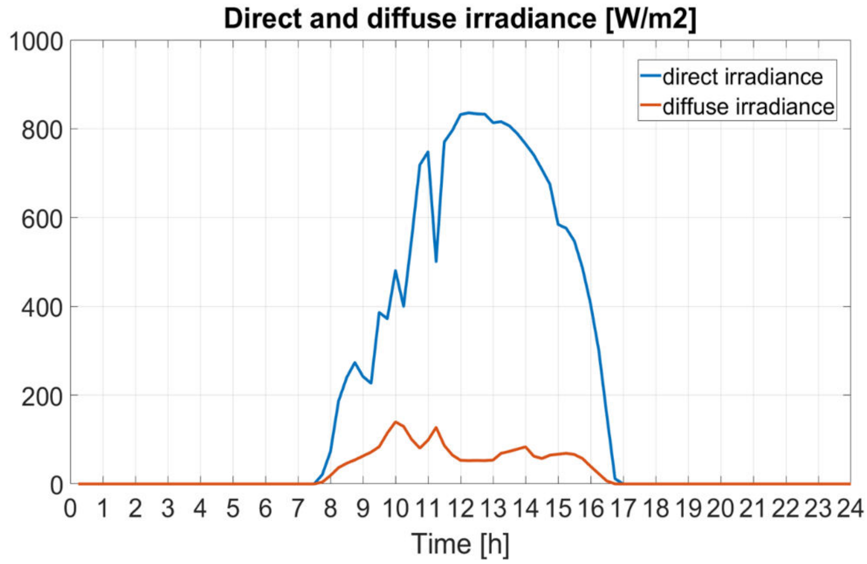

Figure 3.17. Direct (normal) and diffuse (horizontal) solar irradiance for a sunny day in January.

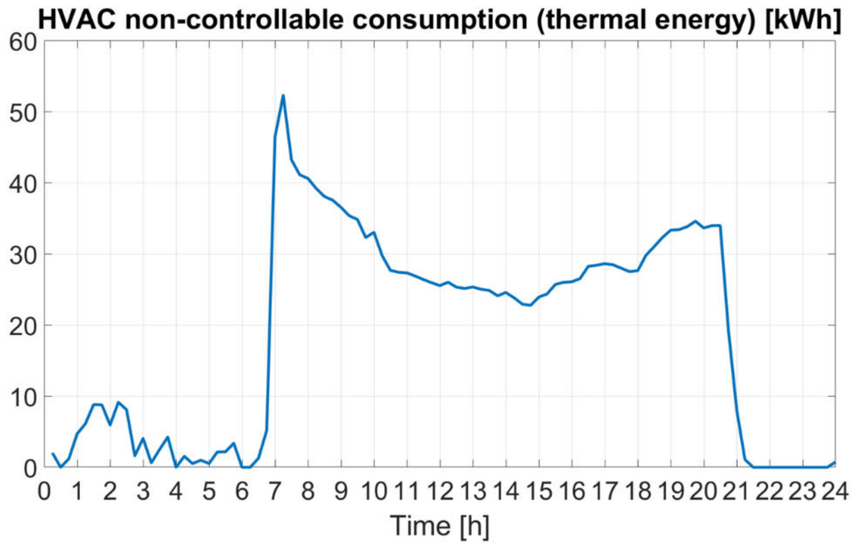

Figure 3.18. Non-controllable consumption of thermal energy on the HVAC level, for a sunny workday in January.

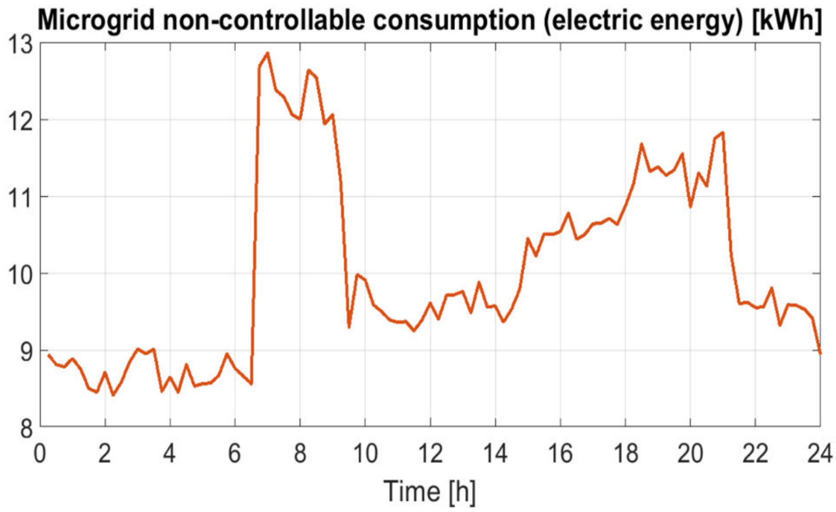

Figure 3.19. Non-controllable electrical energy consumption on the microgrid level, for a sunny workday in January.

3.4 The optimized building operation – heating season

The presentation of the optimized HEP building behaviour will be given by passing through different levels of the 3Smart system and analysing the optimized behaviours computed. For each level three responses are given corresponding to the three different modes of operation:

- conventional control;
- 3Smart system operation when flexibility is not called (or, without activation);
- 3Smart system operation when flexibility is called (or, with activation).

First the responses on the zone level are analysed. In conventional control on the zone level we consider that in each zone exists a simple hysteresis controller that incrementally opens the radiator valve as long as the temperature in the room is lower than the reference, and vice versa. This way of operation is actually the state-of-the-art of conventional control algorithms for rooms temperature regulation in heating. Conventional control on the zone level is leaned also to conventional control on higher levels, i.e. meaning that for the conventional control response on the zone level the heating medium is prepared by following the conventional control algorithm on the central HVAC level.

In Figure 3.20. one may see a typical temperature profile of one of the zones of the HEP building. In conventional control heating starts at 2:00 because of some large zones which cannot be heated in time otherwise. Reference temperature in the zone is set to 23°C. With conventional control (blue line) the air temperature in the zone is above the comfort limits in certain part of the operating hours which is due to the increased solar irradiance in the room. Heating is available during the entire day, but the temperature is required to be within the comfort limits only within the occupancy periods, i.e. between 08:00 and 18:00. With 3Smart each room is individually started to be heated at the right moment to reach the required comfort level at the start of the occupancy period and further. In heating actually the electricity consumption of the heating system is not that significant as the only pronounced electricity consumption point is the circulation pump. Its consumption is accounted within the optimization on the central HVAC system level, but it is rather small (Figure 3.27). Thus there is also practically no difference in operation of the heating system when flexibility for electricity is called or not called. Comfort improvement measured as average deviation from the set point is over 51.47% for the case of 3Smart controls compared to conventional control.

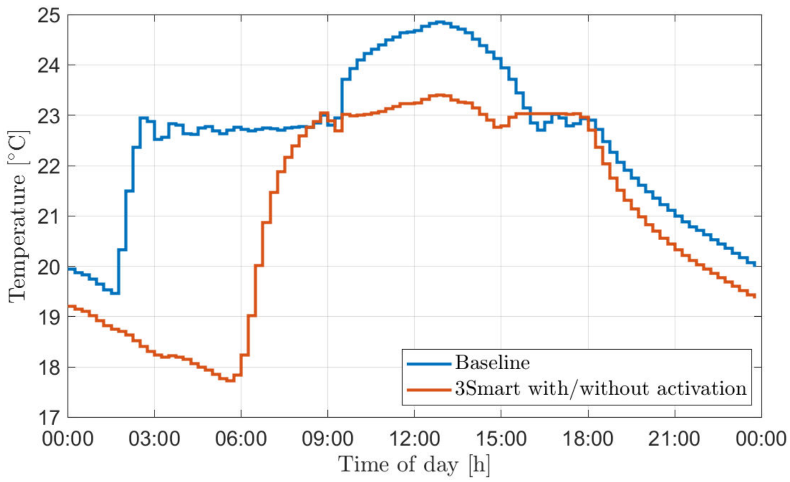

Figure 3.20. A typical response of temperature for a room in HEP building within the analysed day.

Figure 3.21 shows the required energy for transmittance from radiators to air in the room whose temperature response is shown just above. Also radiator valve mean opening for the 15 minutes interval and return medium temperature are shown, in Figure 3.22 and Figure 3.23., respectively.

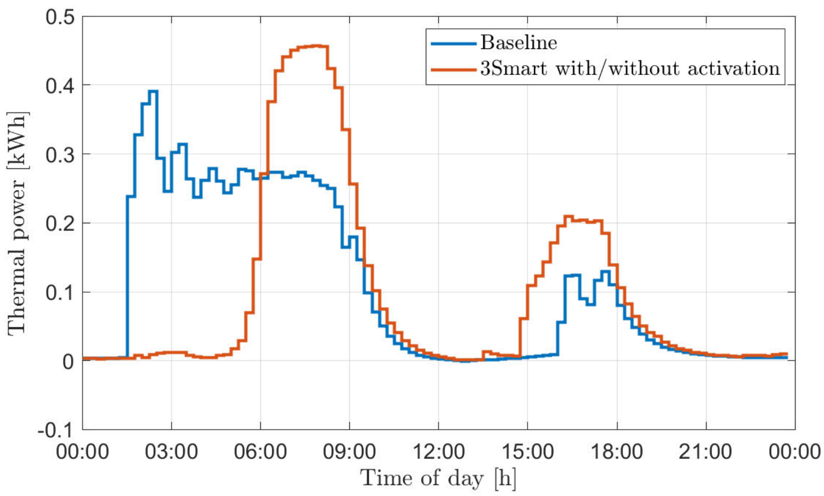

Figure 3.21. Thermal energy exerted to air of the considered room in HEP building within the analysed day.

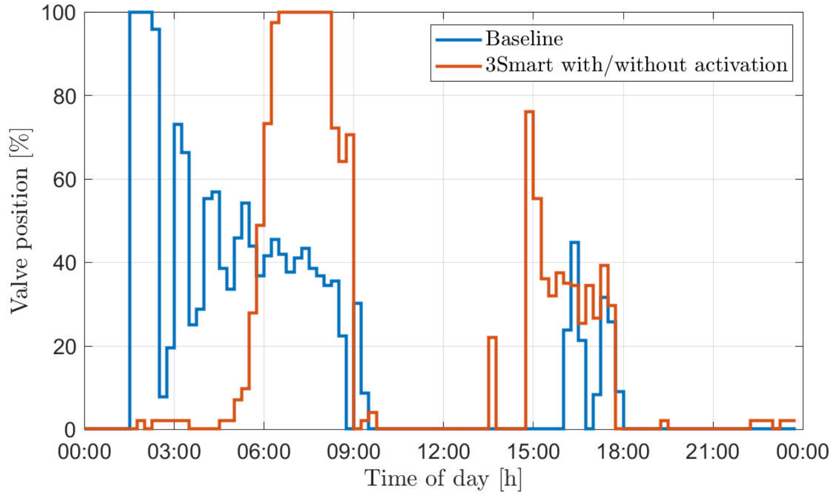

Figure 3.22. Radiator valve position in the considered room in HEP building within the analysed day.

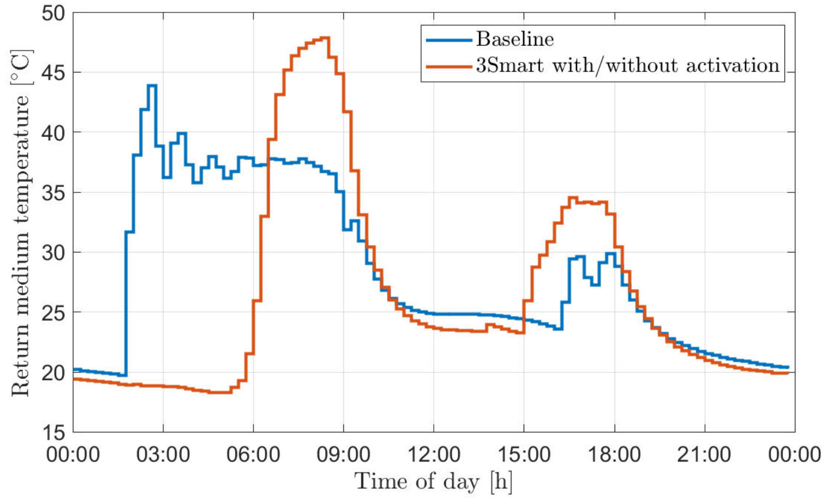

Figure 3.23. Radiator return medium temperature in the considered room in HEP building within the analysed day.

The required individual energies from different zones are merged together on the central HVAC system level to decide on the optimal supply medium starting temperature (at the output of the heat exchanger towards the building) that is able to provide enough heating energy to all the zones at the minimum of cumulative cost of the heating energy provided from the heat exchanger and the electricity for the circulation pump.

The supply medium temperature at the output of the heat exchanger is the decision variable for the central HVAC system level. In conventional control this temperature is decided based on the outdoor temperature. With 3Smart one may see the intentional pre-heating in early morning to prevent high peak heating powers prior to establishment of comfort temperatures in different zones.

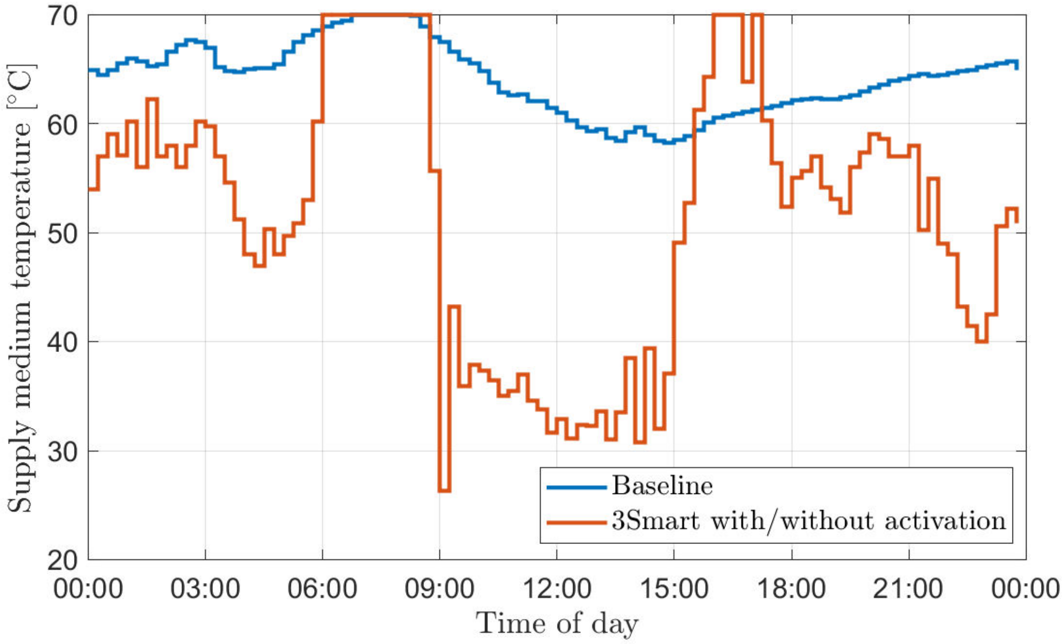

Figure 3.24. Supply medium temperature at the output of the heat exchanger towards the building.

In conventional control, where the supply temperature at the output of the heat exchanger is governed by the outdoor temperature, and where all rooms start heating simultaneously at 02:00 one may see a high peak in the thermal energy consumption – see Figure 3.25. Namely, heating up all the radiators at once produces this high peak which would in reality require a heating exchanger with the nominal power of at least 2.8 MW, which is the peak value of the thermal energy consumption in the scenario with baseline controller. . On the other hand, 3Smart controls plan the heating during the entire day interval which enables no shock at the beginning of the working hours. The thermal energy consumption with 3Smart controls nowhere exceeds 330 kWh in 15 minutes (i.e. 1 MW heating power). Through synchronization with the zones level heating of all rooms is properly scheduled. The heating energy consumed is significantly less as well as power peaking reduced which results in significant lowering of heating energy expenses, as evidenced in Table 3.2. below.

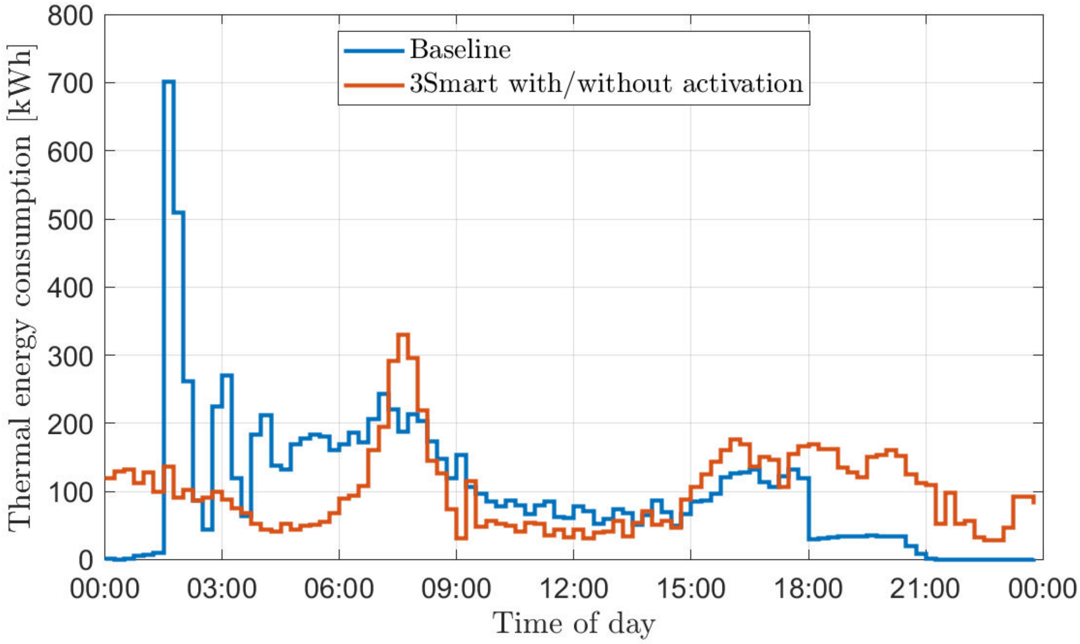

Figure 3.25. Water-side thermal energy consumption of the central HVAC system.

Figure 3.26. shows the electricity consumption of the circulation pump, whereas the associated medium flow is depicted in Fig. 3.27. In conventional control there is a significant peak load of the pump present at 02:00 when all radiator valves in the building suddenly get open as the time-based heating starts in all rooms. This peak consumption amounts to some 30.91 W. With 3Smart controls this peak does not occur at the beginning of the working hours and is much smaller. It amounts to some 20.51 W.

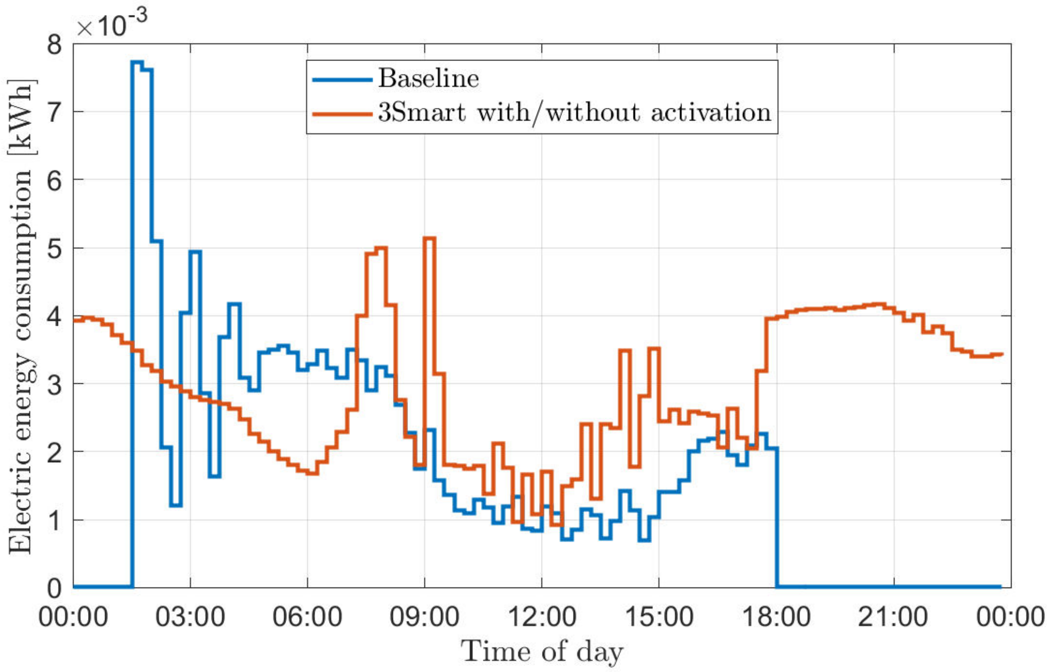

Figure 3.26. Electric energy consumption of the hydraulic pump.

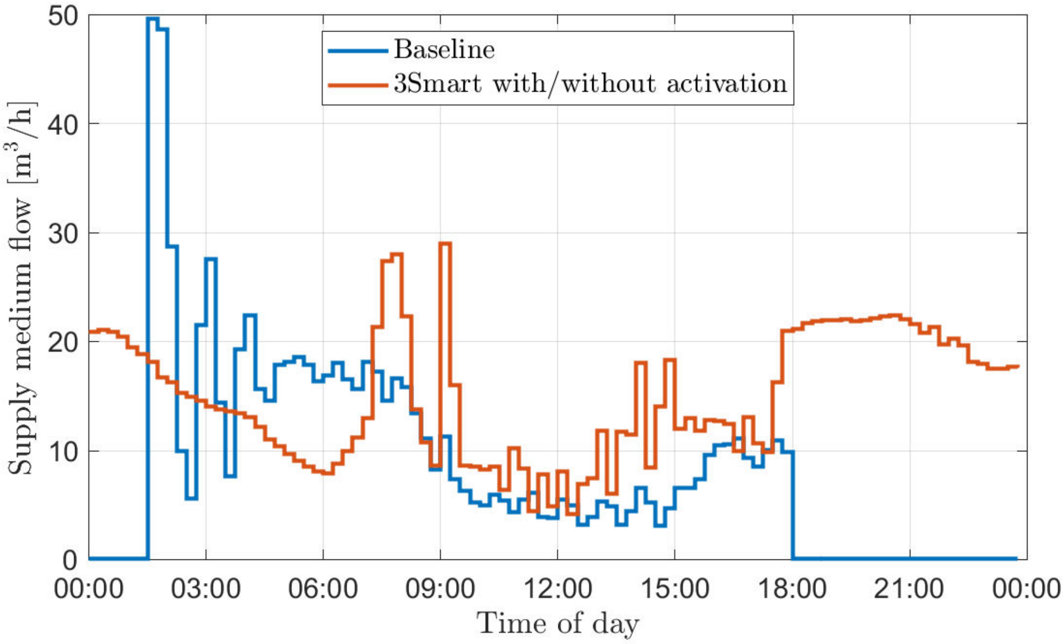

Figure 3.27. Supply medium flow in the central duct.

The microgrid level decides on the energy exchange of the battery system with the remainder of the building, in order to optimally shape the profile of electricity exchange with the grid. In the case of conventional control, the battery system is used to flatten the energy exchange with the distribution grid. In the heating season, when the consumption of electricity from the indoor climate system is not significant, the battery system is almost able to flatten the demand towards the grid. However, it turns out that the peak power price needed to be paid within 3Smart is somewhat higher, but still lower than the expense of batteries degradation. Even the payments for flexibility are rather low, so in this case HEP building stays out of the flexibility market. Thus, the 3Smart system decides that it is better that the battery system is not used and no flexibility is offered to the electricity grid. Figure 3.29 shows the planned energy exchange with the battery system and Figure 3.30 gives the total of electricity exchange of the HEP building with the grid.

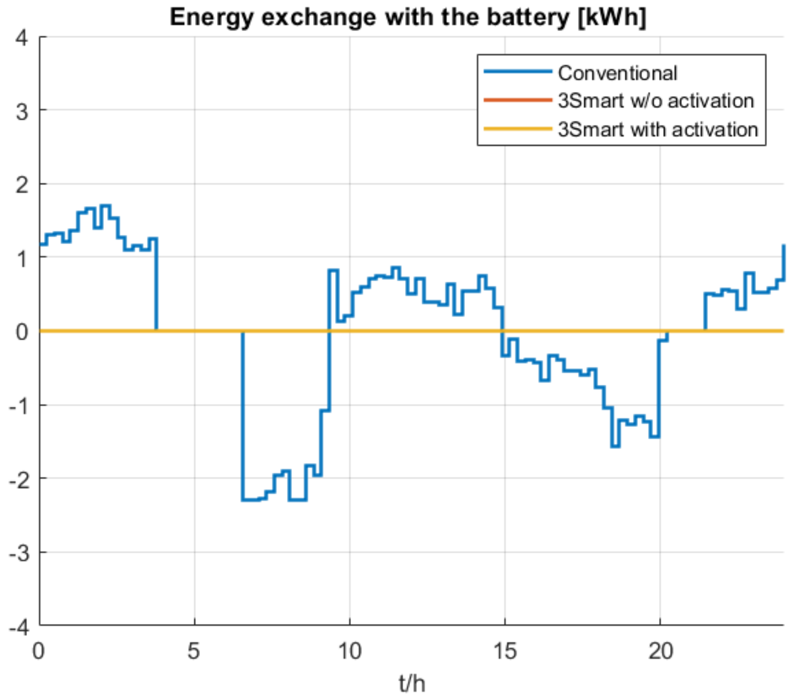

Figure 3.28. Energy exchange with the battery system.

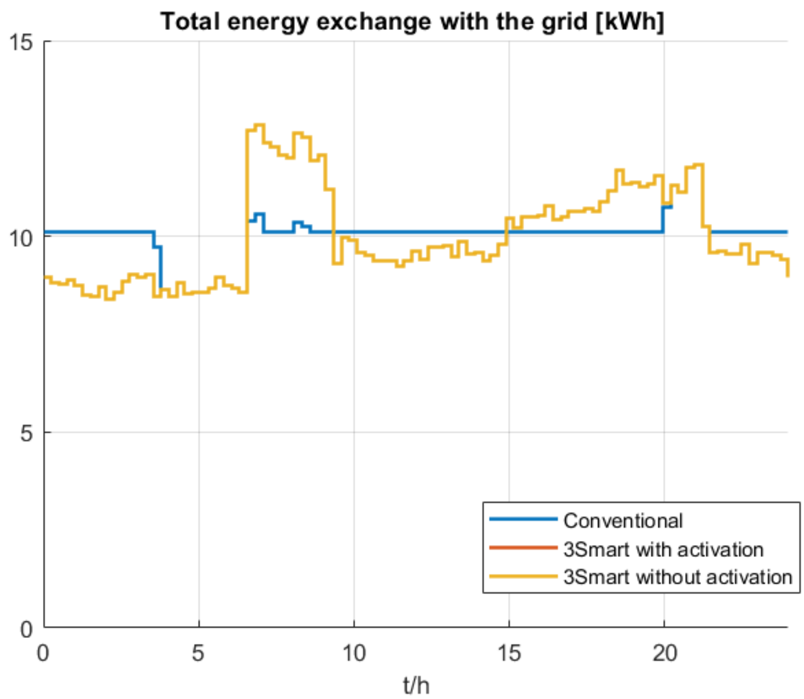

Figure 3.29. Total electricity exchange of HEP building with the grid.

The final economical evaluation of HEP building operation for a sunny workday in the heating season is given in Table 3.2. A significant cost reduction potential is exhibited by applying 3Smart controls in the building, especially taking into account that no flexibility towards the grid is provided in this case. However, these promising results should be considered with caution since still the losses model used in predictive control needs to be enhanced with flow dependence, as a future work.

Table 3.2. Comparison of economical performances of the conventional and the 3Smart system operation on HEP building for a sunny workday in the heating season.

	Conventional control	MPC – w/o activation	MPC – with activation
Heating	445.02 €	442.89 €	442.89 €
Electricity, microgrid operation, flexibility	83.26 €	67.02 €	67.02 €
Total	528.28 €	509.91 €	509.91 €

One can assess a benefit of 18 EUR daily in building operation in the analysed day in the heating season thanks to the 3Smart system operation.

Bibliography

[1] D7.1.2 Integrated planned energy management modules on all the buildings and in the grid for the Croatian pilot, 3Smart deliverable, December 2019.

Output Quality Report

Output title: T5.1 Pilot-deployed modular energy management platform	
Type of output:	☐ Documented learning interaction ☐ Strategy/ Action Plan ☐ Tool ☑ Pilot action
Contribution to PO indicator:	**P25 Number of pilot actions to improve energy security and energy efficiency developed and/or implemented**

Summary of the output (max. 1500 characters)
The output shows how the developed 3Smart tool is applied to 5 diverse pilot sites in 5 countries of the Danube region (HR, SI, AT, BA, HU). It is completed with showing performance of the 3Smart modules on different pilots. Also in this revised output are added now operational logs and seasonal analyses from all pilots. The Croatian pilot consists of two buildings in Zagreb, one of UNIZGFER and another of HEP, and of the pilot electricity distribution grid of HEP around these two buildings. The Slovenian pilot consists of a Primary school building and Sports centre of IDRIJA, with the electricity grid of ElektroP around it. The Austrian pilot consists of two buildings of the municipality Strem, which are the primary school and the retirement and care centre. In addition, the electricity distribution grid of EnergyG is also part of the pilot. Bosnia and Herzegovina pilot consists of a business building in property of EPHZHB in Tomislavgrad and of the pilot electricity distribution grid of EPHZHB around the building. The Hungarian pilot consists of a buildings complex of EON in Debrecen and of the pilot electricity distribution grid of EON around the building. The five individual reports show how the 3Smart tool is organized on pilots, how it operates the buildings and the grids, and show also the seasonal analysis of operation for characteristic days with assessed economical benefits used in Output T4.2 for performing cost-benefit analyses of pilots installations exactly regarding the part of adding-up the 3Smart platform to the automation systems.

Added value

The diverse pilots used for testing and validating the operation of the 3Smart tool have shown that it is adaptable to buildings and grids of different configurations. In zones buildings are equipped either with fan coils or radiators or with floor heating/cooling, in central HVAC level they use heat pumps or heat exchangers and on the level of major building energy flows control (microgrid level) versatile systems are found – batteries, controllable loads, controllable photovoltaic units, combined heat-power units, but even none. In all cases interaction between building levels and with the grid-side modules is established where the grids are also with different configurations and operational challenges.

The testing is performed off-line and on-line. Off-line testing reveals the optimal planned daily operation of the building and grid, and the building is through it able to decide how much flexibility power it can offer to the grid. In on-line operation it is validated whether the designed modules can process well the data on-line obtained from the building.

Important added value is that all pilots have been explored with a seasonal analysis procedure to obtain their best possible reactions during characteristic days in heating and cooling season, with enforced day-to-day repeatable behaviour. Within this analysis it is also determined how much flexibility it pays off to the building to provide towards the grid in the given pricing conditions. These analyses give full insight how different subsystems of a building cooperate together to yield an economical optimum for building operation while ensuring or improving comfort for their occupants compared to conventional control. All responses obtained are compared for exactly the same scenarios also with state-of-the-art conventional controls performance such that the benefit of 3Smart operation on the site over conventional controls can be assessed and used for cost-benefit analyses for pilots (within 3Smart these are provided as Output T4.2).

Applicability and replicability

This output shows how the 3Smart platform can be organized for a particular configuration of buildings and grids and how it can be tested for economical viability in preliminary studies for performing the investment for 3Smart tool installation, and then how it is commissioned and on-line operated.

The results of the project and 3smart platform can be interesting to all stakeholders and other parties in all 5 pilots. In the future, it is expected that proper responses of energy consumption to the demands of grid operators will be rewarded through different demand response schemes, and with time that such operation will also become a legal obligation of the buildings and other end-consumers (like today basic automation systems have become). As demand response is practically impossible without employing predictive control and optimizations, systems like 3Smart will in a longer run become a necessity. All plans and installations concepts are applicable in all countries across the Danube region, and further.

Suggestions for improvement, if applicable

The results obtained on all sites show possibility of significant costs reduction through smart energy management of buildings and through participation in demand response service needed by the grid. It is indeed interesting to see how the optimization modules exploit different dynamic features and lags existing in rooms, their heating/cooling elements, central HVAC system and microgrid to yield optimal behaviour in terms of economical performance while maintaining comfort. It is an interplay of different elements computed automatically, usually far beyond the reasoning of the most experienced building operators. Interesting is also to see the procedures of identifying different simple models of elements in buildings from basic physics, mathematical modelling, measurements and manufacturers datasheets that capture their major dynamical and energy-related behaviour. They are the key unlocking activities to be able to harness the building in a simplistic way and start performing something in an optimal way for it.

On grid-side it is also interesting and fascinating to see that procedure for determining flexibility prices automatically generates them based on historical load profiles, technical and economical parameters, and how further the buildings can be optimally engaged as flexibility providers to minimize losses and keep grid operation constraints respected.

For sure the developed 3Smart modules, especially the complex ones employing on-line mathematical optimizations, need to be further numerically tested and upgraded to come to the industrial level of reliability and enable massive replication, but a great work is done within 3Smart to start going along this route.

Output Quality Level	☐ Low ☐ Average ☐ Good ☑ Excellent

Name of the Quality Manager

Signature of the Quality Manager

Prof. dr. Mato Baotić, ______________________

Prof. dr. Hrvoje Pandžić, ______________________