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 D7.3.3

Operational logs and their seasonal analysis – Austrian pilot

Project Acronym	3Smart
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Funding Scheme	Interreg Danube Transnational Programme
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Project Duration	36 months
Work Package	7
Task	7.3
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Code name	**Version:** 1.1 Final ☒ Final draft ☐ Draft ☐
Type of deliverable	Report
Security	Public
Deliverable participants	UNIZGFER, EEE, STREM, EnergyG
Authors (Partners)	Mario Vašak, Tomislav Capuder, Anita Martinčević, Nikola Hure, Hrvoje Novak, Danko Marušić, Paula Perović, Marko Kovačević (UNIZGFER), Andrea Moser (EEE), Bernhard Deutsch (STREM), Martin Zloklikovits (EnergyG)
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, for the Austrian pilot. 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 Austrian pilot	Mario Vašak, Anita Martinčević, Nikola Hure, Danko Marušić, Hrvoje Novak, Marko Kovačević, Paula Perović, Tomislav Capuder (UNIZGFER)
1.1	20 February 2020	Checked and edited the document	Mario Vašak (UNIZGFER)

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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 Austrian 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 Austrian pilot consists of two buildings of the 3Smart project partner Strem – primary school and the retirement and care centre – and of the pilot electricity distribution grid of partner EnergyG 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 D7.3.2 [1].

This deliverable concerns the explanation of the 3Smart modules setup for the Austrian 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 which is operated also with the 3Smart modules. The buildings are analysed in conditions specific for different seasons – heating for the primary school and heating and cooling for the retirement and care centre, 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 zone?
    - 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 Strem primary school building is presented. Then in Chapter **Pogreška! Izvor reference nije pronađen.** this is also performed f or the retirement and care centre. 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. Strem primary school operational logs and seasonal analysis

In Strem primary school there is no equipment for cooling and there are no controllable elements on the microgrid level that would be operative outside the heating season. The operational logs and seasonal analysis for the primary school are performed thus only for the heating season, and a sunny workday in November is chosen as a representative.

2.1 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 November.

The long-term grid-side modules computation ended with no flexibility requests, but to illustrate what would happen in the case when flexibility is needed one interval of flexibility is artificially entered, as follows:

- 12:00-13:00.

The pricing conditions computed by the long-term module were also too small for building participation and are thus artificially enlarged three times to show the effect on the building (otherwise, buildings would not opt to participate in demand response):

- reservation price: 0.063 EUR/kW/15 min;
- activation price: 0.258 EUR/kWh;
- penalty price: 2.577 EUR/kWh.

The electricity is priced at 0.173 EUR/kWh and heat from the district heating grid is priced at 0.1 EUR/kWh.

Additional parameters taken into account are consisted of the relevant meteorological conditions, namely outdoor air temperature profile (shown in Figure 2.1) and direct and diffuse solar irradiance profiles (shown in Figure 2.2), as well as the non-controllable consumptions on the HVAC level (thermal energy consumption profile shown in Figure 2.3) and the microgrid level (electrical energy consumption profile shown in Figure 2.4).

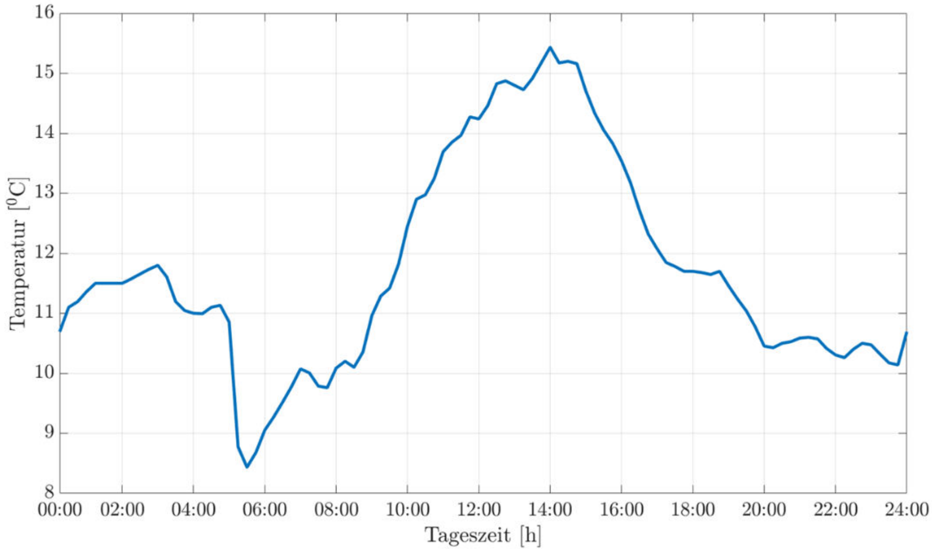

Figure 2.1. Outdoor air temperature for a sunny day in November.

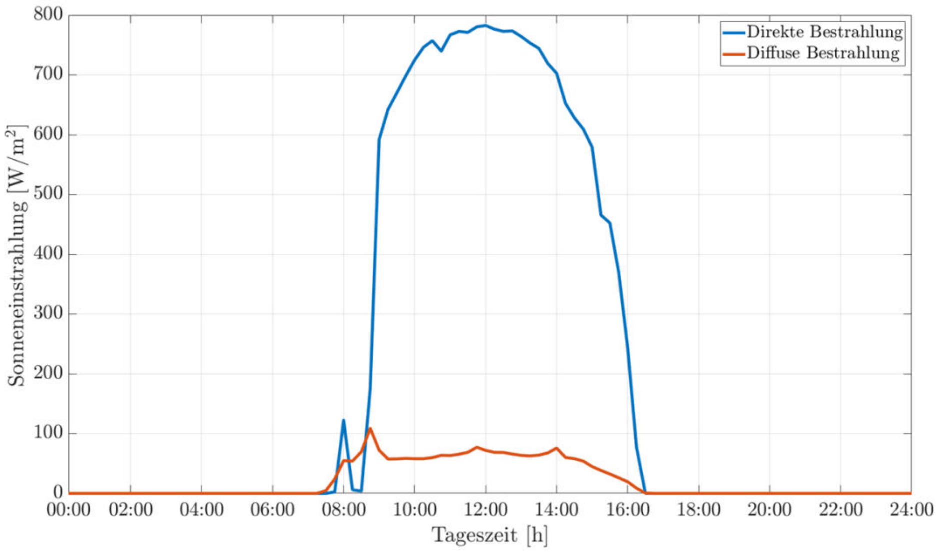

Figure 2.2. Direct (normal) and diffuse (horizontal) solar irradiance for a sunny day in November.

The non-controllable thermal energy consumption on the HVAC level (Figure 2.3) accounts for the consumption of radiators throughout the building in toilets and locker rooms. The non-controllable electrical energy consumption on the microgrid level (Figure 2.4) is consisted of all electricity consumption except for the consumption of the fan of the fan coil in the gym hall, which is controllable.

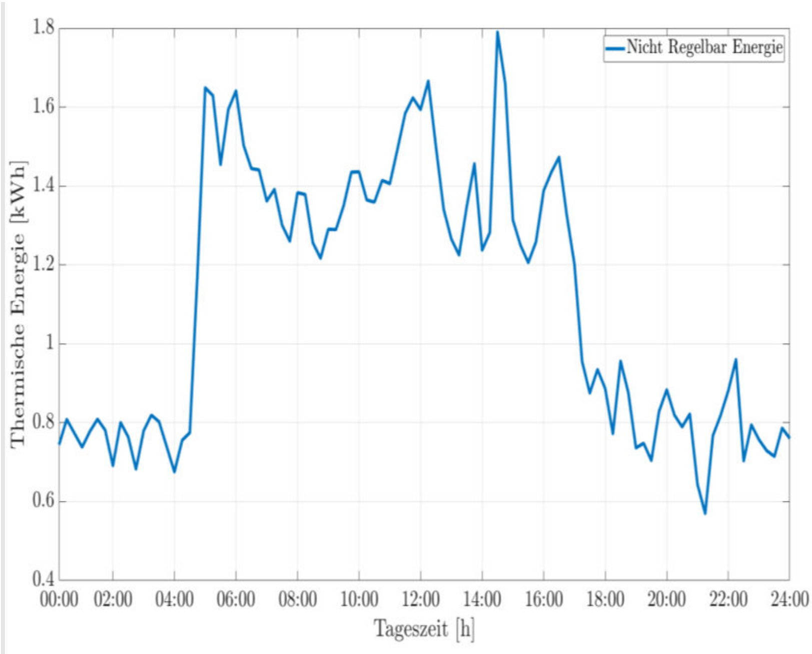

Figure 2.3. Non-controllable consumption of thermal energy on the central HVAC system level, for a sunny workday in November.

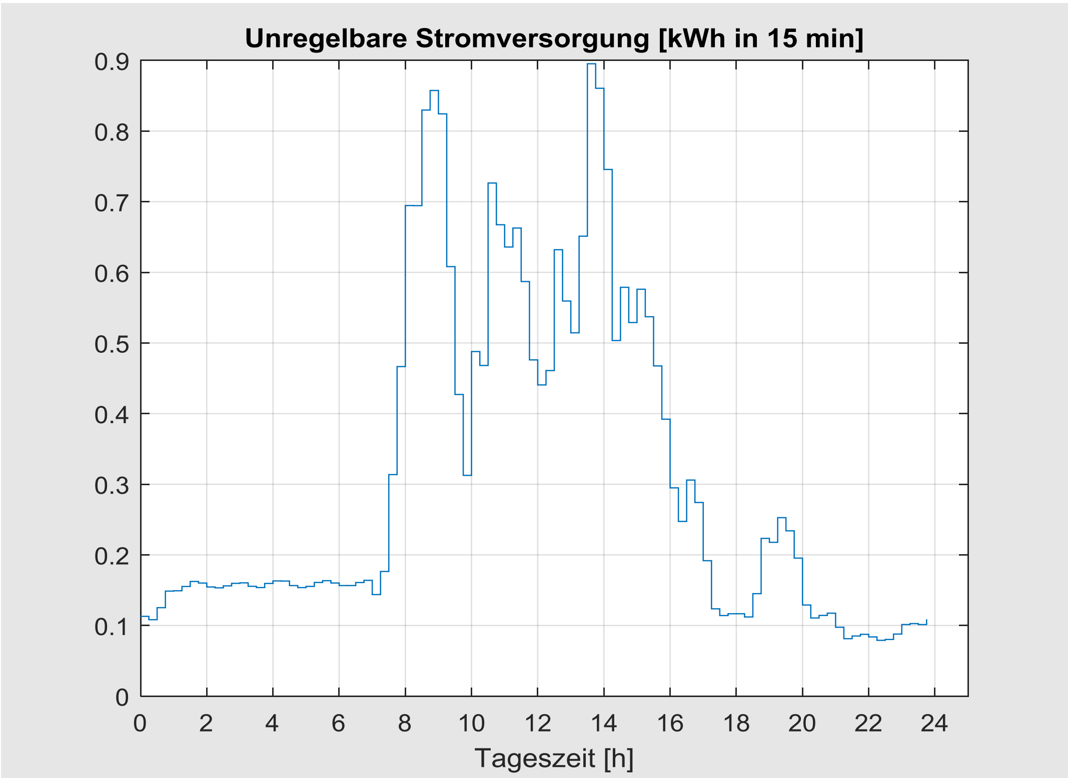

Figure 2.4. Non-controllable electrical energy consumption on the microgrid level, for a sunny workday in November.

2.2 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 (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 controller that switches the valve on when the temperature is lower than the reference temperature and vice versa. This way of operation is actually the state-of-the-art conventional control algorithm for rooms temperature regulation in heating. It 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. 3Smart valve actions are computed on 15 minute levels and represent the average valve opening within these 15 minutes (Z.I.2 module actually actuates the valve with proper time modulation of valve open and valve closed position to get the desired average valve opening in 15 minutes).

The building has overall 9 controllable zones (Z-1 – Z-9). Zones Z-1 – Z-8 are heated with radiators connected in series, and room Z-9 is the gym hall where heating is exhibited with a fan coil. The zones with radiators are supplied via two ducts: north duct and south duct, while the gym hall fan coil is supplied from a separate duct. All three ducts are supplied from the same heating substation source. There is also one more duct present that supplies non-controllable spaces (toilets and storage room) and also uses heat from this same heating substation. Radiators in rooms on the duct south are ordered in series as follows: Z-4 --> Z-5 --> Z-6 --> Z-7 --> Z-8 --> Z-4. Z-4 is the central corridor in school and its radiators are in one part situated at the beginning of the duct and in one part at its end. Z-4 has also radiators situated on the north duct. The north duct order of radiators in different rooms is as follows: Z-4 --> Z-1 --> Z-2 --> Z-3 --> Z-4. Each room has its predefined reference temperature schedule throughout the day.

In Figure 2.5 overview of the rooms is given with their belonging to different supply ducts and the room orientation in order to more easily follow the behaviours exhibited in different rooms.

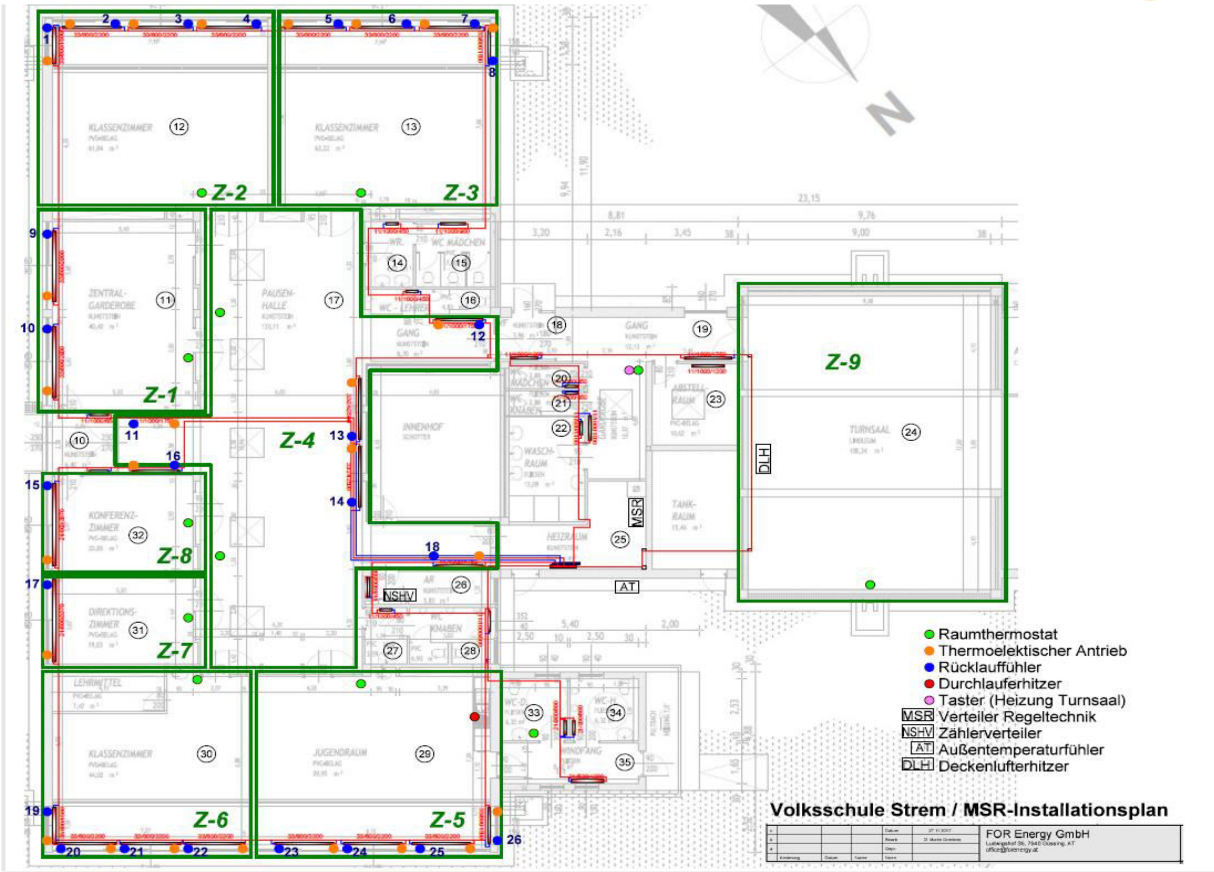

Figure 2.5. Organization of rooms in Strem primary school.

In figures 2.6.-2.9. the behaviour exhibited in Z-1 can be observed.

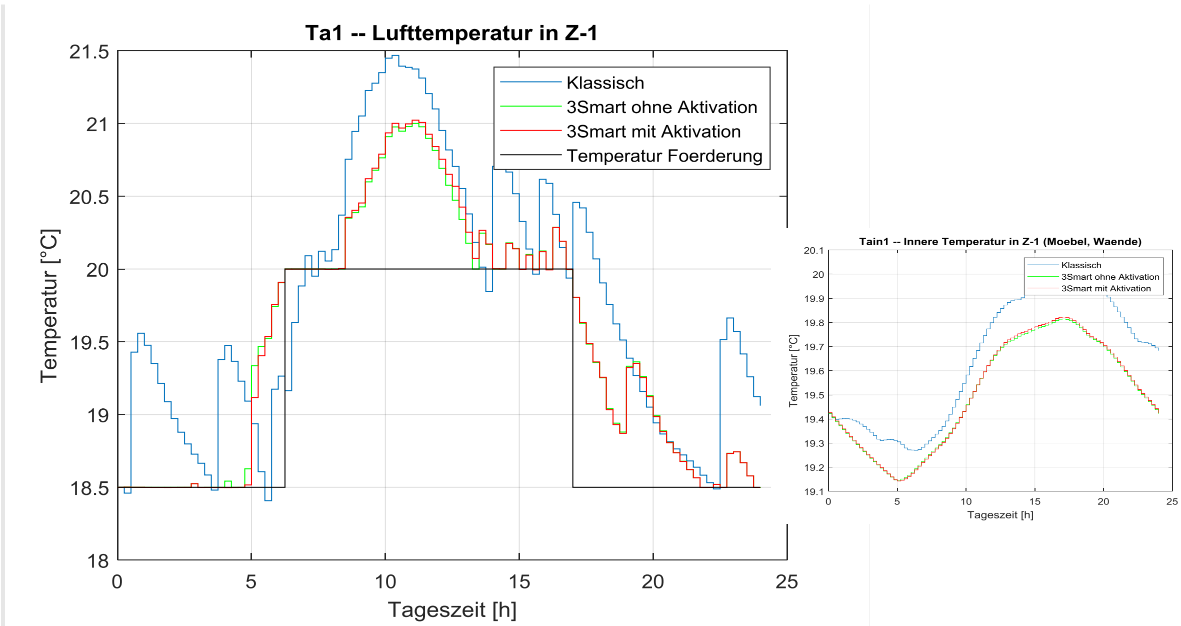

Figure 2.6. Room temperature over time in Z-1 for conventional control and 3Smart strategies. Small figure shows the behaviour of the inner room temperature state (representing walls and furniture).

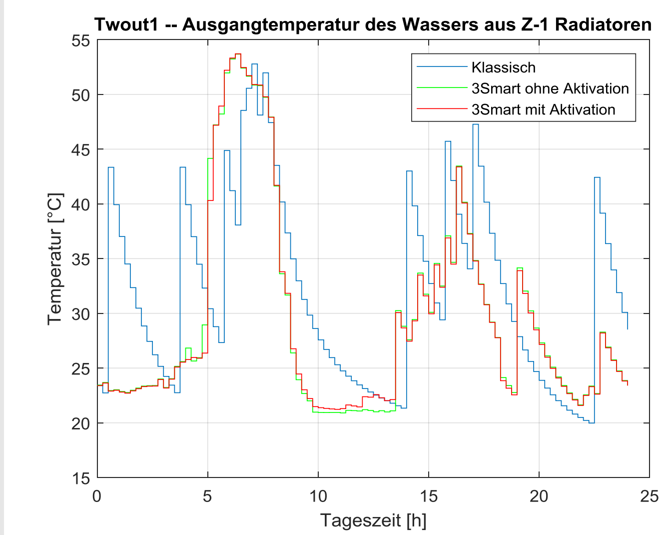

Figure 2.7. Behaviour of the return medium temperature of the radiator in Z-1.

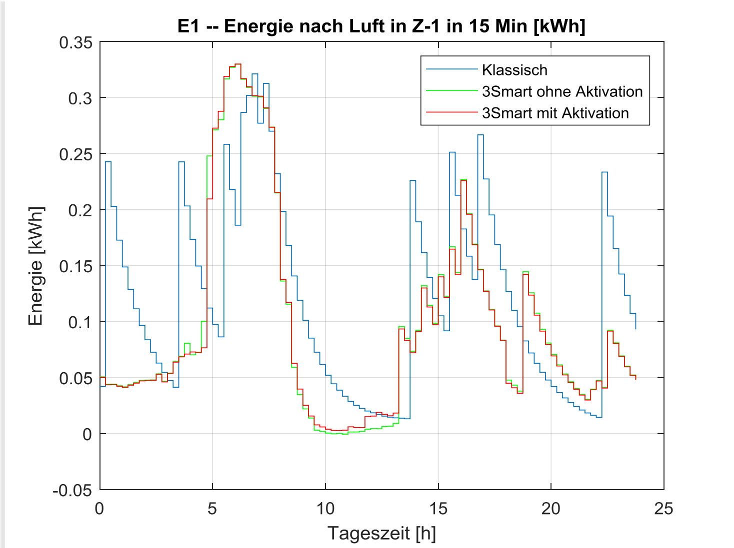

Figure 2.8. 15-minutes energies exerted to room air from the radiator in Z-1.

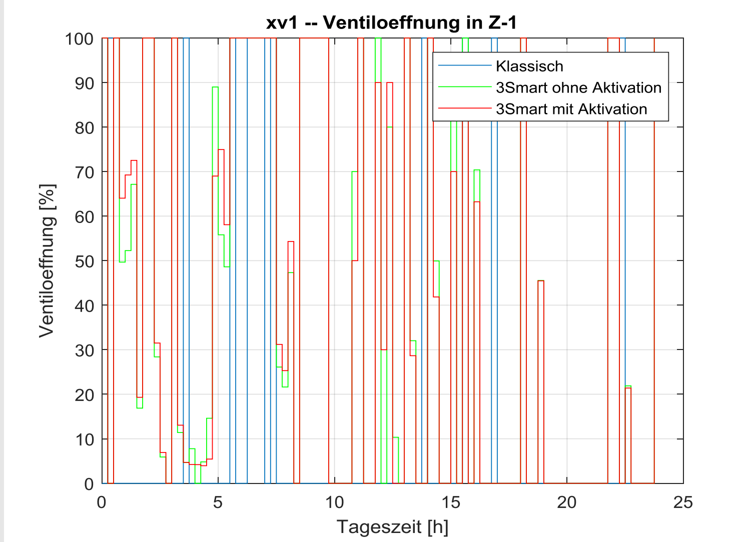

Figure 2.9. Valve opening of the radiator in Z-1.

One may see a difference in responses at the part of the day when sunshine starts to influence the building – by relying on predictions 3Smart more abruptly reduces the heating as it relies on free energy from the sun that is about to come, and also minimizes the overheating and discomfort due to it. Also it may be spotted that 3Smart ensures the temperature at next midnight is the same as the initial temperature such that the behaviour is repeatable.

The behaviour exhibited in Z-2 is shown next (figures 2.10-2.13).

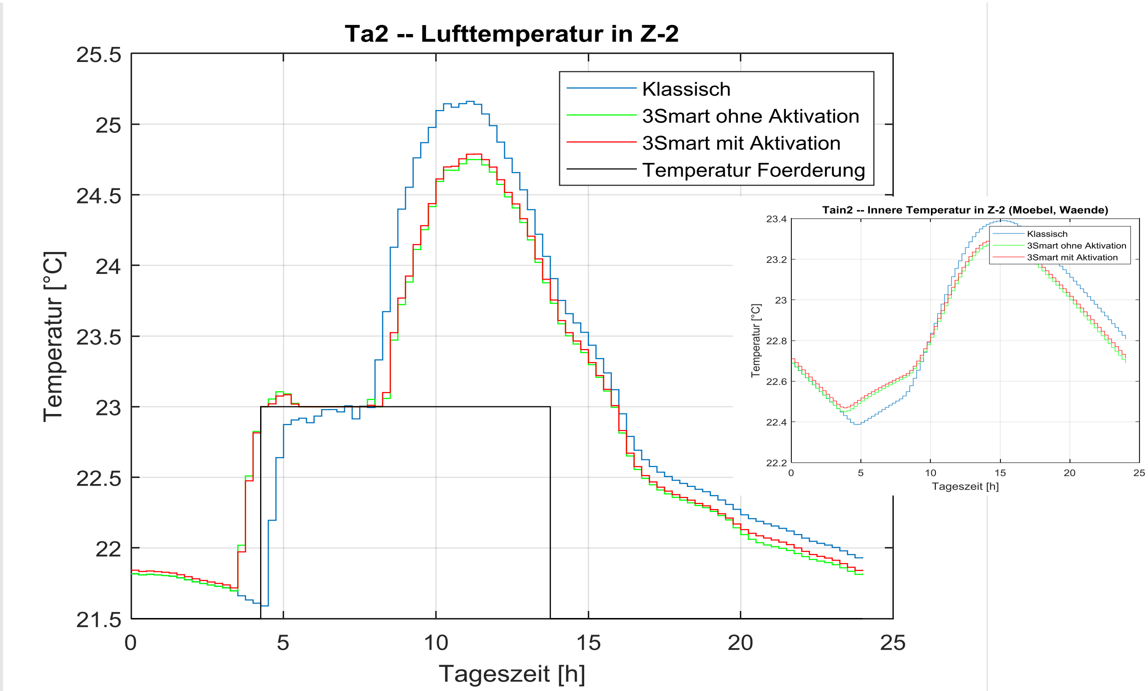

Figure 2.10. Temperature in Z-2. Small figure shows the behaviour of the inner room temperature state (representing walls and furniture).

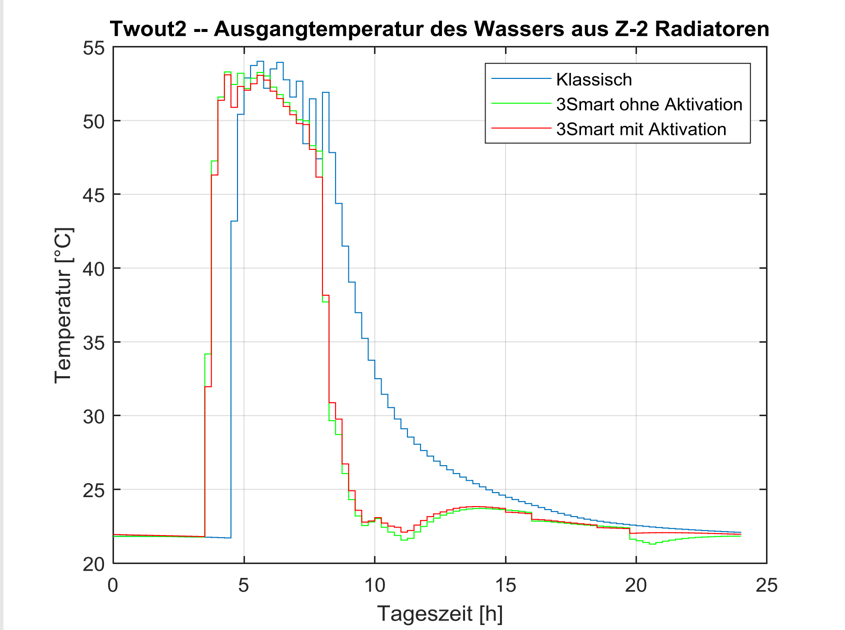

Figure 2.11. Return medium temperature in Z-2.

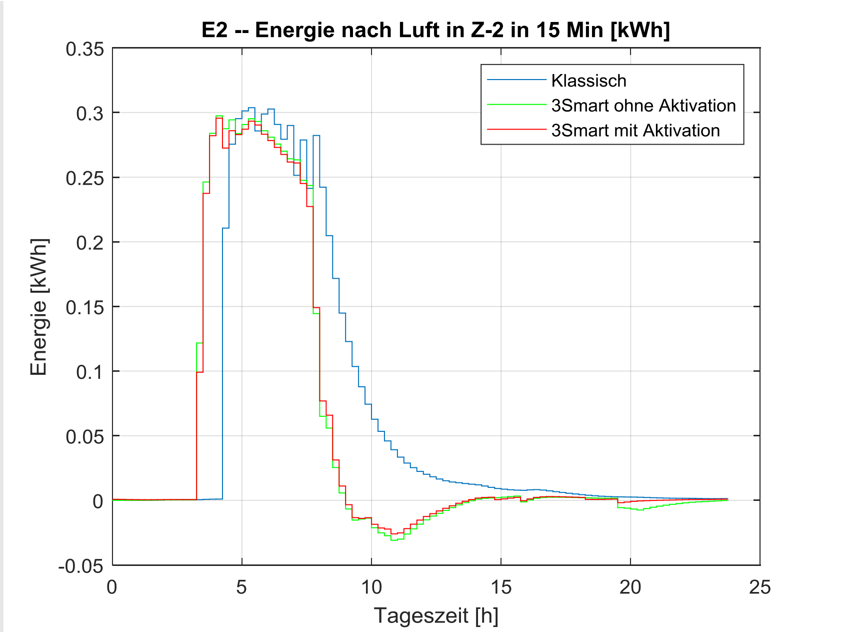

Figure 2.12. Energy to air in Z-2.

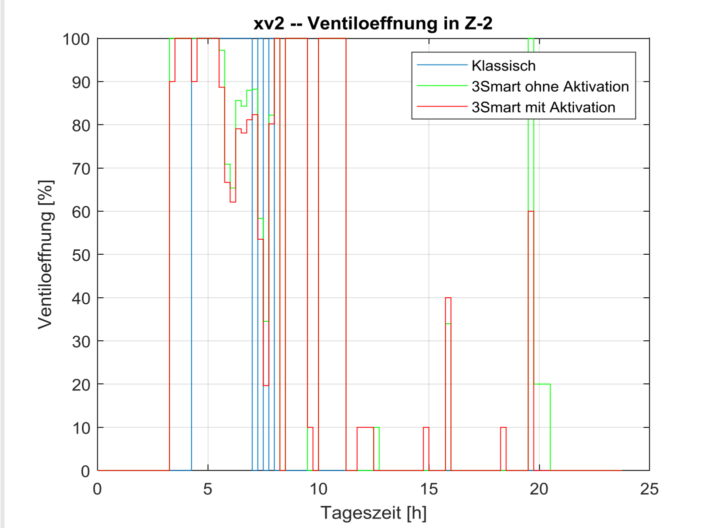

Figure 2.13. Valve opening in Z-2.

In Z-2 one may also see an interesting behaviour where the circulation medium is cooled on north-oriented rooms and used in Z-2 which is on the south corner of the building to reduce oveheating and take on the medium the heat for north-oriented rooms (see negative energies in Figure 2.11). This effect is not very pronounced, but is very interesting to show different potentials existing with smart controls to remove the heat from one part of the building, where there is a surplus and discomfort due to it, to the other part where this heat is needed and savings can be achieved based on it.

The behaviour exhibited in Z-3 is shown next (figures 2.14-2.17).

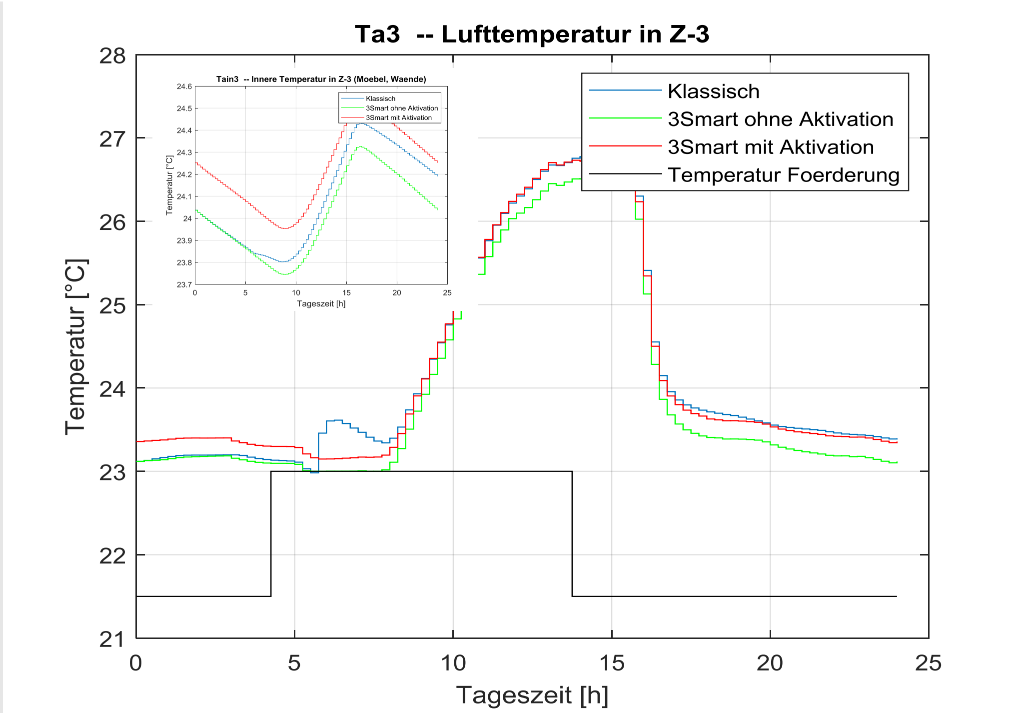

Figure 2.14. Temperature behaviour in Z-3. Small figure shows the behaviour of the inner room temperature state (representing walls and furniture).

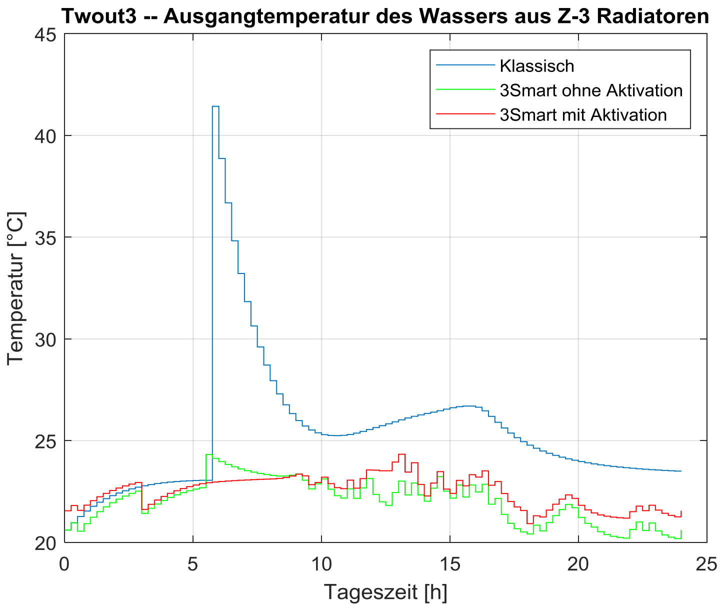

Figure 2.15. Return medium temperature in Z-3.

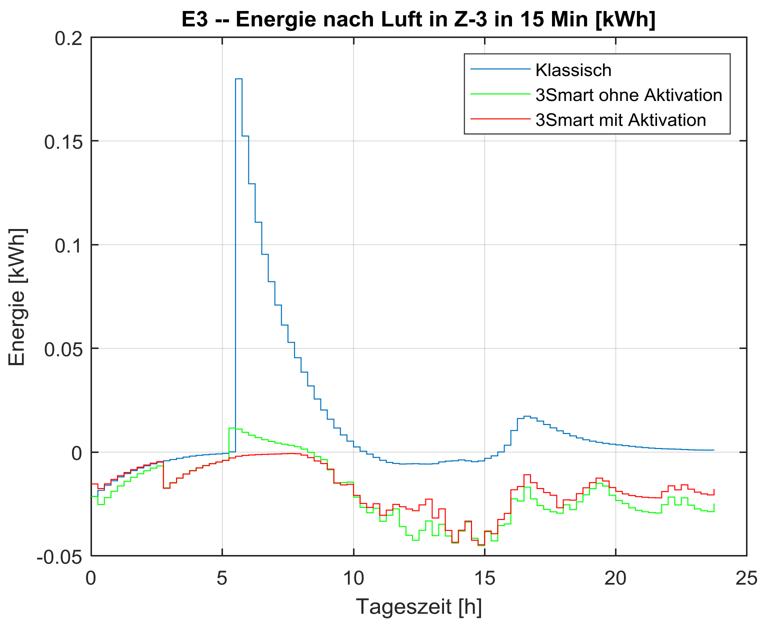

Figure 2.16. Energy provided to air in Z-3.

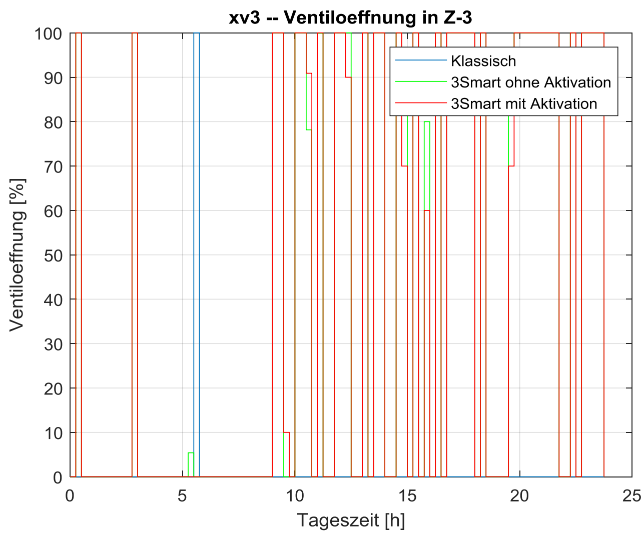

Figure 2.17. Valve opening in Z-3.

In Z-3 is the effect spotted in Z-2 previously (slight cooling) also visible. Note that 3Smart is able to recognize that the heat taken to medium can be taken further while conventional control is not able to recognize it and keeps the valve closed almost the entire day.

The behaviour exhibited in Z-4 is shown next (figures 2.18.- 2.21). Z-4 radiators are situated both on the north and the south supply duct, and on each of the ducts its radiators are placed both at the beginning and at the end of the radiators series.

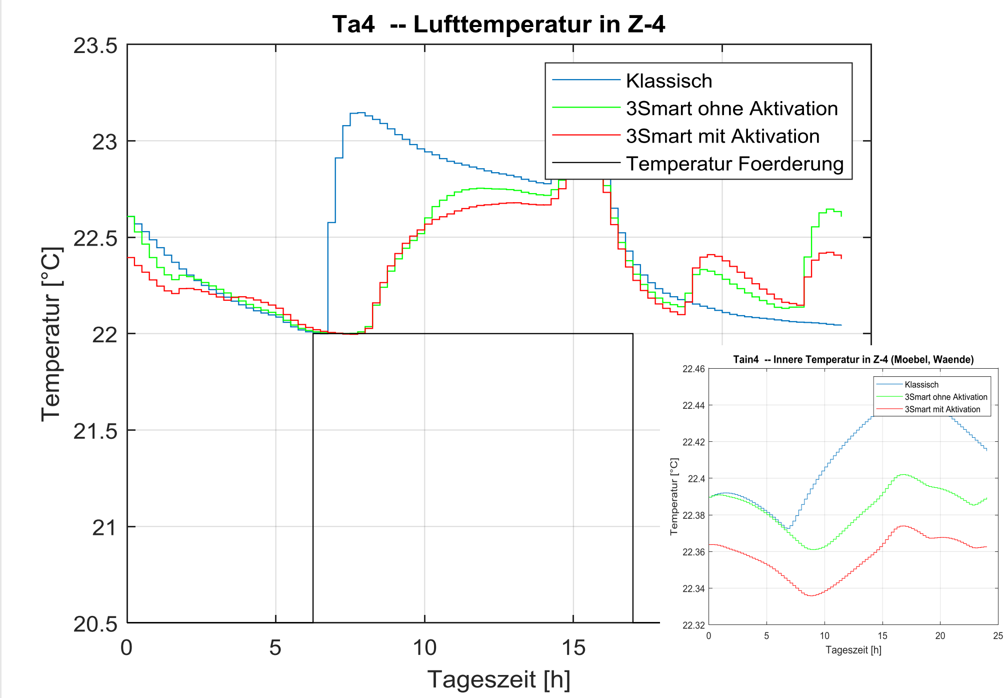

Figure 2.18. Temperature in Z-4. Small figure shows the behaviour of the inner room temperature state (representing walls and furniture).

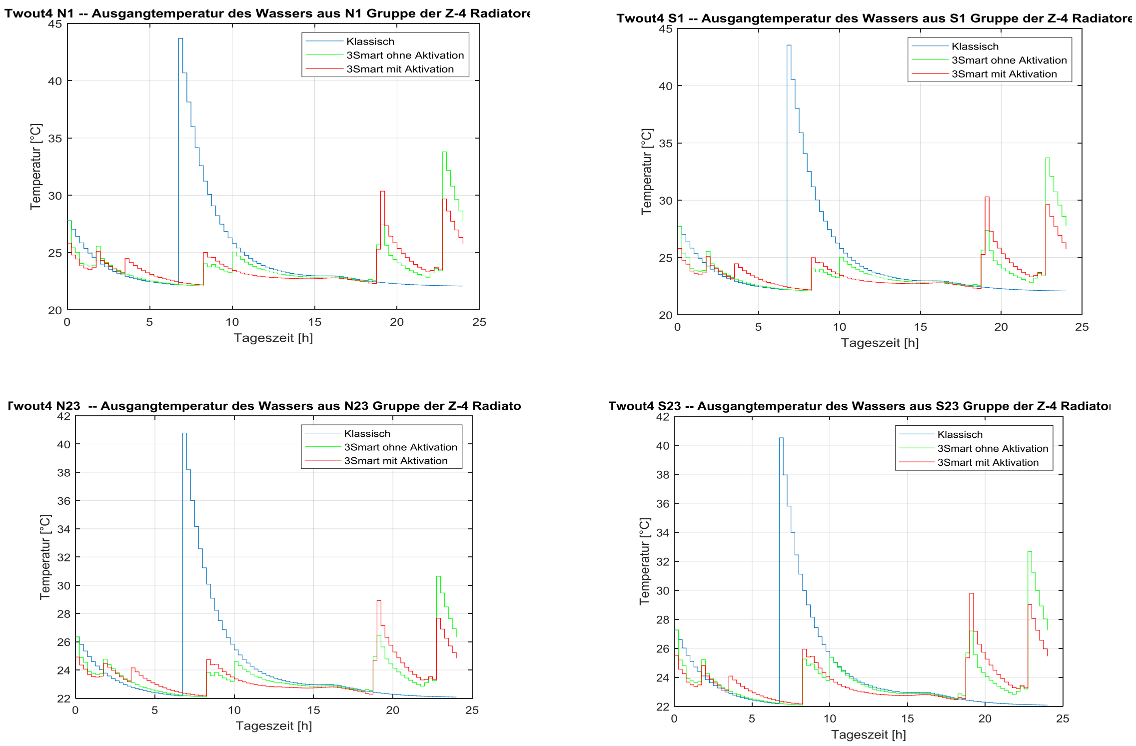

Figure 2.19. Return medium temperatures from the four positions of radiators in Z-4 (left: north duct; right: south duct; up: first radiator on a duct; down: last radiators on a duct).

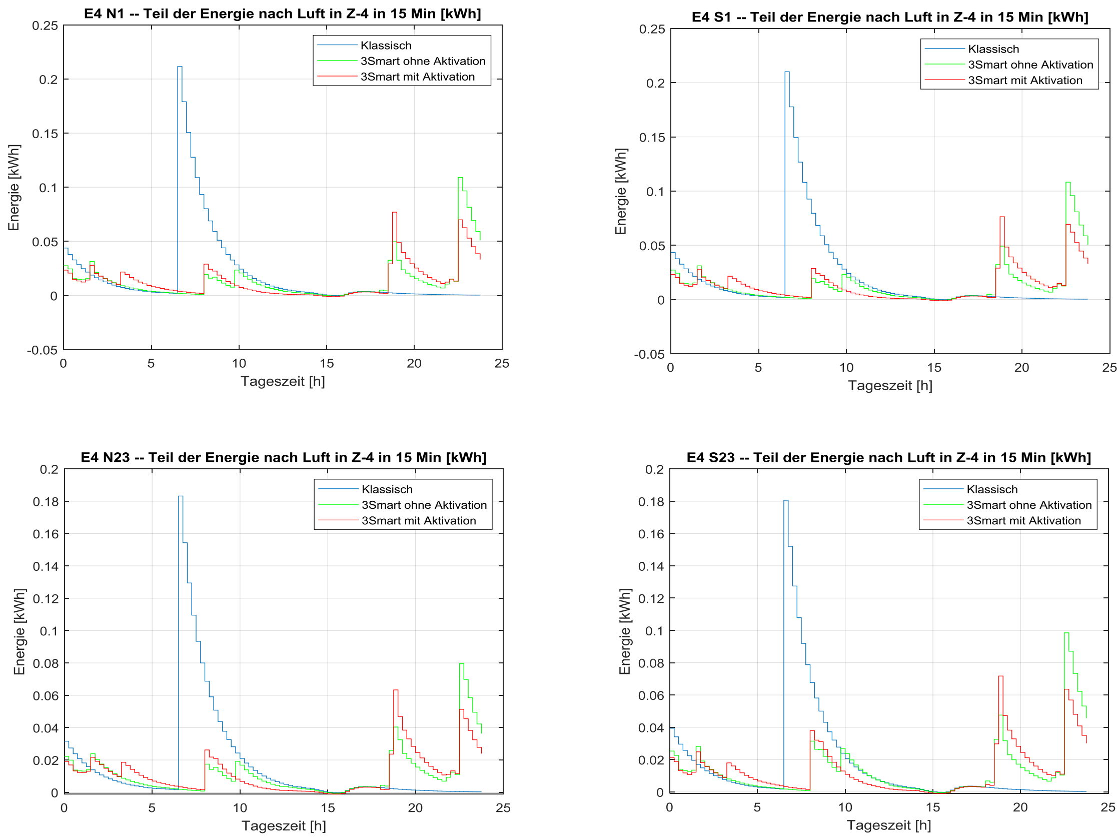

Figure 2.20. Energies provided to room air from different radiators groups in Z-4. (left: north duct; right: south duct; up: first radiator on a duct; down: last radiators on a duct).

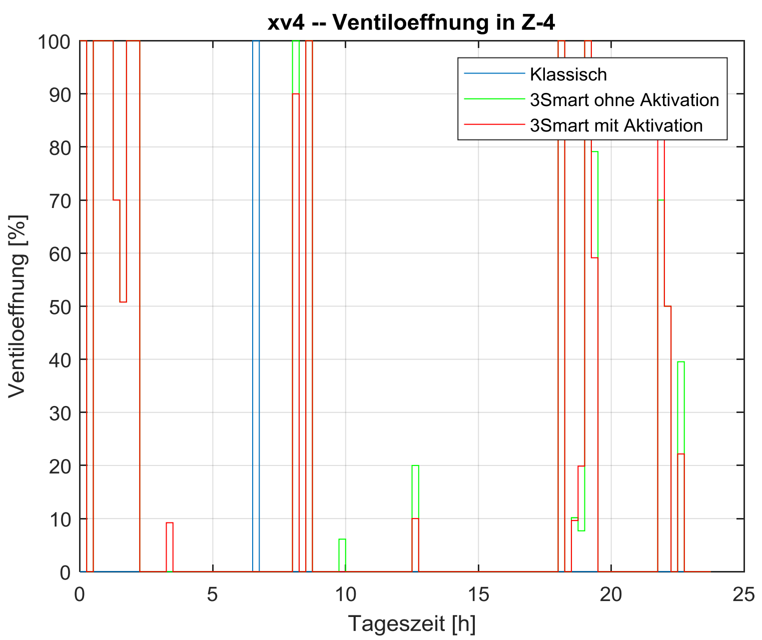

Figure 2.21. Valve opening for Z-4.

Results obtained with conventional control and with 3Smart are similar, though 3Smart achieves lower overheating and leaves the room in the same condition for the next day.

The behaviour of Z-5 is shown next (figures 2.22-2.25).

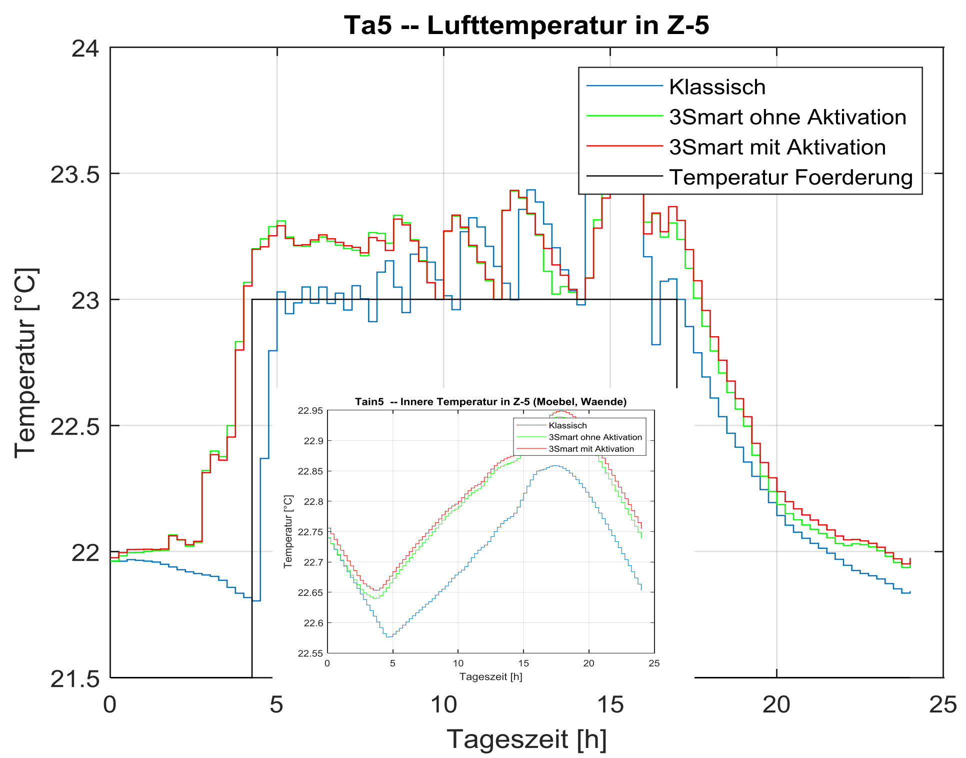

Figure 2.22. Z-5 room temperature behaviour. Small figure shows the behaviour of the inner room temperature state (representing walls and furniture).

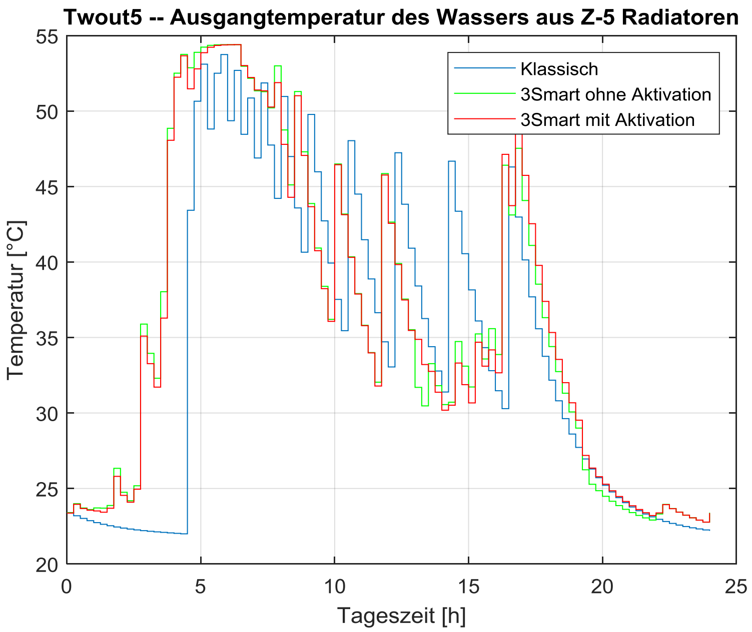

Figure 2.23. Return medium temperature in Z-5.

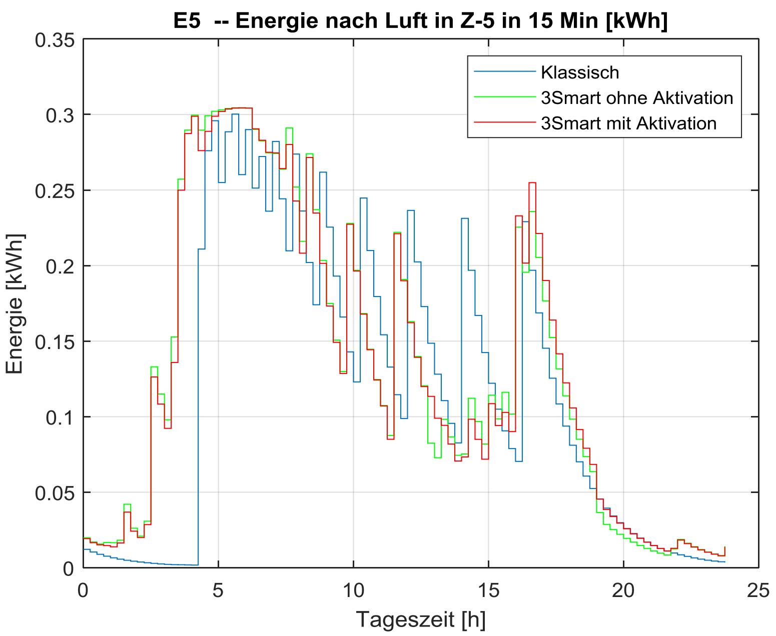

Figure 2.24. Energy provided to air in Z-5.

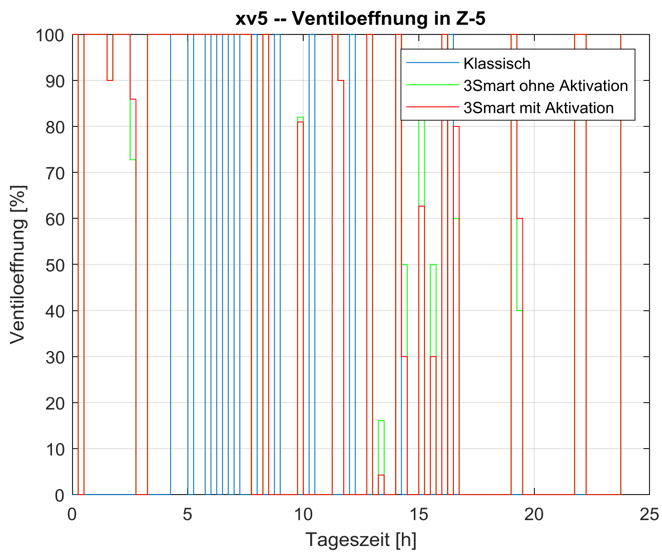

Figure 2.25. Valve opening in Z-5.

Also in Z-5 it is visible that 3Smart prepares the room temperature also for the next day and is thus active also later in the afternoon and in the evening.

The behaviour of Z-6 is shown next (figures 2.26-2.29).

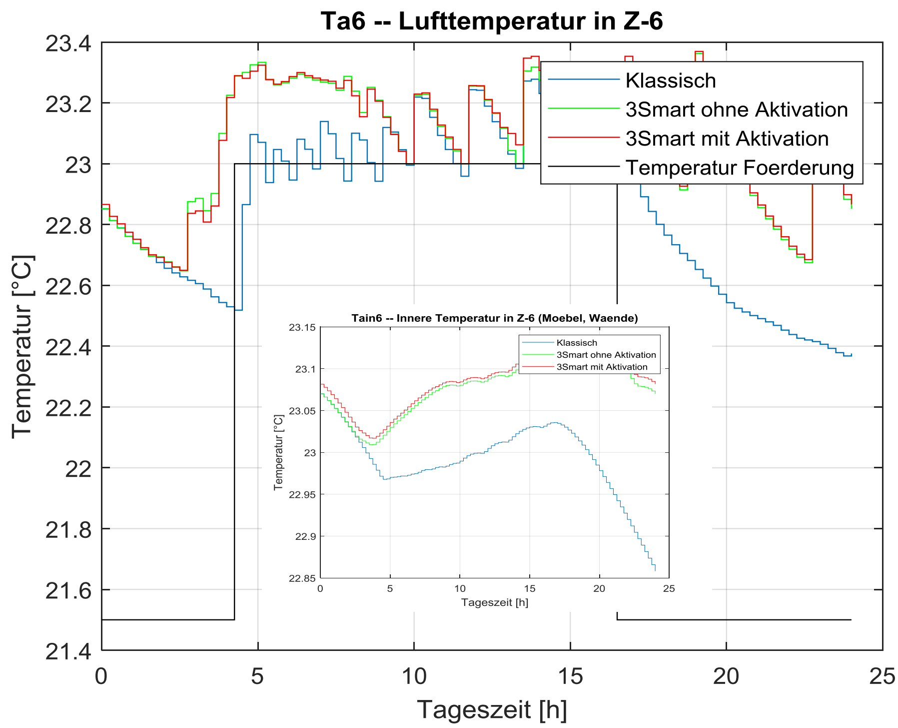

Figure 2.26. Temperature behaviour in Z-6. Small figure shows the behaviour of the inner room temperature state (representing walls and furniture).

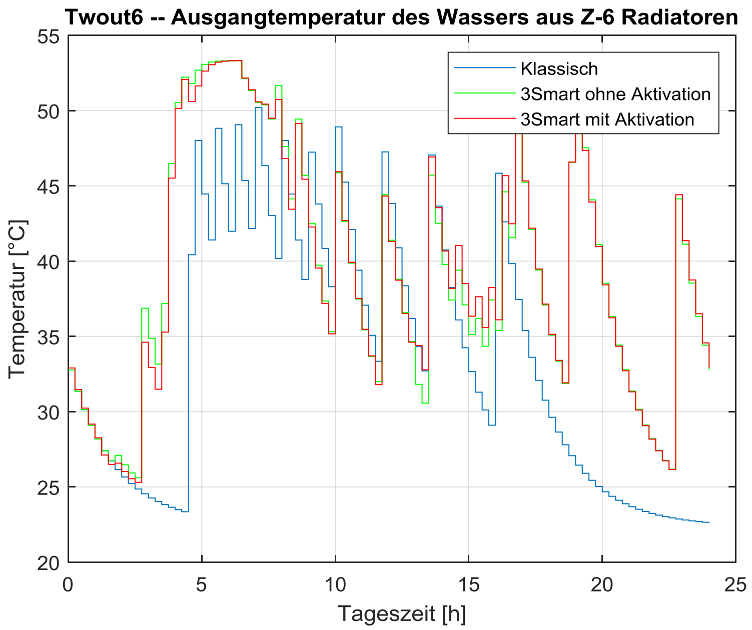

Figure 2.27. Return medium temperature in Z-6.

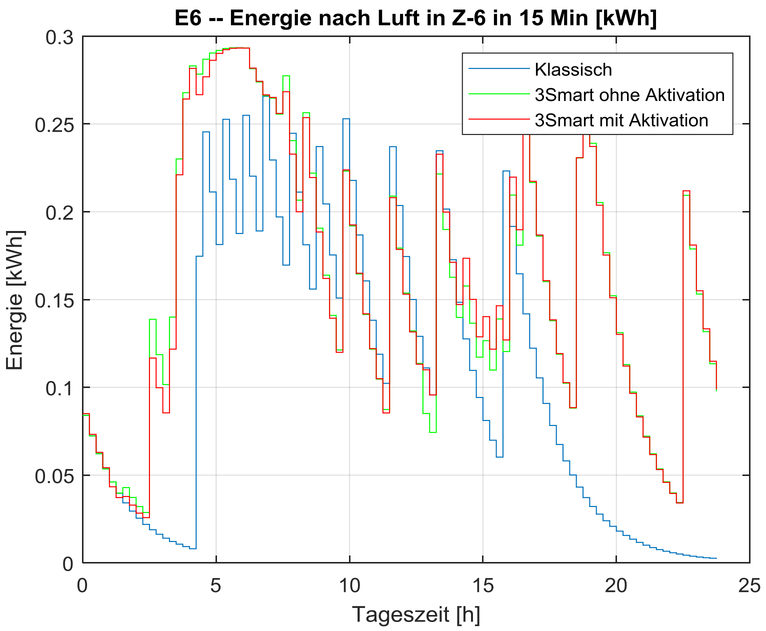

Figure 2.28. Energy provided to air in Z-6.

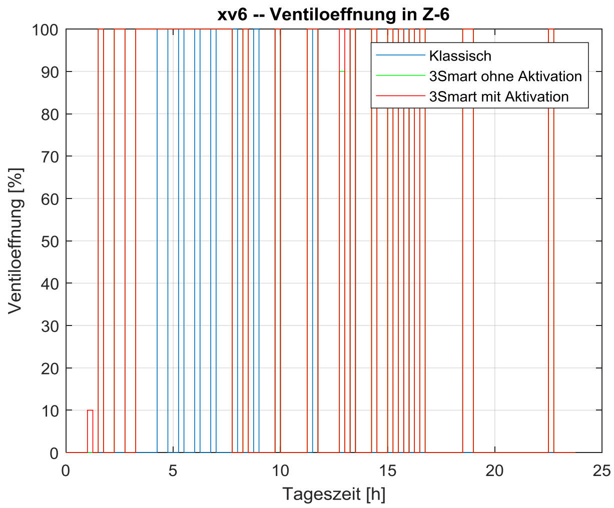

Figure 2.29. Valve opening in Z-6.

The behaviour of Z-7 is shown next (figures 2.30-2.33).

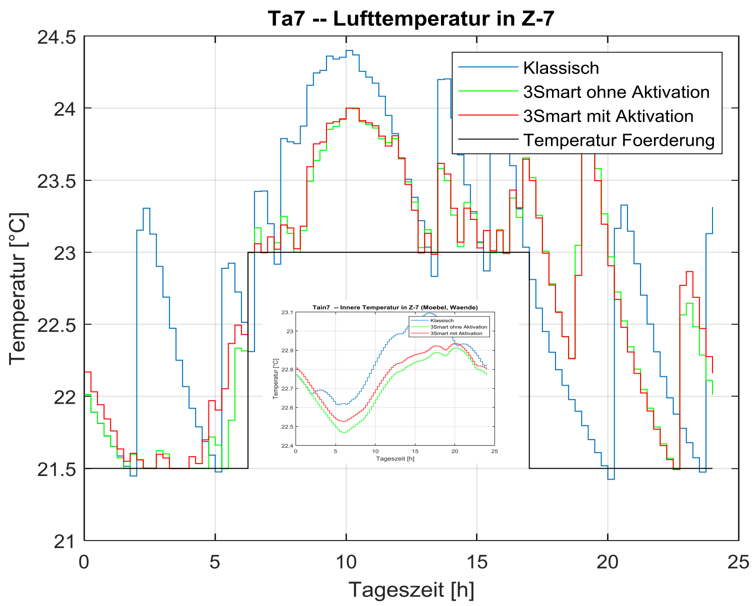

Figure 2.30. Room temperature in Z-7. Small figure shows the behaviour of the inner room temperature state (representing walls and furniture).

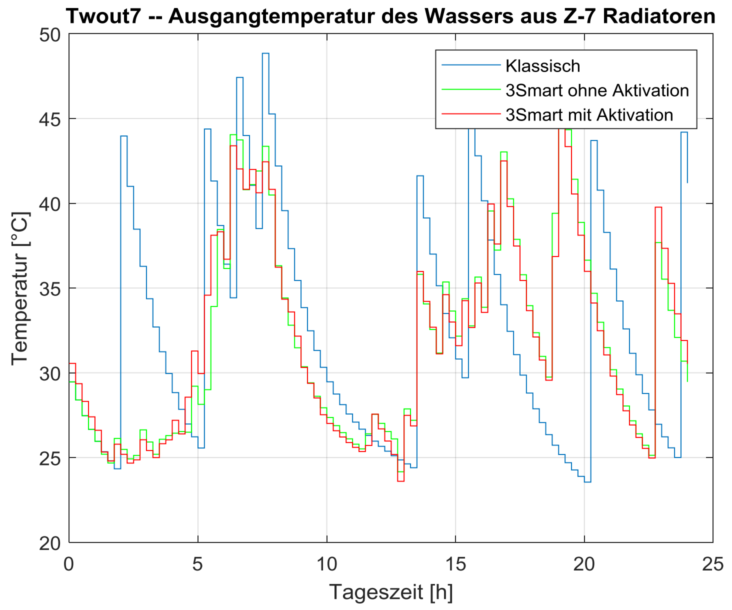

Figure 2.31. Return medium temperature in Z-7.

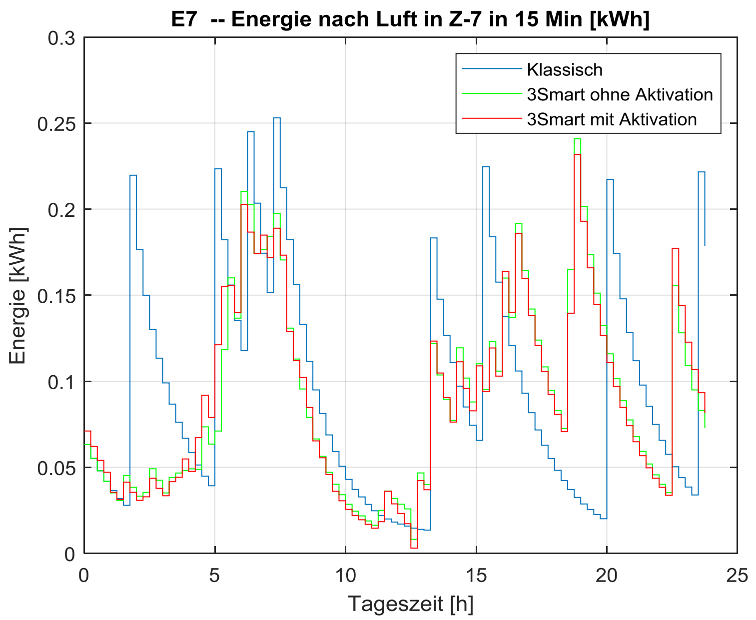

Figure 2.32. Energy provided to air in Z-7.

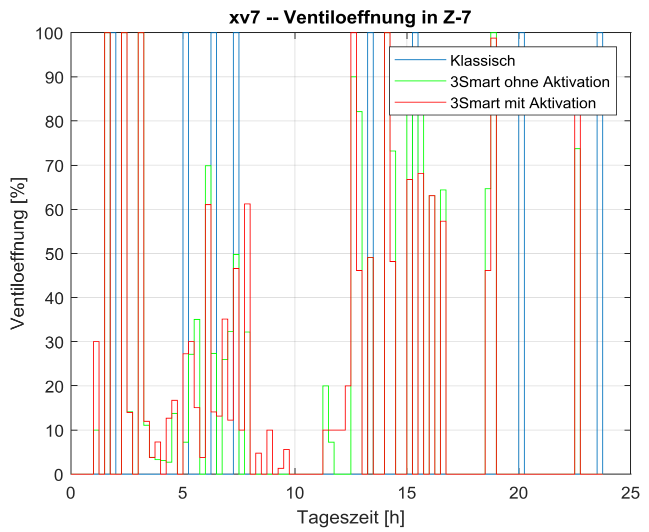

Figure 2.33. Valve opening in Z-7.

Responses for room Z-8 are shown next (figures 2.34-2.37).

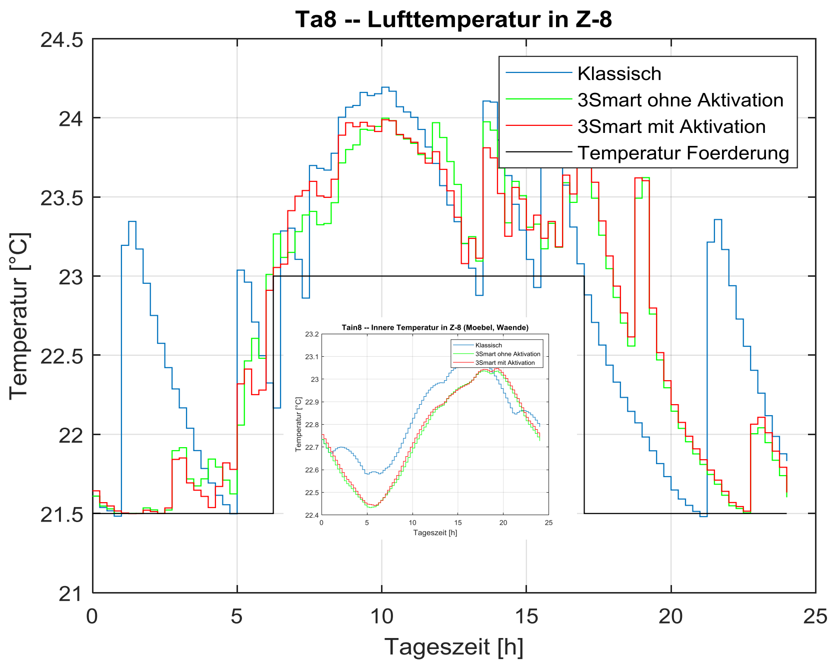

Figure 2.34. Air temperature in Z-8. Small figure shows the behaviour of the inner room temperature state (representing walls and furniture).

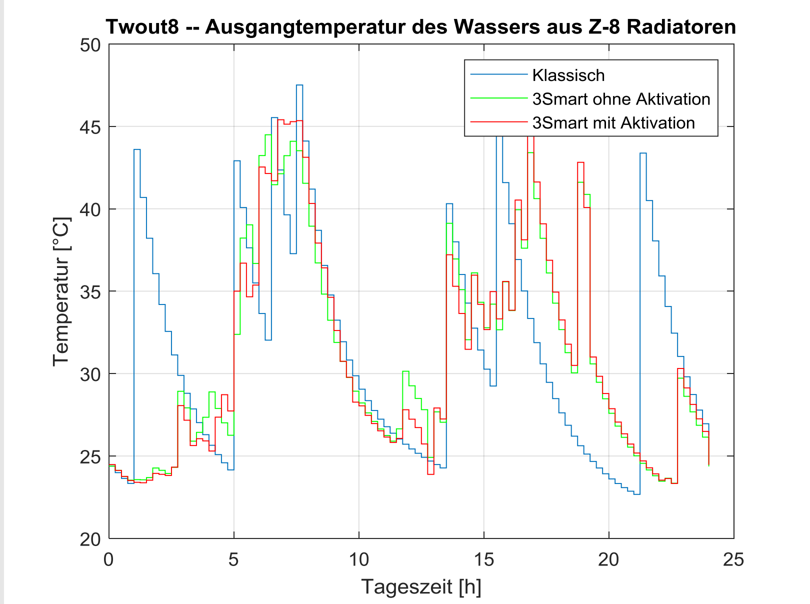

Figure 2.35. Return medium temperature in Z-8.

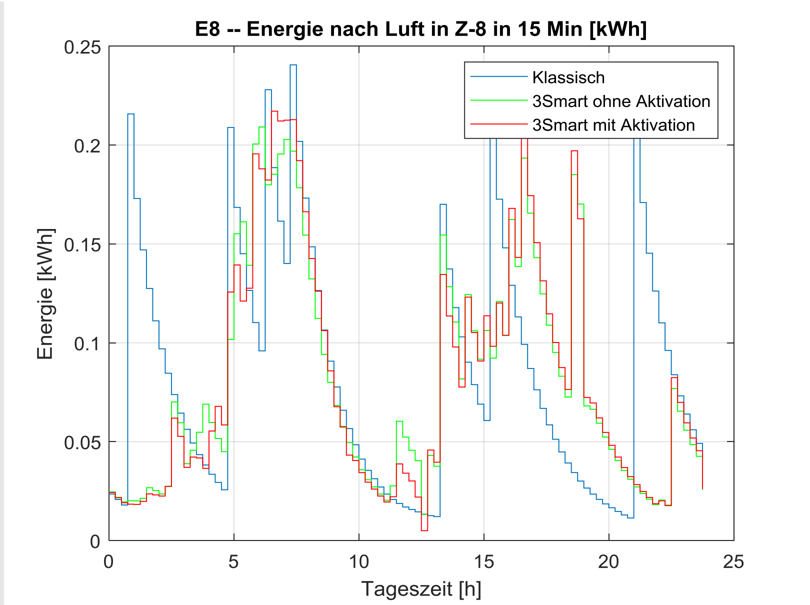

Figure 2.36. Energy provided to room air from radiators in Z-8.

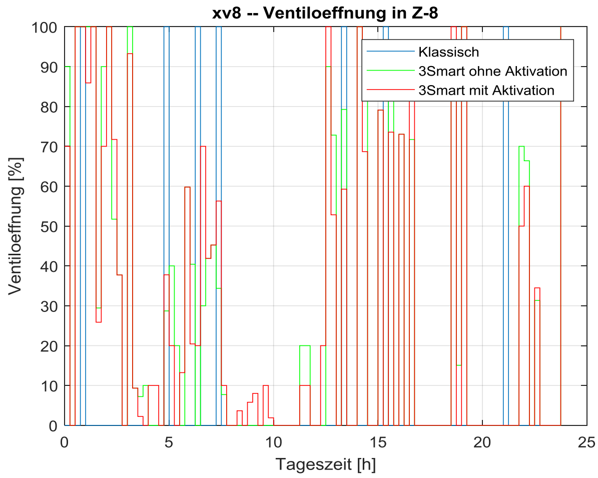

Figure 2.37. Valve opening in Z-8.

No large difference in responses between the classical control and 3Smart can be spotted at first by just looking at the zones level for rooms 1-8, but actually with 3Smart the energy is sourced from the system in a synchronized way for all rooms, such that there are periods when the heating medium temperature is raised to feed all rooms simultaneously and then the medium temperature is again decreased on the central duct to reduce losses. E.g., note that all rooms for which heat is necessary in the evening with 3Smart have the heating focussed in period 18:30-19:15. This exactly corresponds with the period when the starting temperature is set to high value, and before and after is kept on low values. This coordination significantly contributes to lowering of the energy losses in this old, series duct system.

Z-9 is equipped with fan coil for heating. It is also supplied from the heating substation, but through a separate duct. The fan coil in Z-9 is the only controllable element in the building that consumes electricity and through its smart control the building can participate in demand response. As it is a rather small load, the power flexibility size will be rather exemplary, but will show how the system is reorganized to exploit this flexibility provision potential. Responses exhibited in Z-9 are provided within figures 2.38-2.41.

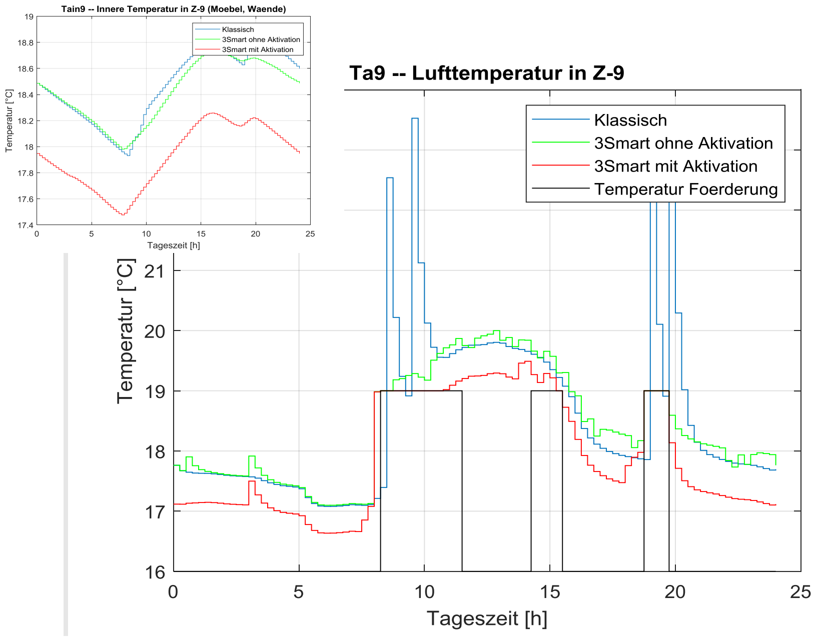

Figure 2.38. Air temperature in Z-9.

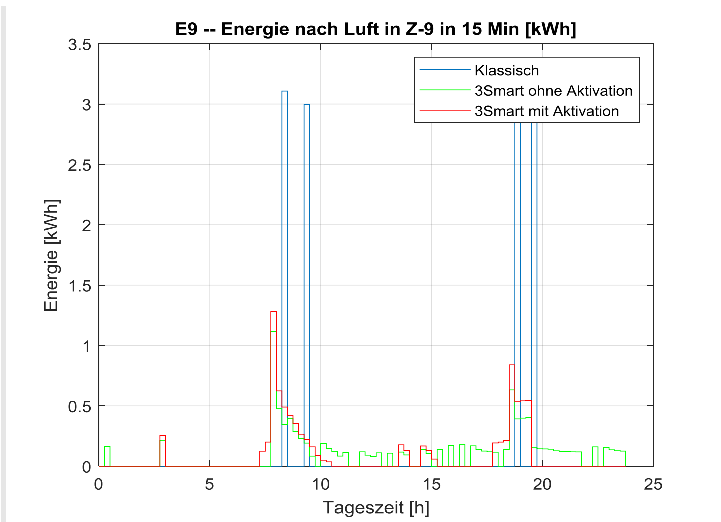

Figure 2.39. Energy provided to room air from the fan coil.

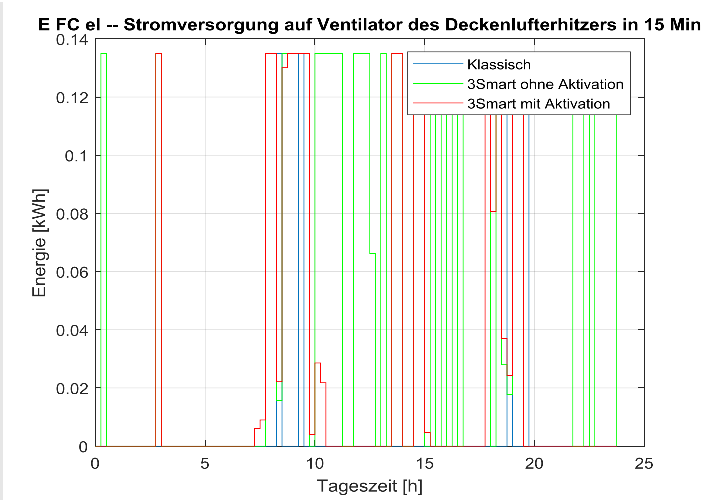

Figure 2.40. Electricity consumed on the fan coil in Z-9.

The behaviour in Z-9 shows the possibility of flexibility provision in electricity. When the flexibility is not activated, intentionally more electricity is spent in the flexibility period 12:00-13:00. When the flexibility is called, the consumption is moved from that interval thus giving way to flexibility. Also, as will be shown in the electricity consumption, the 3Smart system engages the fan more since the supplied heating medium temperature is lower in the case of 3Smart. Thus, 3Smart decides that it is worth to sacrifice somewhat the electricity consumption of the fan while achieving significantly less heat losses in piping. As both economical prices of heat and electricity are used in optimization, 3Smart is able to optimally weigh between the two and assess the economically optimal operation point.

On the central HVAC system level, the main decision relates to the starting temperature of the medium running through all the ducts. Figure 2.41 shows the temperature behaviour for the starting medium towards the rooms from the building's heating substation. In conventional control, whenever there is a room with an open valve or energy request, i.e. with the air temperature lower than the required minimum temperature, the temperature of the starting medium is set at 60°C. Otherwise, the heating substation is not providing any heat and the medium gets cooled with dissipation in the duct system – which is actually the major cause of the inefficient operation. 3Smart system on the other hand gets along with this old series radiators connection configuration by synchronizing the heating needs of rooms and the starting medium temperature, and also exploits the medium cooling phase in the duct to catch the heat for the rooms – that is why it is possible to get so abrupt temperature lowering transients of the medium for the case of 3Smart operation.

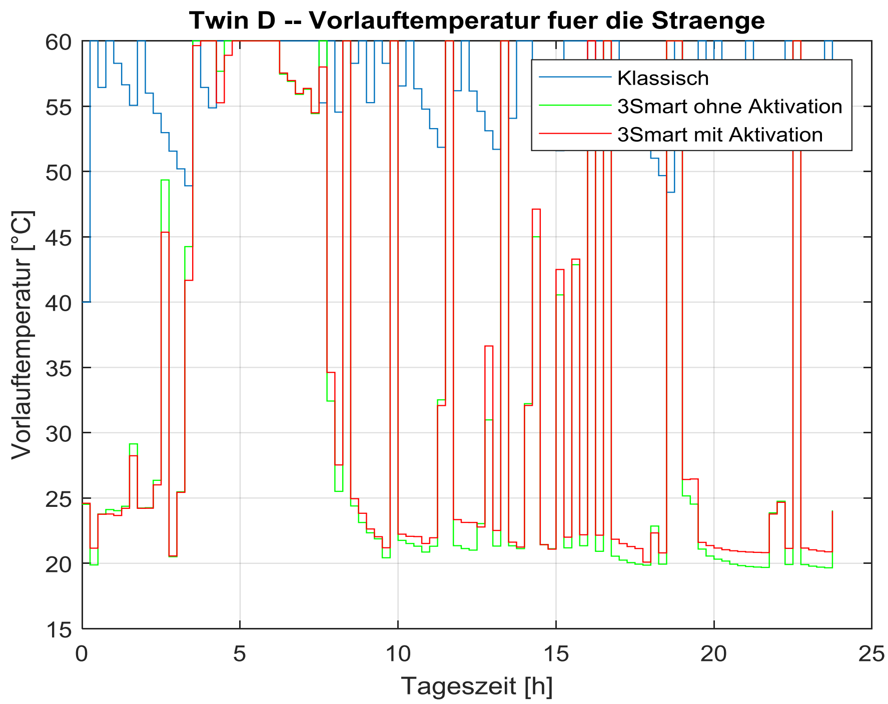

Figure 2.41. The commanded starting medium temperatures on the heating substation.

One may notice much higher supply temperatures of the duct in classical operation. Namely, predictive control elaborates that it is more efficient to coordinate the heat consumption on all rooms and focus their consumptions in a short time period when the temperature in the duct is raised. Outside this time interval the heating medium is practically left at room temperature. Low temperature of the medium in intervals with little heating needs also enables to perform slight cooling in some overheated rooms due to external sunshine and use this energy in other building parts which are not exposed to sunshine.

Energies spent on different supply ducts are provided next, in figures 2.42-2.44, and the result of planned operation by 3Smart is clearly visible in reduction of heating energy consumption on all supply ducts, which mostly relates to reduced losses. One may notice that there are even periods when heating energy from duct south is taken from slightly overheated rooms and actually transferred to other ducts which additionally reduces consumption of heating energy from the district heating. Of course, cumulatively the overall energy consumption on the heating substation is never negative (see Figure 2.48) as the heating substation cannot cool the medium, but 3Smart inherently also exploits these opportunities offered for savings and for reduction of space overheating. Such proficient operation cannot be exhibited with classical control. Periods of negative energy are more visible on duct south (especially in the morning hours, 8-12) where for a period of time the duct starting water is cooler than the return water, meaning that the heat is sucked from overheated spaces and for that amount reduced the need for heat from the district heating grid.

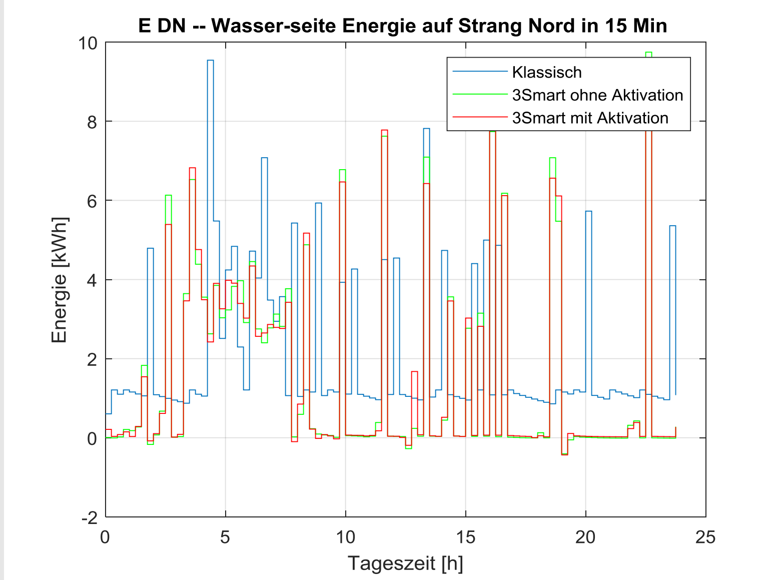

Figure 2.45. Consumed water-side energy on duct north.

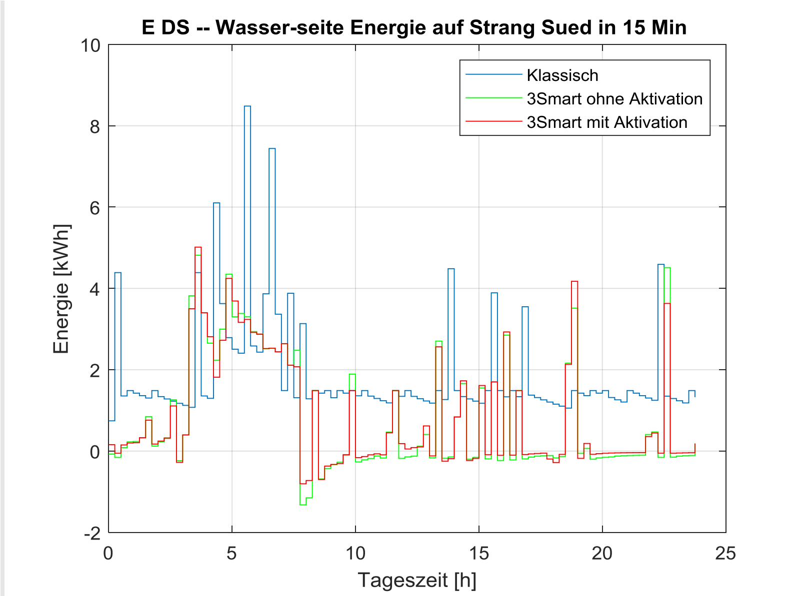

Figure 2.46. Consumed water-side energy on duct south.

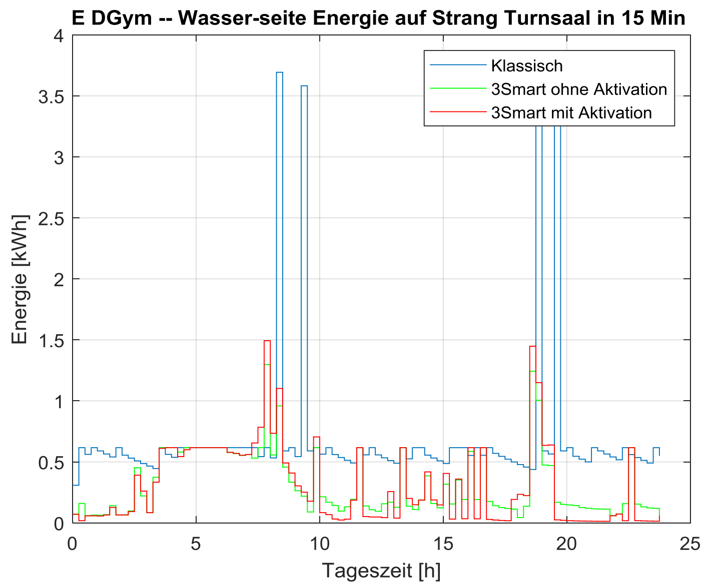

Figure 2.47. Consumed water-side energy on duct gym.

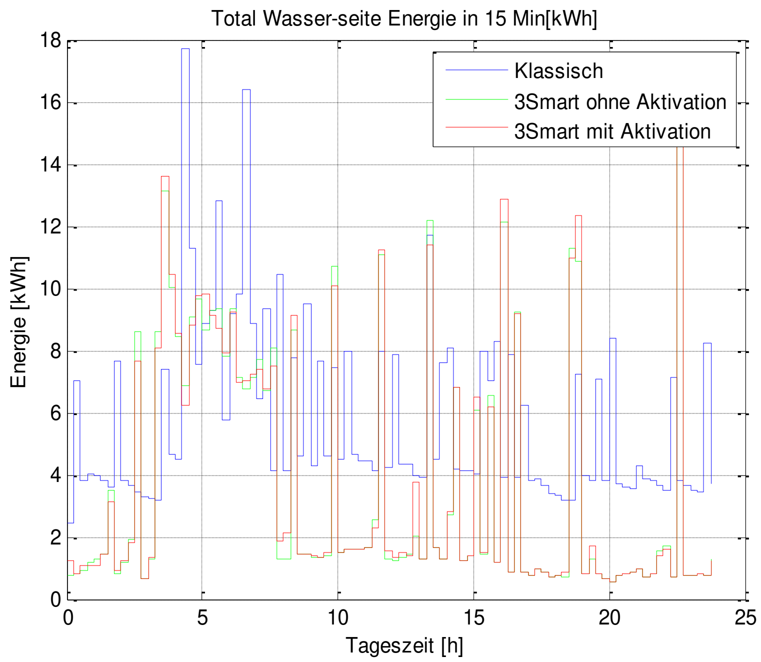

Figure 2.48. Total heating energy consumption of the primary school

The overall energy consumption figures are quite remarkable – conventional control results in daily heat consumption of 554 kWh, while 3Smart strategies without and with flexibility activation show consumptions of 363 kWh and 366 kWh, respectively, which is a heat consumption reduction of some 34%.

Also the microgrid level in Strem primary school is quite specific – it has no controllable elements, but is used to optimally bind the controllable consumption of the fan coil fan in the gym hall with the remaining non-controllable consumption of the building. Within it also the optimal flexibility bid of the building is computed, which is quite low because the fan coil fan power rating is only 540 W. Microgrid signals the actual prices for perturbation of the current controllable electricity consumption profile to the central HVAC level and with it the consumption of the fan coil fan can be adapted to yield optimal benefit for the building. The finally achieved electricity exchange with the grid is shown in Figure 2.49.

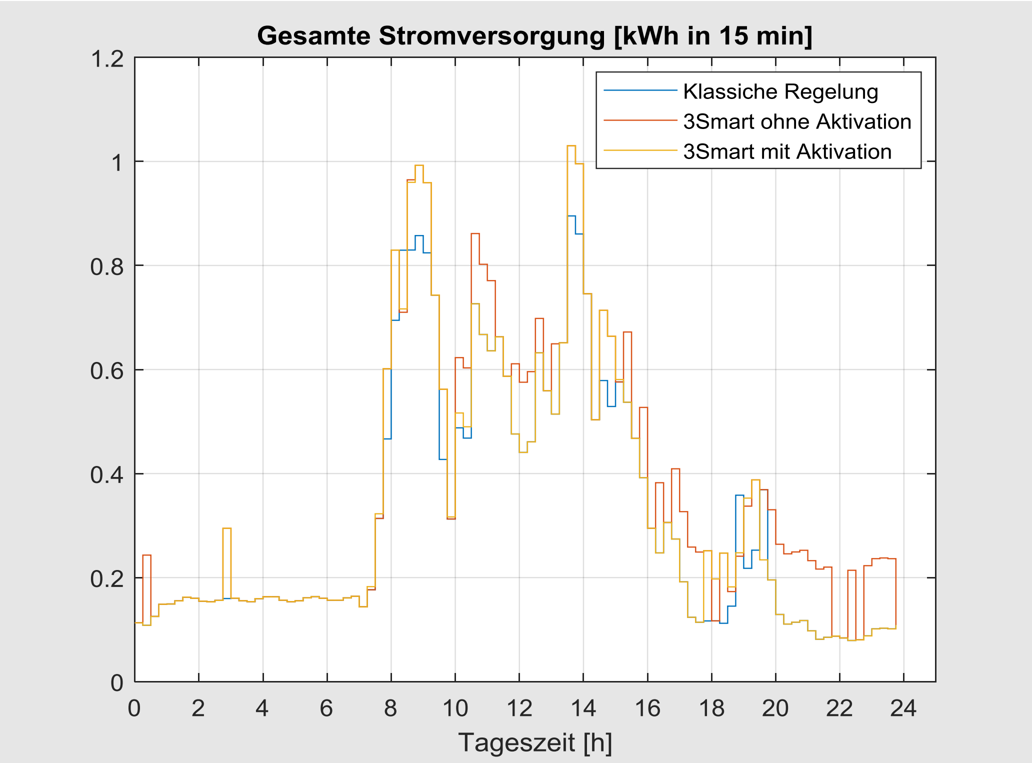

Figure 2.49. Overall electricity exchange profile between the building and the grid.

In Figure 2.49. the possibility of flexibility activation is visible in the flexibility time interval. The flexibility offer is only 240 W. The electricity costs are between 0,5 EUR and 1 EUR higher with 3Smart than with classical control, thanks to the more intensive usage of fan coil fan under lower supply temperatures. However, it is compensated with high heating costs reductions and turns out to be the economical optimum for the building.

The overall financial performance of the primary school building in Strem for the considered day in the heating season is presented in Table 2.1.

Table 2.1. Comparative representation of daily financial performance of conventional control and 3smart controls

	Conventional control	3Smart – w/o activation	3Smart – with activation
Heating	55,51 €	36,31 €	36,55 €
Electricity, microgrid operation, flexibility	5,19 €	6,20 €	5,58 €
Total	60,70 €	42,51 €	42,13 €

The average daily gain of 3Smart versus conventional control can be computed from the numbers in Table 2.1 by presuming that activation will occur in 50% of cases, such that the gain would be an average between 18,19 EUR and 18,57 EUR, so 18,38 EUR or roughly daily gain of 18 EUR can be assessed.

3. Retirement and care centre 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 long-term grid-side modules computation ended with no flexibility requests, but to illustrate what would happen in the case when flexibility is needed one interval of flexibility is artificially entered, as follows:

- 12:00-13:00.

The pricing conditions computed by the long-term module were also too small for building participation and are thus artificially enlarged three times to show the effect on the building:

- reservation price: 0.063 EUR/kW/15 min;
- activation price: 0.258 EUR/kWh;
- penalty price: 2.577 EUR/kWh.

The electricity is priced at 0.173 EUR/kWh and heat from the district heating grid is priced at 0.1 EUR/kWh.

Additional parameters taken into account are consisted of the relevant meteorological conditions, namely outdoor air temperature profile (shown in Figure 3.1) and direct and diffuse solar irradiance profiles (shown in Figure 3.2), as well as the non-controllable consumptions on the HVAC level (thermal energy consumption profile shown in Figure 3.3) and the microgrid level (electrical energy consumption profile shown in Figure 3.4).

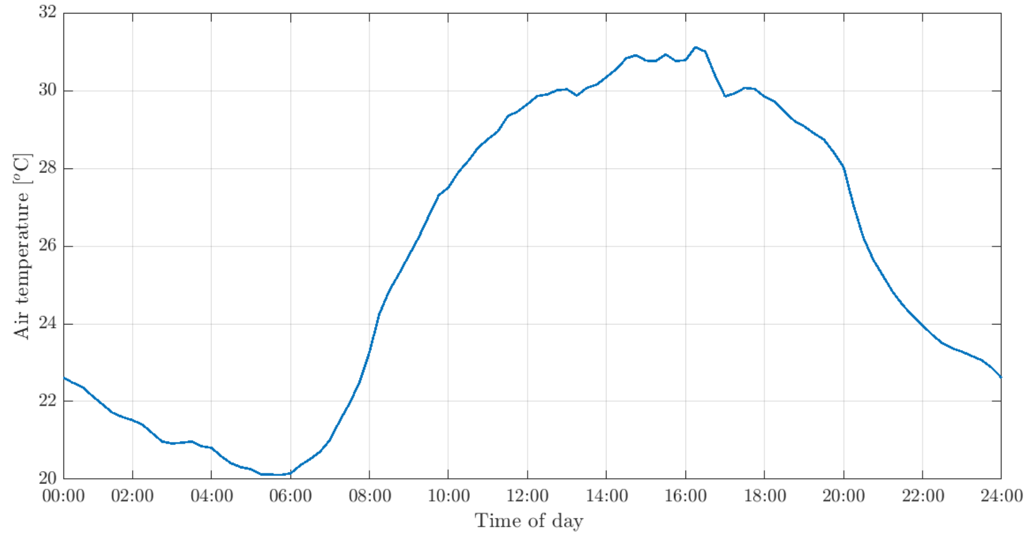

Figure 3.1. Outdoor air temperature for a sunny day in July.

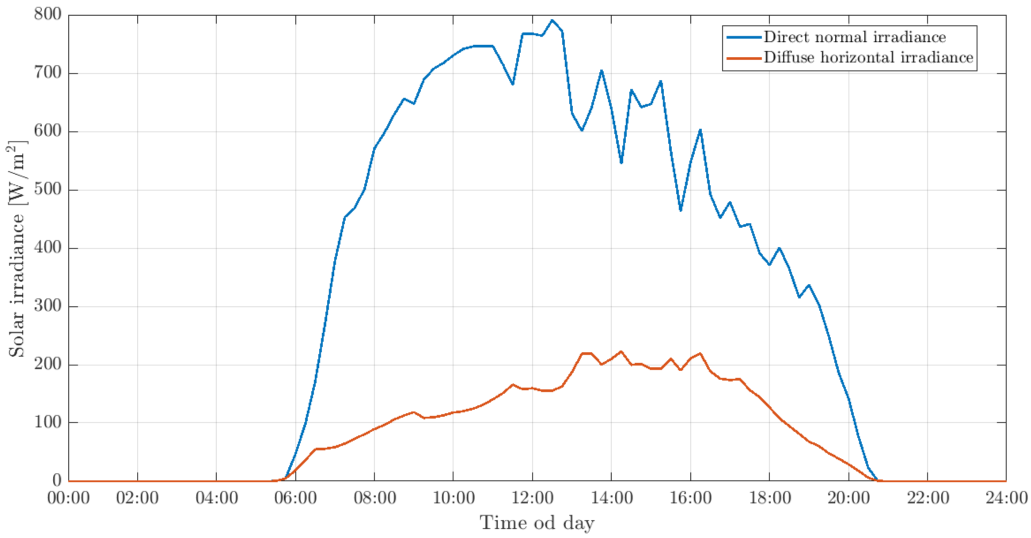

Figure 3.2. Direct (normal) and diffuse (horizontal) solar irradiance for a sunny day in July.

Non-controllable thermal energy consumption on the central HVAC system level accounts for the consumption of the non-controllable cooling circuits in the building supplied from the same chiller. On duct south where controllable zones are located in cooling there no non-controllable zones (unlike in heating). The non-controllable electrical energy consumption on the microgrid level is consisted of the energy consumption of the building subtracted by chiller consumption and battery system energy exchange.

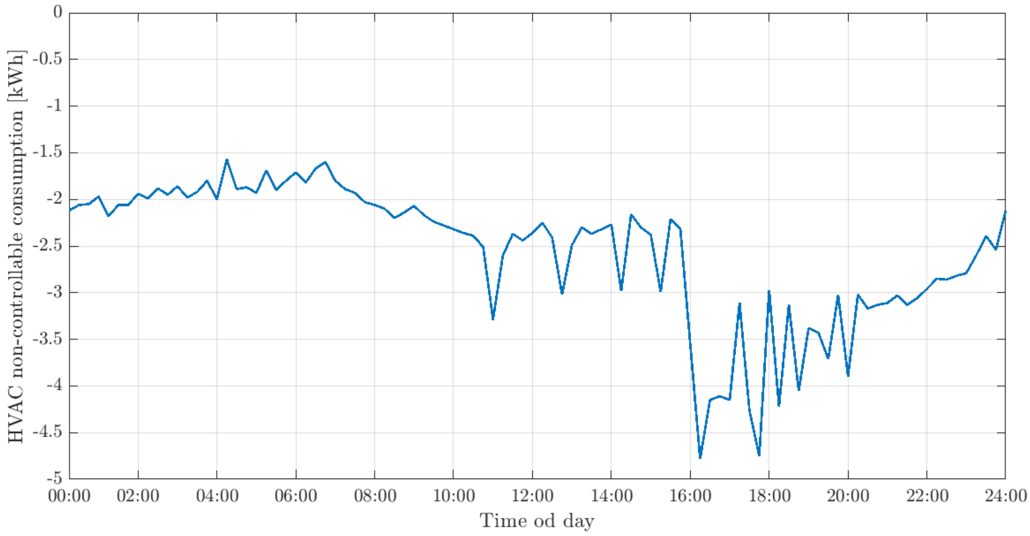

Figure 3.3. Non-controllable consumption of thermal energy on the HVAC level, for a sunny workday in July.

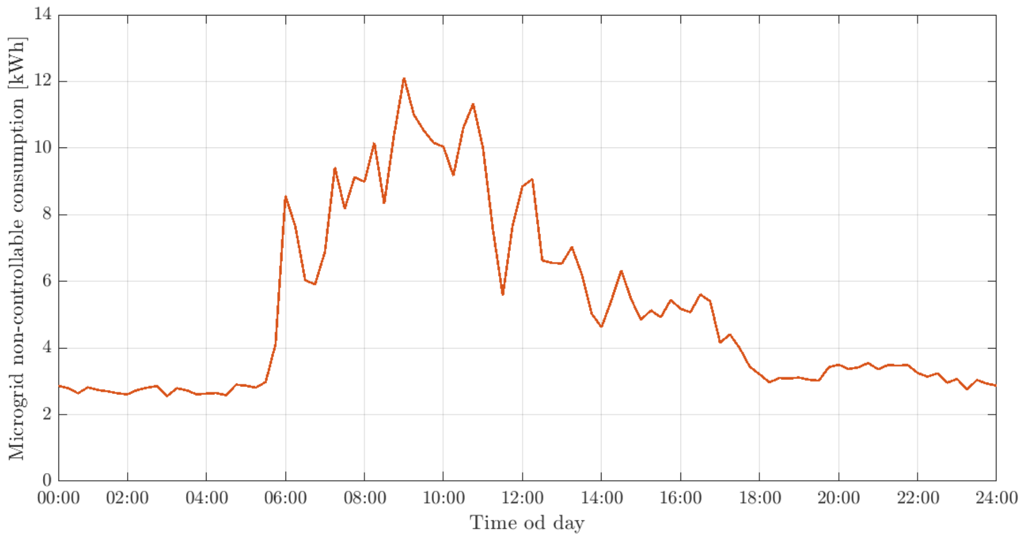

Figure 3.4. Non-controllable electrical energy consumption on the microgrid level, for a sunny workday in July.

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 (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 controller that incrementally increases the valve opening when the temperature is higher than the reference temperature and vice versa. This way of operation is actually the state-of-the-art conventional control algorithm for rooms temperature regulation in cooling. It 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 3.5. one may see a typical temperature profile of one of the zones of the retirement and care centre building. A temperature comfort should be achieved in all 40 controllable zones where the temperature during the period 08:00-18:00 should be kept in range [23.5°C, 24.5°C].

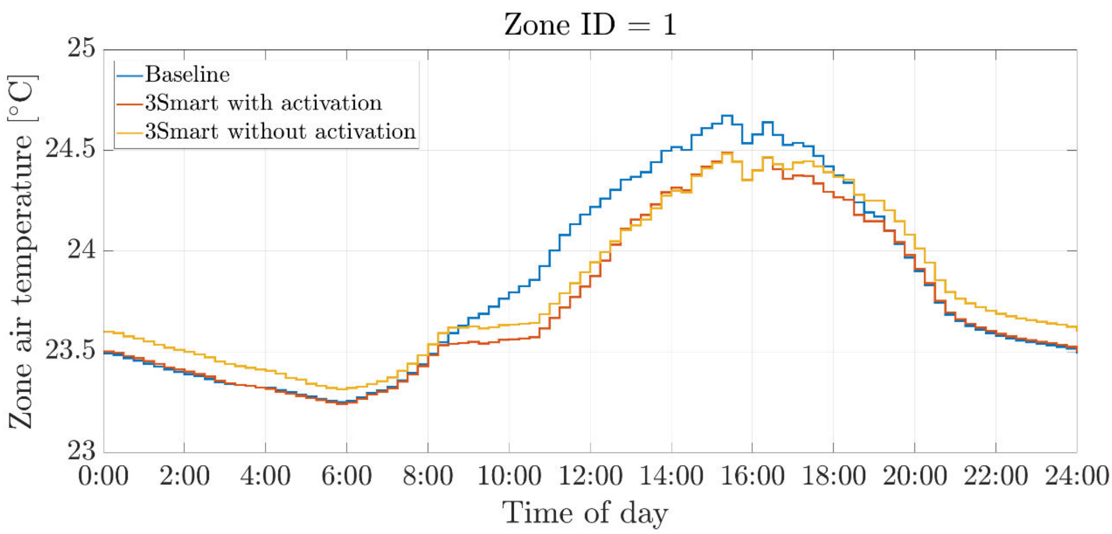

Figure 3.5. Temperature behaviour in one exemplary zone of the retirement and care centre.

The baseline controller is based on the reactive control where only current system state influences the valve position. The clear lack of the predictive feature in the baseline controller results with disrupted thermal comfort in most of the zones which manifests as the temperature outside the allowed range. On the contrary, with 3Smart controller the temperature is kept within the defined range in all zones during the required period.

The cooling needs in terms of energy provided from the floor cooling element in the room air, for the zone with temperature behaviour in Figure 3.5, are provided in Figure 3.6. In the figure also the return medium temperature and valve opening profile is shown.

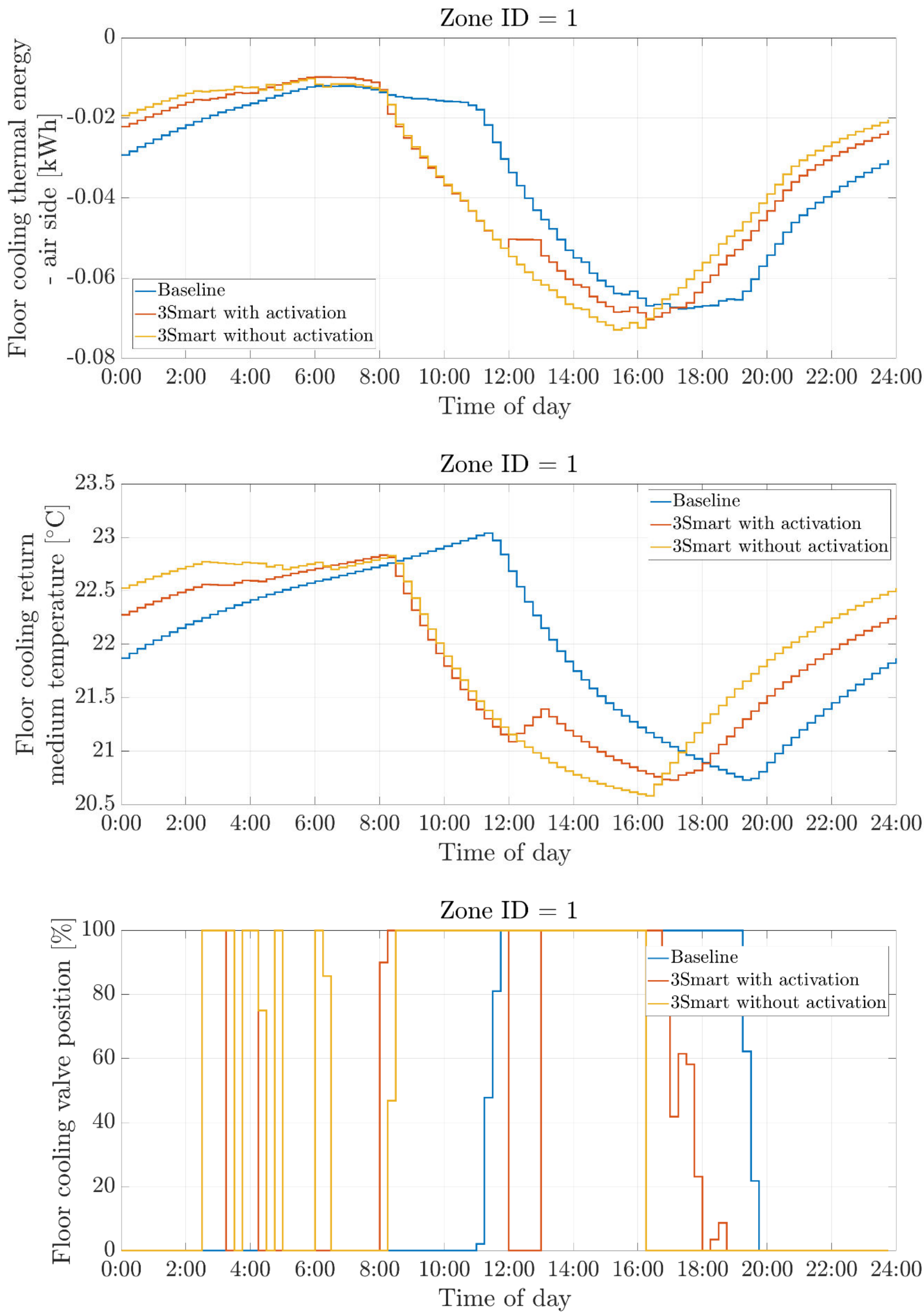

Figure 3.6. Cooling energy provided from the floor cooling element to room air. Return medium profile and valve opening.

On the central HVAC system level the starting medium temperature for duct south is computed, which is to be achieved by low-level control loop on the mixing valve of duct south. The decided temperature profile is shown in Figure 3.8. With conventional control, the temperature on duct south is kept constant, on temperature 17 °C. Higher values of supply temperature indicate closing of the mixing valve. The 3Smart without activation shows the higher activity of the mixing valve throughout the horizon.

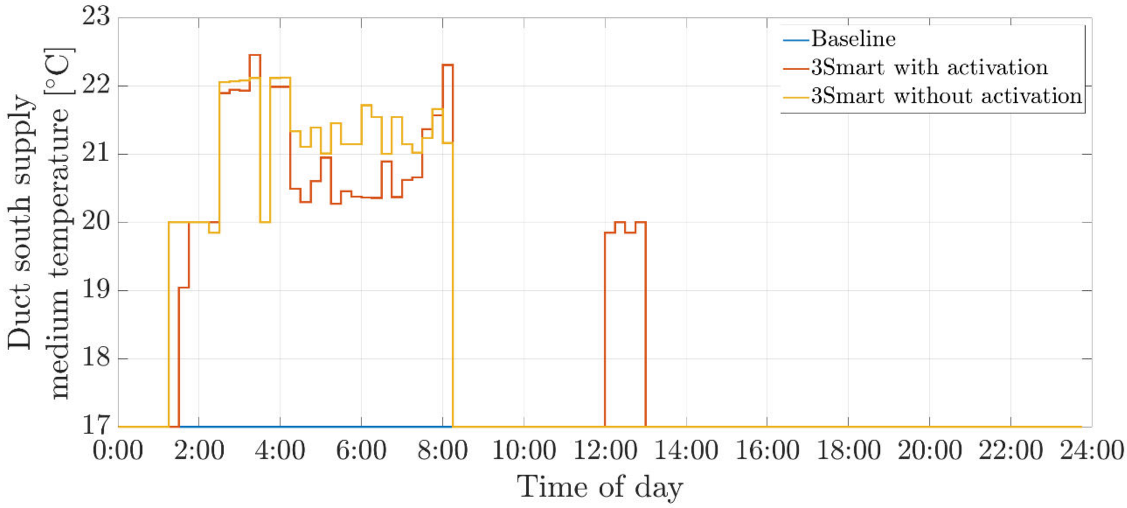

Figure 3.8. Duct south supply medium temperature profile.

The overall thermal (cooling) energy consumption on the controllable south duct is provided in Figure 3.9. Thermal consumption of the 3Smart controllers is higher than the consumption obtained in the operation without 3Smart, but with 3Smart increased comfort in the zones is achieved. In the case of 3Smart with activation, the thermal energy consumption on the cooling machine is lowered in the flexibility interval.

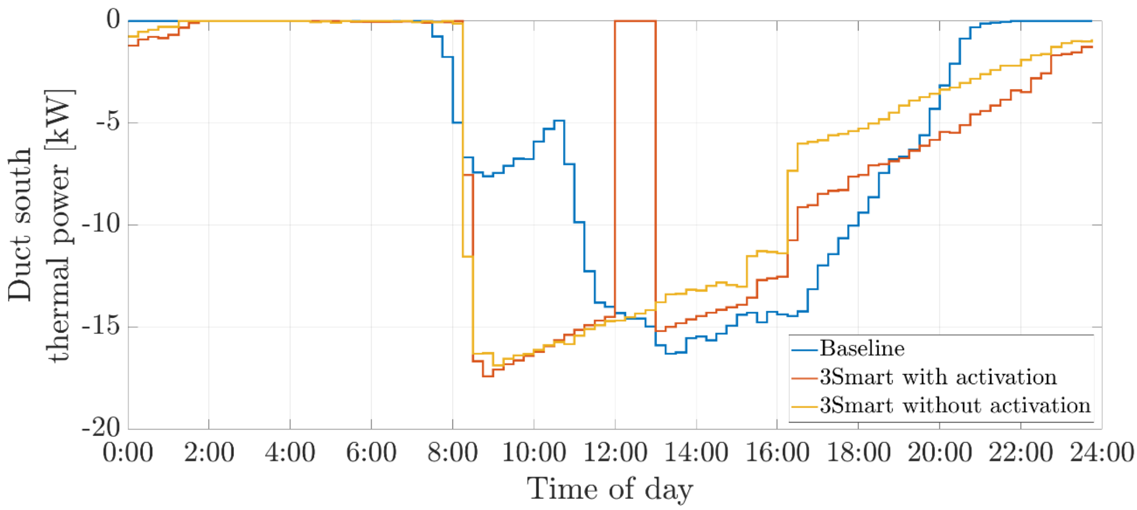

Figure 3.9. Duct south thermal energy consumption for the analysed day.

The overall electricity consumption on the central HVAC system level is shown in Figure 3.10.

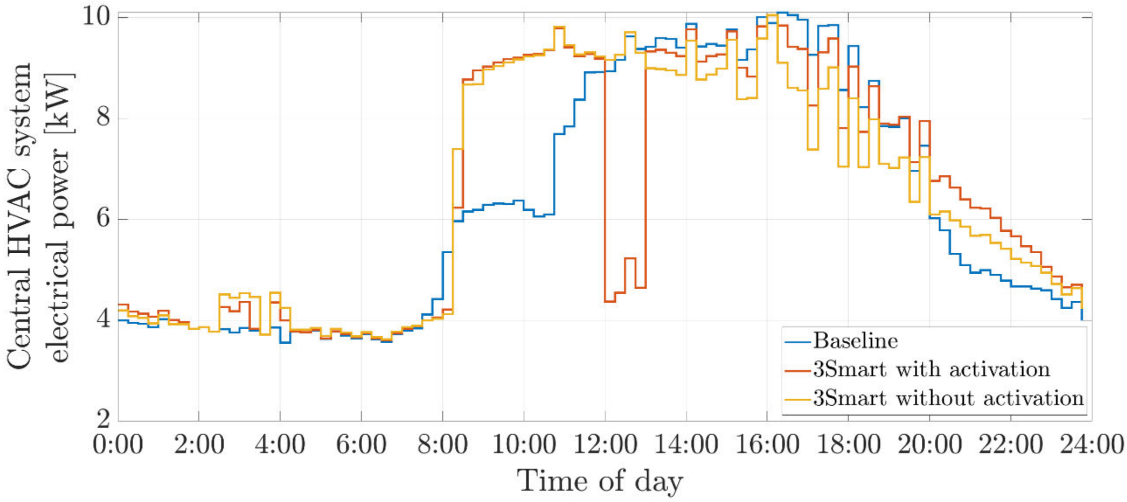

Figure 3.10. The overall electricity consumption on the central HVAC system level for the analysed day of operation in the retirement and care centre.

On the microgrid level the controllable component is the battery storage system for which 15-minute charging-discharging energies are decided. The conventional control algorithm operates the battery in order to flatten the electricity consumption curve of the building. When operated with 3Smart, the microgrid level also tries to exploit the demand response opportunities. By combining battery and HVAC electrical energy profiles the microgrid will lower overall electrical consumption by 4.15 kW to acquire financial benefits. . The exhibited responses of the battery system charging (positive) / discharging (negative) energies are shown in Figure 3.11 while the battery system state of charge response is provided in Figure 3.12.

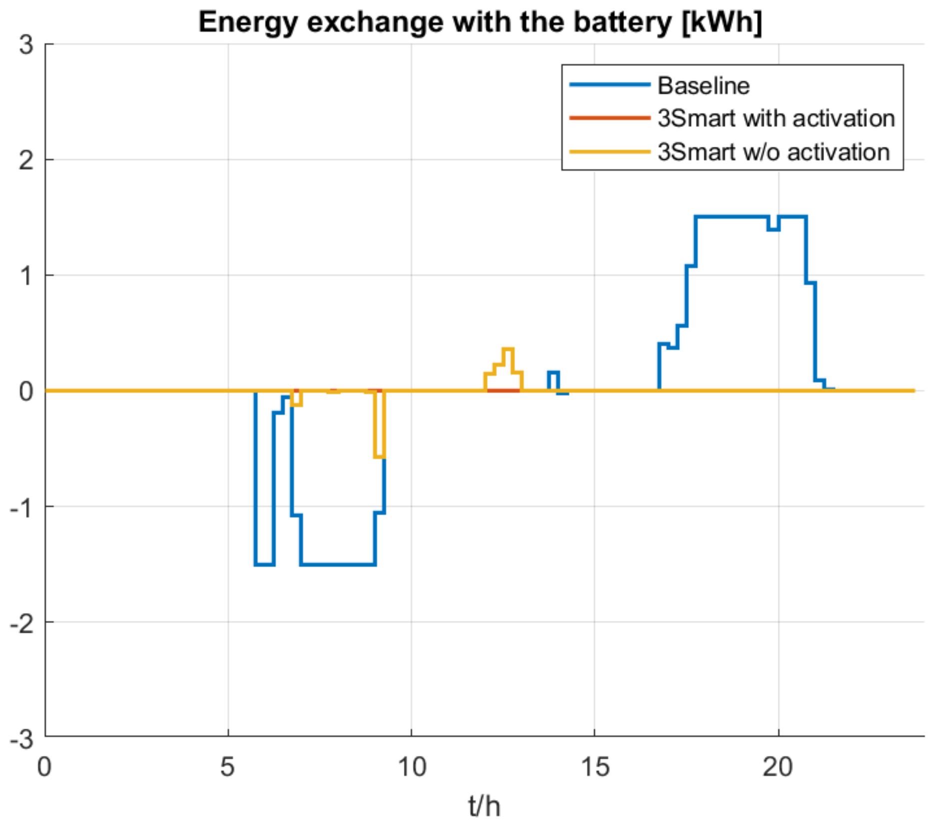

Figure 3.11. Battery charging/discharging energies within the analysed day.

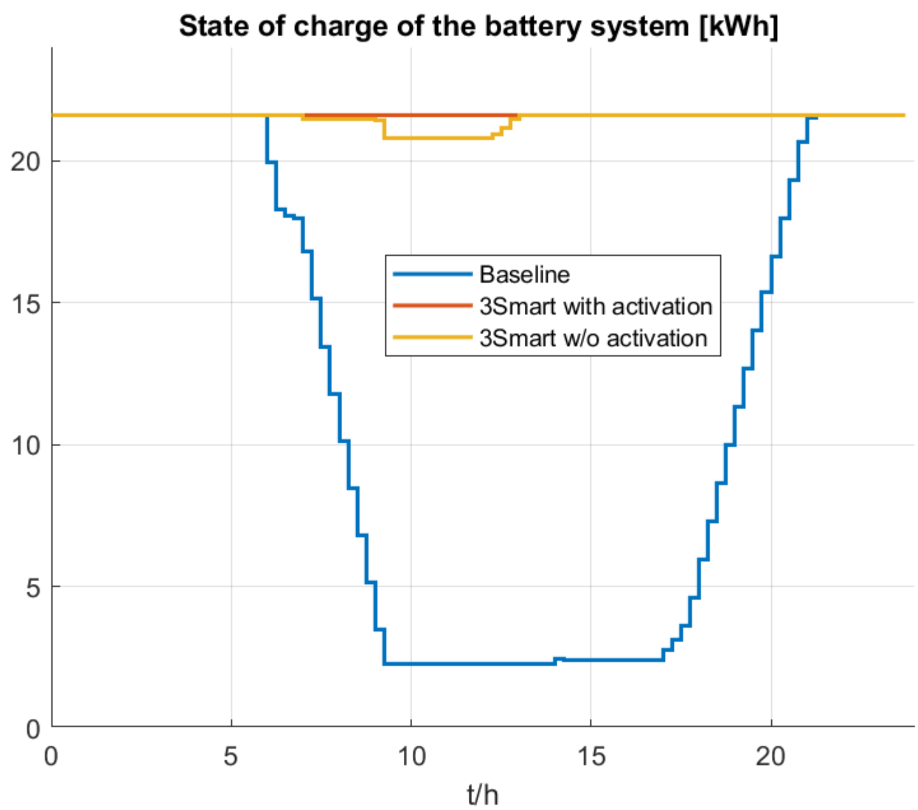

Figure 3.12. Behaviour of state of charge of the battery system within the analysed day.

The overall electricity consumption profile of the building is shown in Figure 3.13.

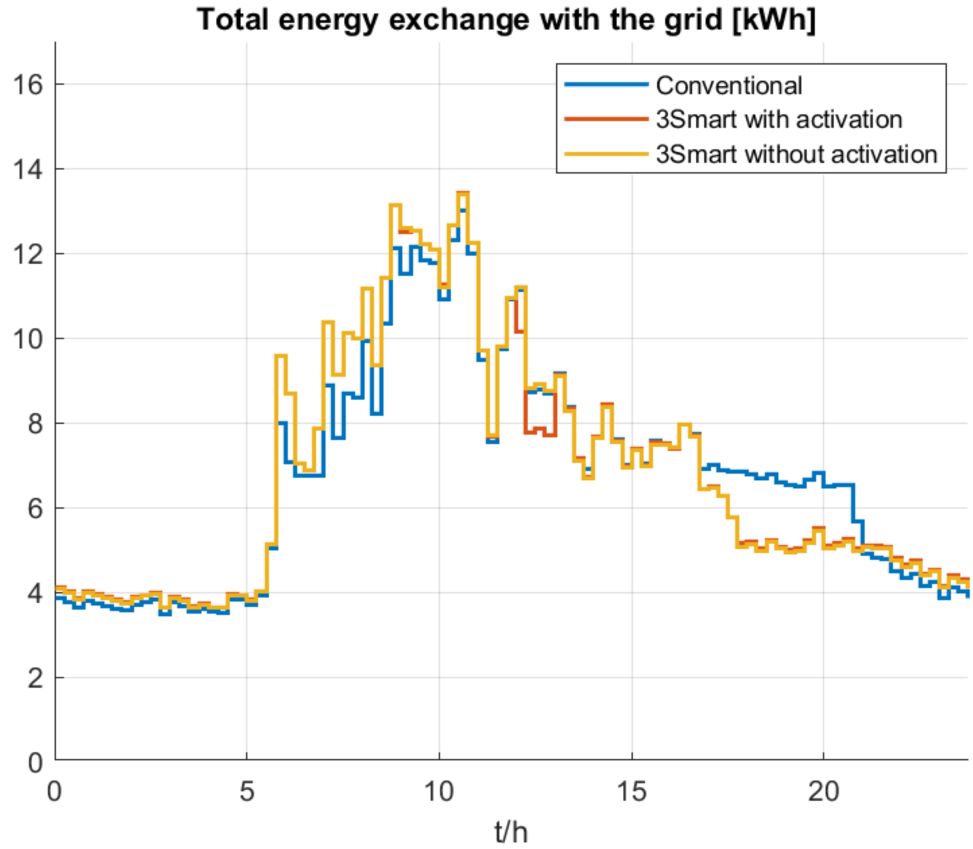

Figure 3.13. The overall electricity consumption profile of the building.

The benefits achievable with 3Smart operation in comparison with conventional control are provided in Table 3.1 where the overall daily operational costs of the building are reported – they include electricity cost, demand response reward and battery degradation due to its usage.

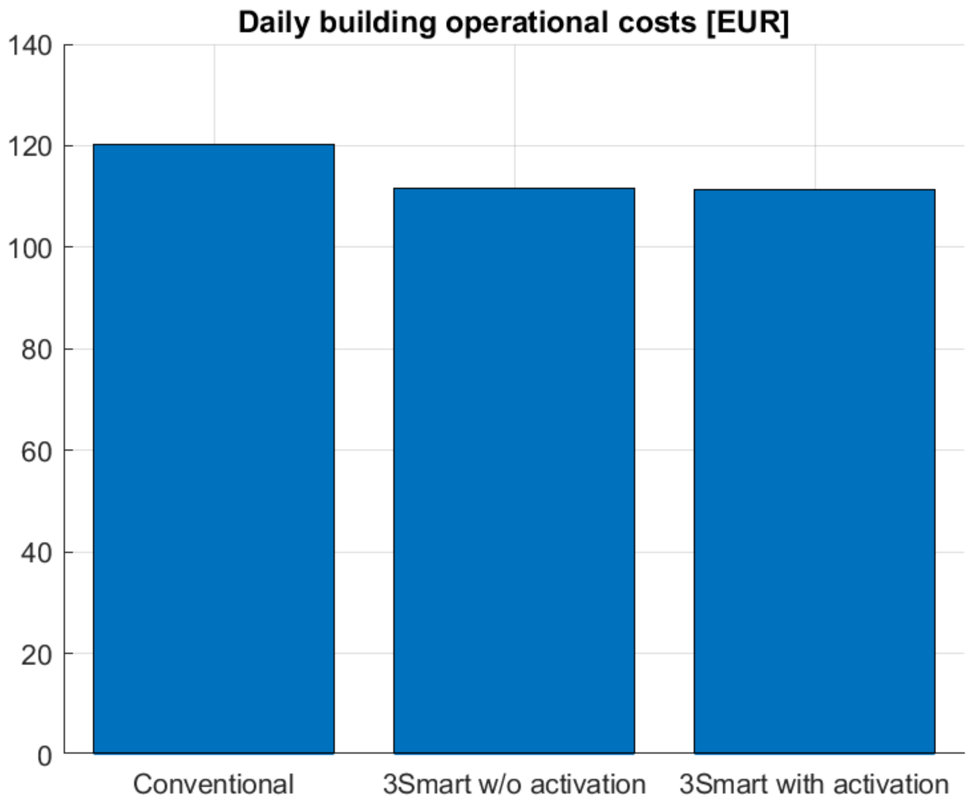

Table 3.1. Daily cost comparison between conventional and 3Smart controls.

	Conventional control	3Smart – w/o activation	3Smart – with activation
Total operational costs	119.83 €	110.91€	110.99€

Considering the daily operational costs provided in Table 3.1, it can be concluded that the 3Smart system achieves on average 8.92 € of operational costs savings.

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 November.

The long-term grid-side modules computation ended with no flexibility requests, but to illustrate what would happen in the case when flexibility is needed one interval of flexibility is artificially entered, as follows:

- 12:00-13:00.

The pricing conditions computed by the long-term module were also too small for building participation and are thus artificially enlarged three times to show the effect on the building:

- reservation price: 0.063 EUR/kW/15 min;
- activation price: 0.258 EUR/kWh;
- penalty price: 2.577 EUR/kWh.

The electricity is priced at 0.173 EUR/kWh and heat from the district heating grid is priced at 0.1 EUR/kWh.

Additional parameters taken into account are consisted of the relevant meteorological conditions, namely outdoor air temperature profile (shown in Figure 3.14) and direct and diffuse solar irradiance profiles (shown in Figure 3.15), as well as the non-controllable consumptions on the HVAC level (thermal energy consumption profile) shown in Figure 3.16 and the microgrid level (electrical energy consumption profile) shown in Figure 3.17.

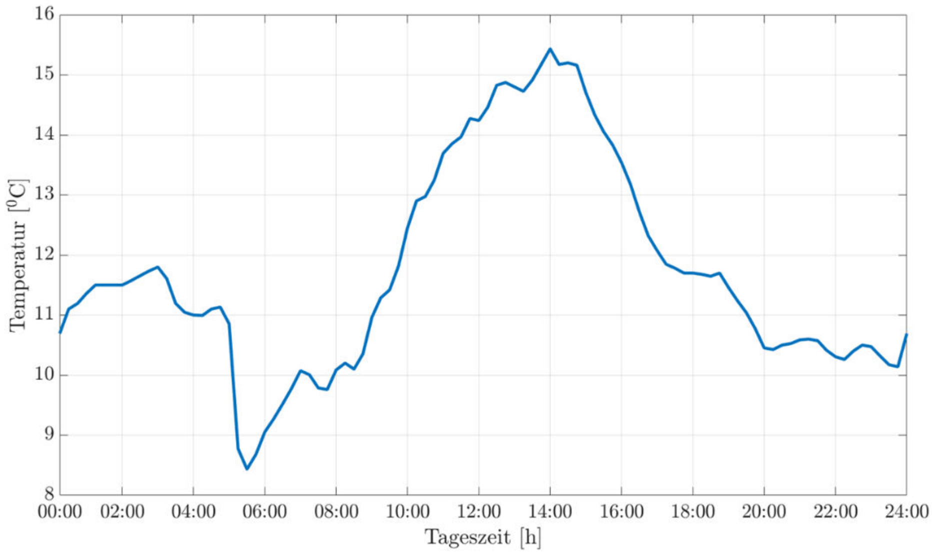

Figure 3.14. Outdoor air temperature for a sunny day in November.

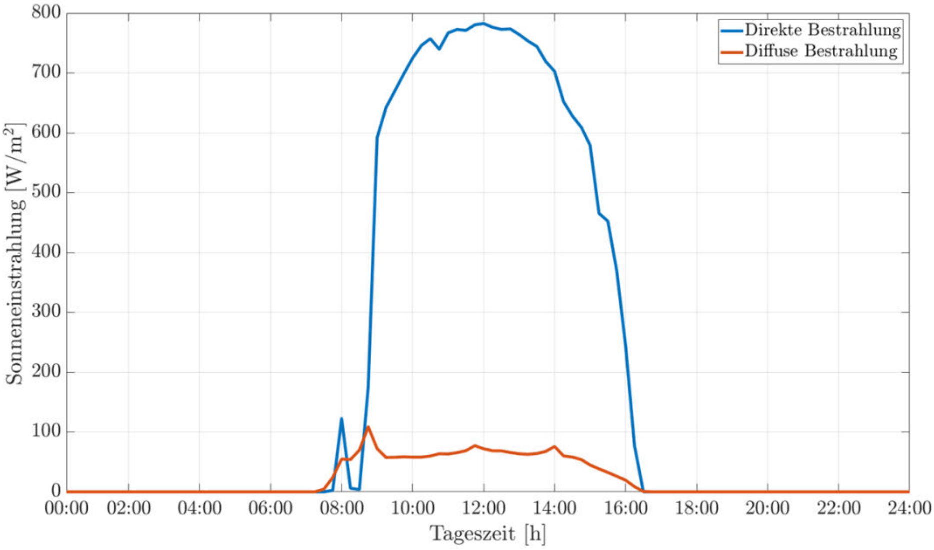

Figure 3.15. Direct (normal) and diffuse (horizontal) solar irradiance for a sunny day in November.

Non-controllable thermal energy consumption on the HVAC level accounts for the consumption of the non-controllable heating supplied from the same heating substation of the building while the non-controllable electrical energy consumption on the microgrid level is consisted of the energy consumption of the building subtracted by the battery system energy exchange. The central HVAC system non-controllable energy consumption is specific since also part of the load on duct south to which controllable zones are connected is also non-controllable. Thus a profile of non-controllable consumption on duct south and of non-controllable consumption on all the remaining heating circuits in the building except for duct south is provided.

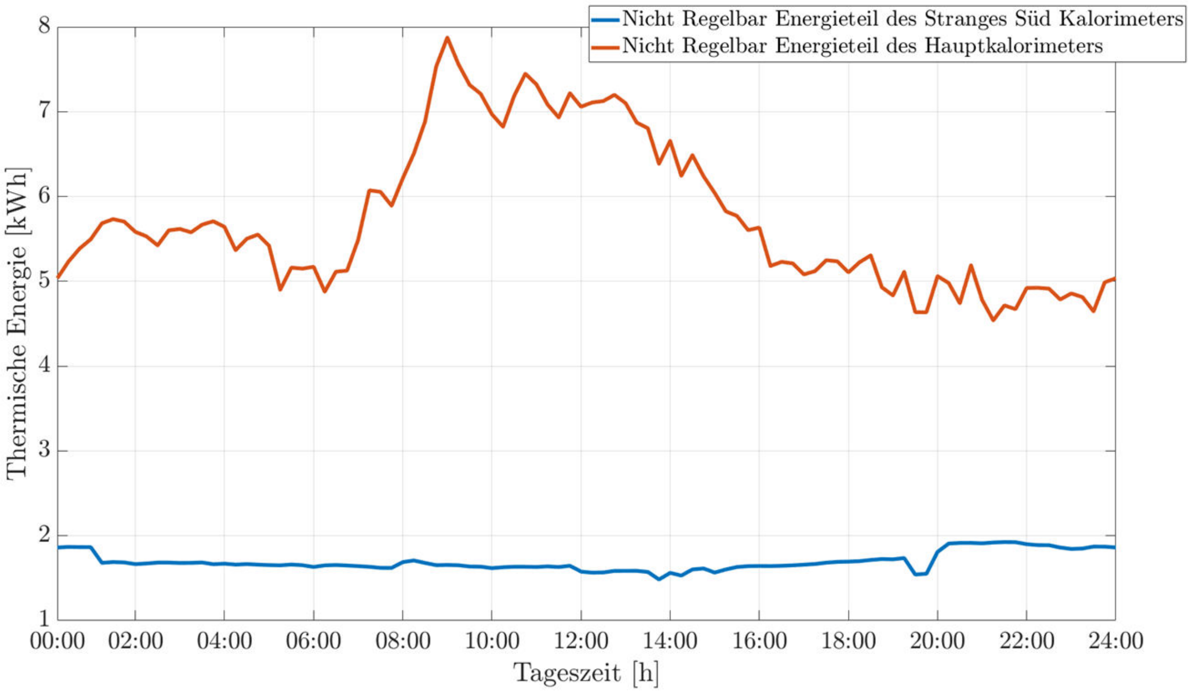

Figure 3.16. Non-controllable consumption of thermal energy on the HVAC level, for a sunny workday in November.

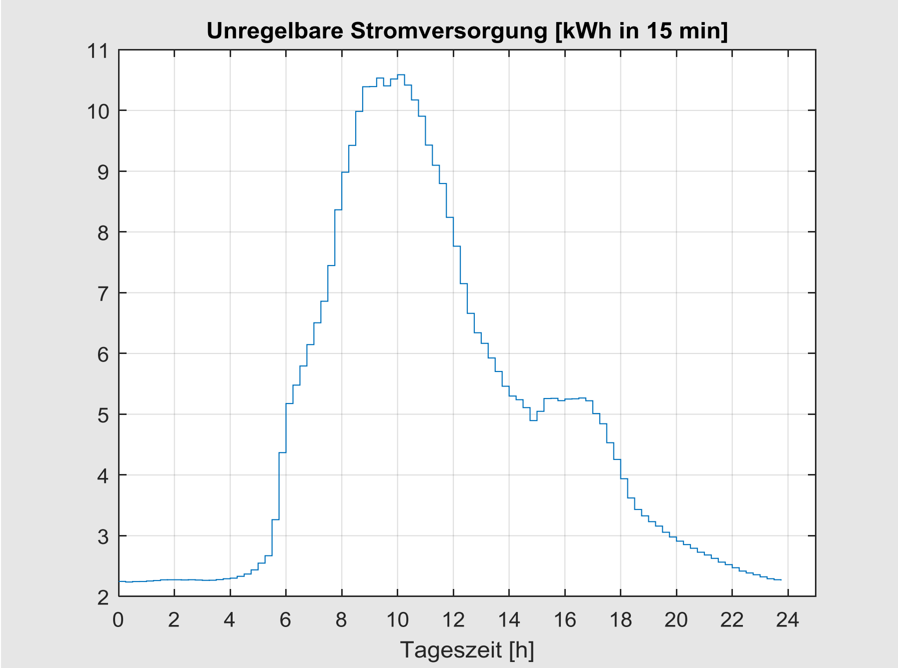

Figure 3.17. Non-controllable electrical energy consumption on the microgrid level, for a sunny workday in November.

3.4 The optimized building operation – heating season

The presentation of the optimized retirement and care centre building behaviour in heating will be given by passing through different levels of the 3Smart system and analysing the optimized behaviours computed. On lower levels in charge for indoor climate (zone, central HVAC system) no significant controllable electricity consumption exists that would allow separation of strategies for the case when the demand response service is called, such that only the comparison between conventional control and one unique 3Smart strategy is shown. On the level of building microgrid still the 3Smart operation when flexibility is not called (without activation) and when flexibility is called (with activation) is distinguished.

First the responses on the zone level are analysed. In conventional control on the zone level it is considered that in each zone exists a simple hysteresis controller that incrementally opens the floor heating 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 3.18 one may see a typical temperature profile of one of the zones of the retirement and care centre building. A temperature comfort should be achieved in all 40 controllable zones where the temperature during the period 08:00-18:00 should be kept in range [23.5°C, 24.5°C].

In conventional control heating is available and controlled all day, in order to have the zones on the correct temperature on time due to the large time constants of the floor heating system. 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, but also with taken into account potential overheating during the day. In conventional control heating starts at 04:00 because of some large zones which cannot be heated-up on time otherwise. In heating actually the electricity consumption of the heating system is not that significant as the only pronounced electricity consumption point is the duct south circulation pump. Its consumption is accounted within the optimization on the central HVAC system level, but it is rather small. Thus there is also practically no difference in operation of the heating system when flexibility for electricity is called or not called.

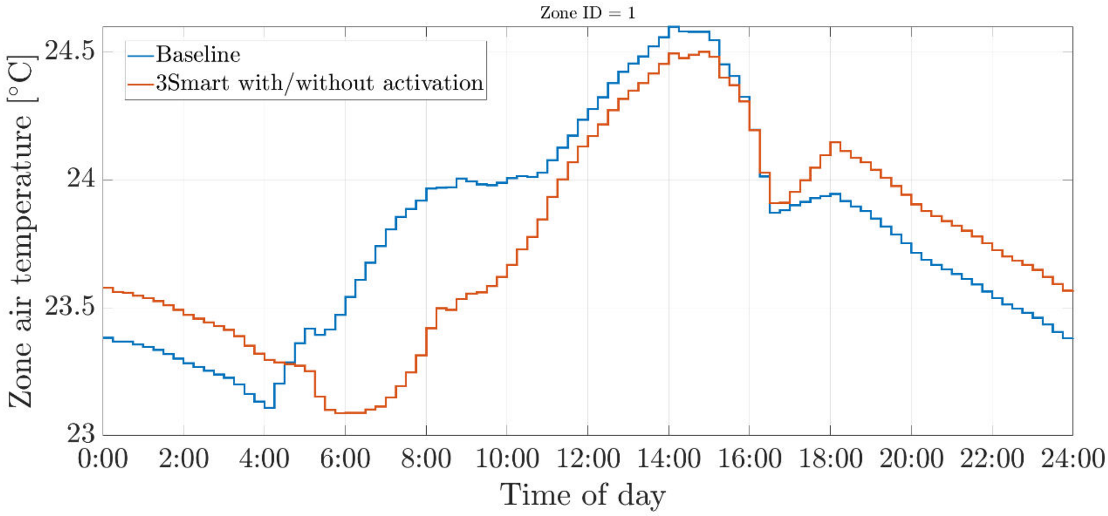

Figure 3.18. Temperature behaviour for one selected room in the retirement and care centre building within the analysed day.

For the room whose temperature response is provided in Figure 3.18, Figure 3.19 shows the heating energy needed to be exerted from the floor heating element. Figure 3.20 shows the behaviour of the return medium temperature for that zone during the analysed day, and Figure 3.21 the planned valve opening profile for it.

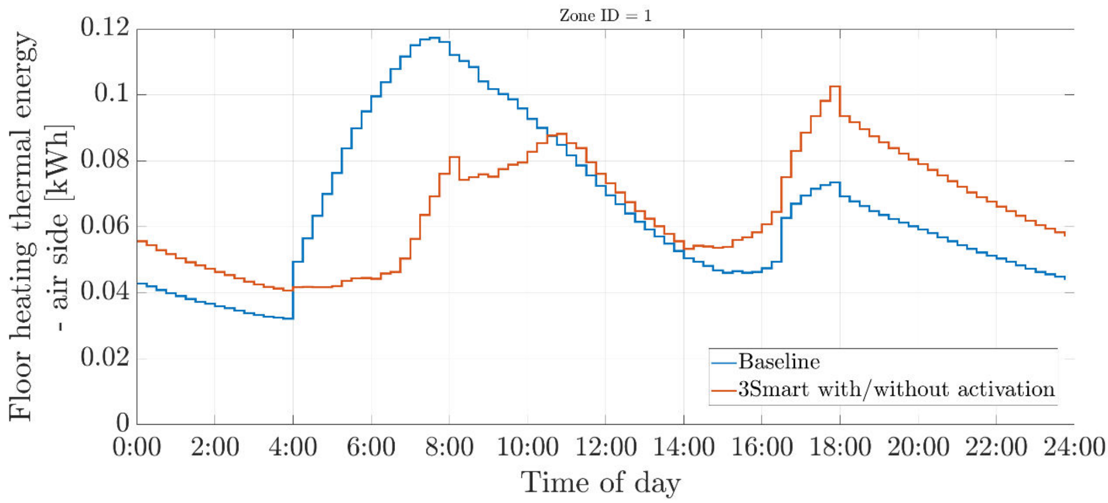

Figure 3.19. Energy provided to air in the retirement and care centre for one exemplary building room within the analysed day.

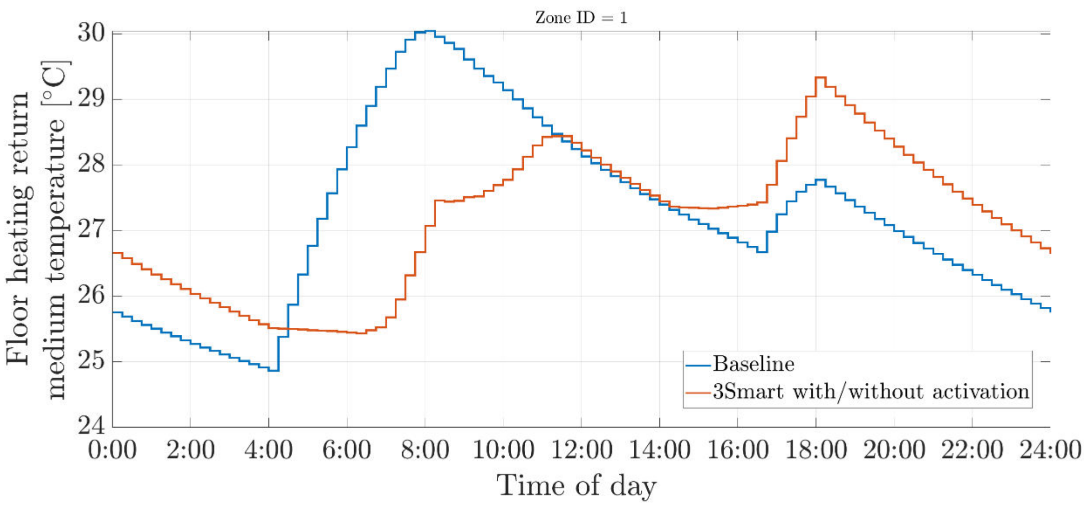

Figure 3.20. Return medium temperature from the floor heating element in the exemplary room in retirement and care centre within the analysed day.

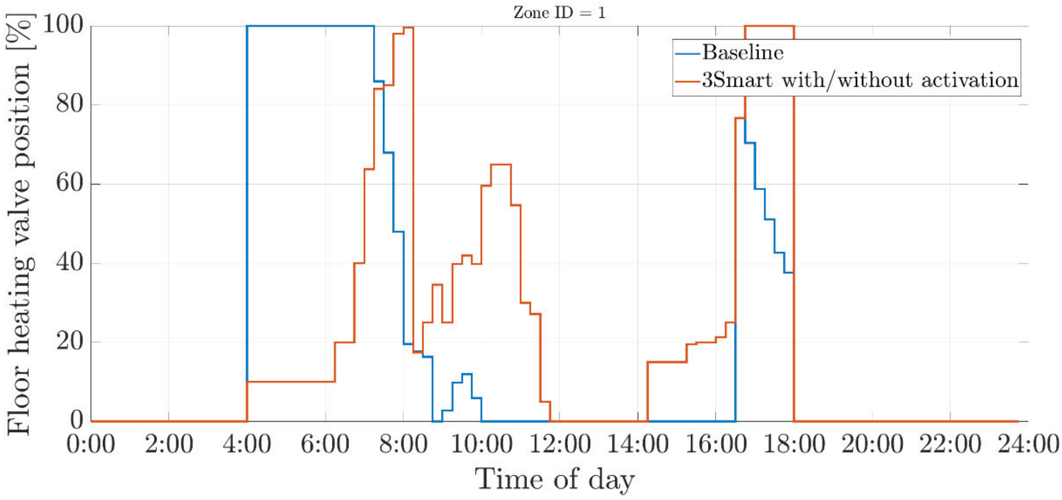

Figure 3.21. Opening of the valve of the floor heating element in the exemplary zone in retirement and care centre building within the analysed day.

With 3Smart operation one may see that the heating load is more evenly distributed throughout the day and the rooms are less overheated during the sunshine period, which is enabled by predictive planning of the temperature profile. Moreover the building operates such that the same way of operation is viable also for the next day as all building states (room temperature, return medium temperature) end in the same state as from which they start. This starting temperature is also optimized to achieve minimum cost.

In the sequel the behaviour in one more room is shown. In this room the sunshine in the middle of the day is more intensive and slight overheating occurs if the heating is not well planned. Thus 3Smart performs a slight abuse of comfort constraints in the early morning such that in the middle of the day practically no overheating occurs, unlike with the conventional control. Figures 3.22-3.25 show the responses exhibited in this room.

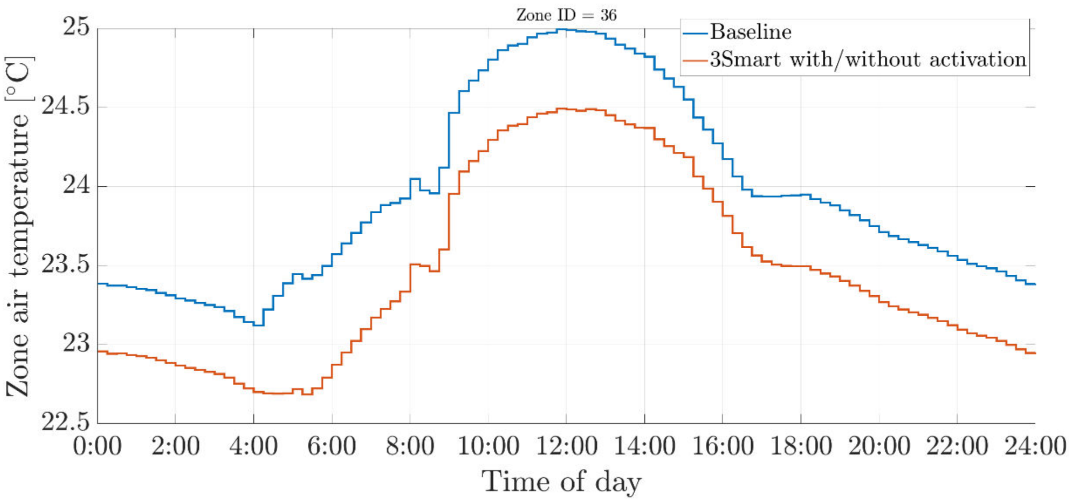

Figure 3.22. Temperature behaviour for a room in the retirement and care centre building within the analysed day.

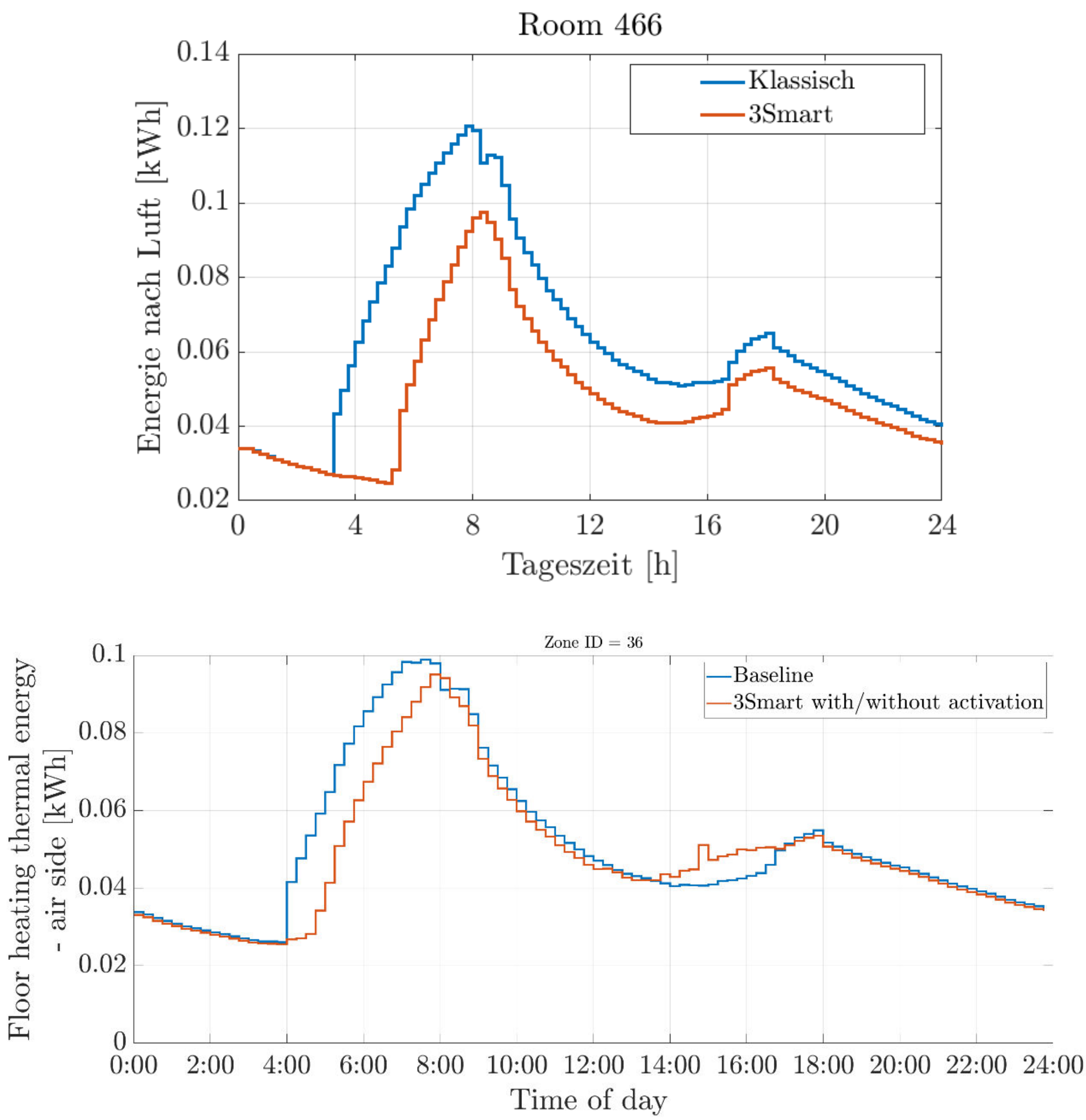

Figure 3.23. Energy provided to air in a room in the retirement and care centre building within the analysed day.

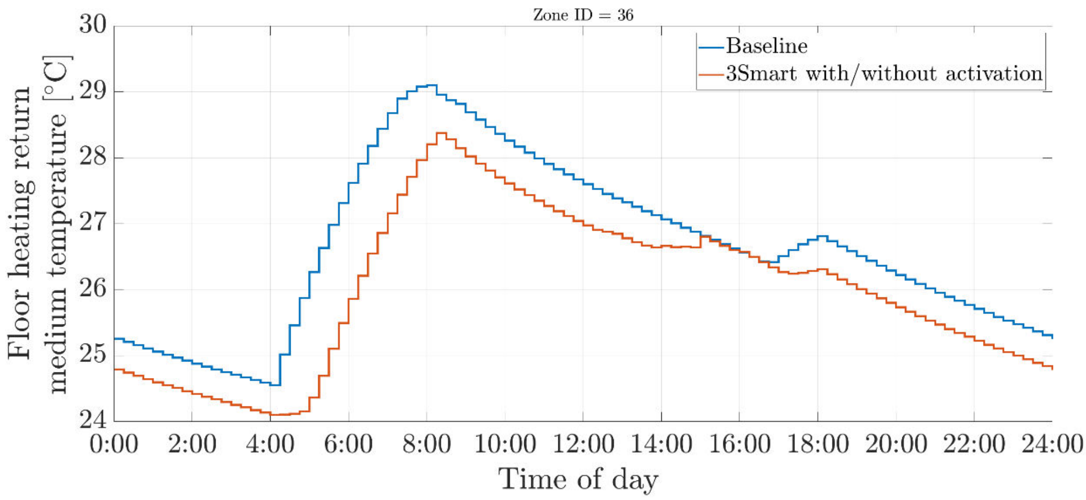

Figure 3.24. Return medium temperature from the floor heating element in the retirement and care centre building room within the analysed day.

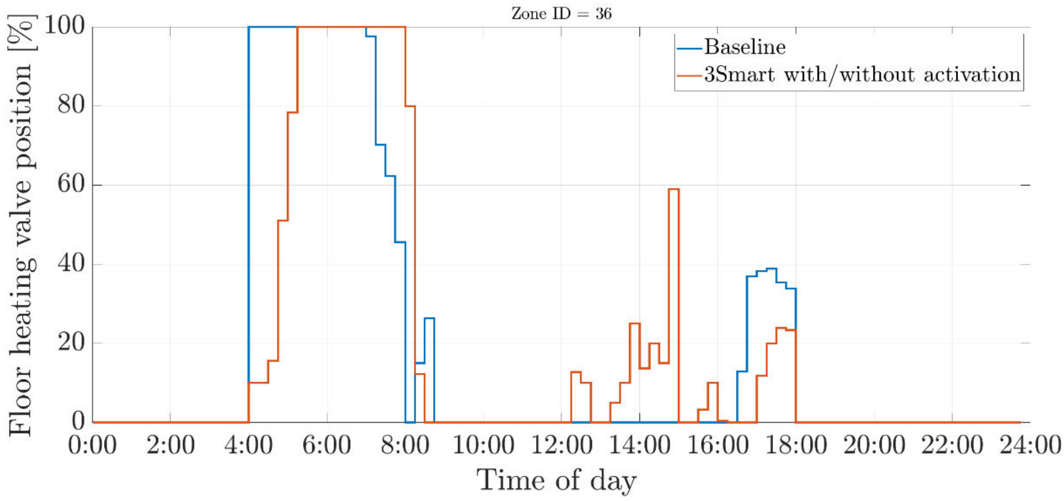

Figure 3.25. Opening of the valve of the floor heating element in the retirement and care centre building room within the analysed day.

Comfort improvement measured as average deviation from the setpoint is over 20% for the case of 3Smart controls compared to conventional control.

The central HVAC system level decides on the starting medium temperature for duct south of the retirement and care centre. On the duct besides 40 controllable zones there is also a significant number of floor heating elements on corridors and for the bathrooms of all rooms which are not controllable and the valves of which are always fully open. Besides on duct south, heat is also consumed in some other parts of the building. The non-controllable heat consumptions of duct south and on the remainder of the building are shown in Figure 3.16. For both conventional control and 3Smart control, both of these non-controllable consumptions are summed with the controllable consumption to represent the entire central HVAC system heating energy consumption. For simplicity of the analysis, the influence of changing starting temperature on duct south on its non-controllable consumption is neglected.

Figure 3.28 shows the starting temperature of the heating medium on duct south, determined by the central HVAC system level. In conventional control the heating medium is constantly kept on 42°C. Return medium temperature on duct south, formed according to zone-level control actions, is provided in Figure 3.29.

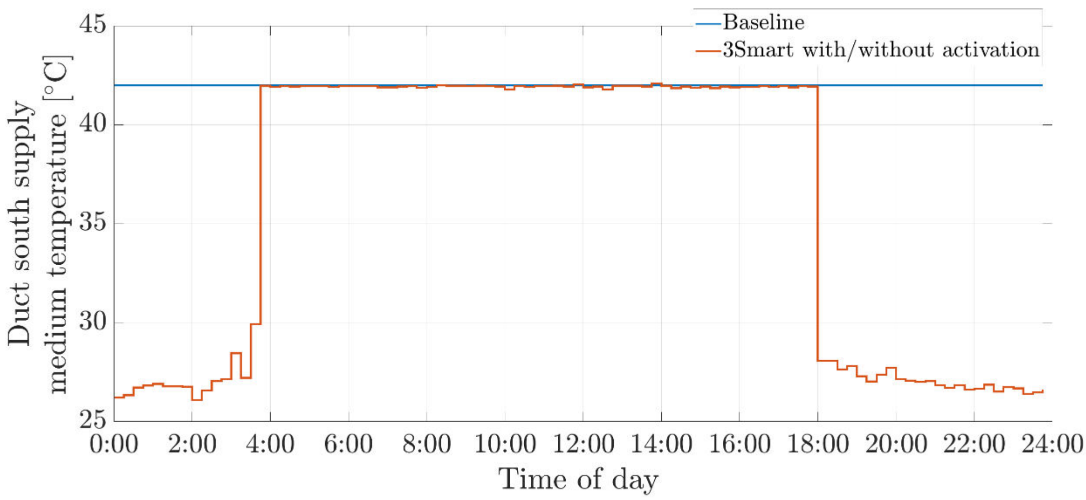

Figure 3.28. Starting medium temperature on duct south.

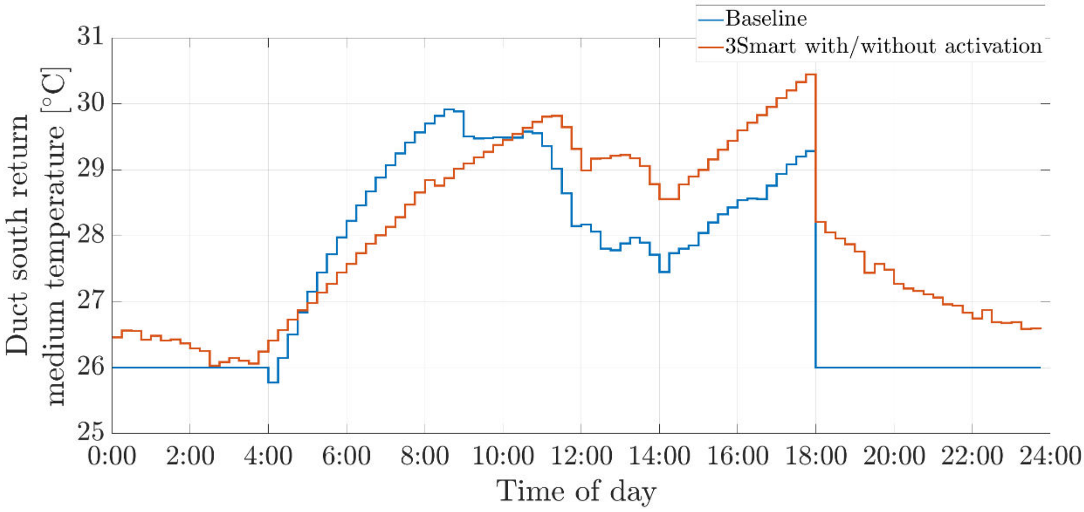

Figure 3.29. Return medium temperature on duct south for the retirement and care centre.

The overall heating energy consumption on duct south (summed controllable and non-controllable) is shown in Figure 3.30.

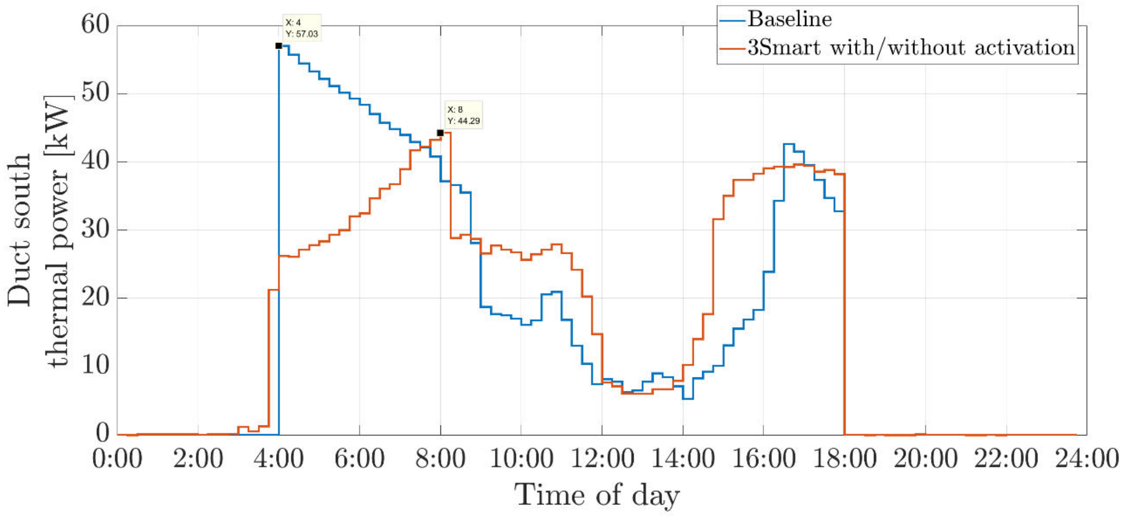

Figure 3.30. The overall heating energy consumption on duct south.

A more even thermal load achieved with 3Smart on the zone level, that results in both lower consumption due to prediction of the forthcoming weather conditions and in better comfort, results also in improvements visible on the central HVAC system level where they are additionally amplified with smart planning of the starting medium temperature to reduce thermal losses on the pipeline. An indirect effect which was not explicitly enforced with the cost function within 3Smart predictive control is lowering of the peak heat power consumed from the network. For duct south this reduction amounts to some 12.74 kW, as shown in Figure 3.30. Due to big inertial mass of the floor heating elements, this peak reduction could be significantly further enlarged for almost none additional costs on the zone level. Within this lies a significant perspective for further reducing the building operational costs. Namely, the building is the biggest consumer of heat on the district heating grid in Strem, and its reduced peaking in heat consumption could bring significant benefits to the heat distribution grid. The overall heat consumption, when also non-controllable consumption from the remainder of the building is added, amounts at 1,1035 MWh with classical control and at 1,1094 MWh with 3Smart, but with significantly improved comfort.

On the microgrid level the system decides on the battery system actuation. Conventional control is used to flatten the electricity consumption profile throughout the day, which is a state-of-the-art control logic in commercial battery systems. 3Smart operates the battery system in order to provide flexibility service towards the grid. It exploits the possibility to charge the battery within the flexibility interval if no activation occurs, and to switch on discharge if flexibility is called. Figure 3.31 shows the planned charging/discharging actuation of the battery system.

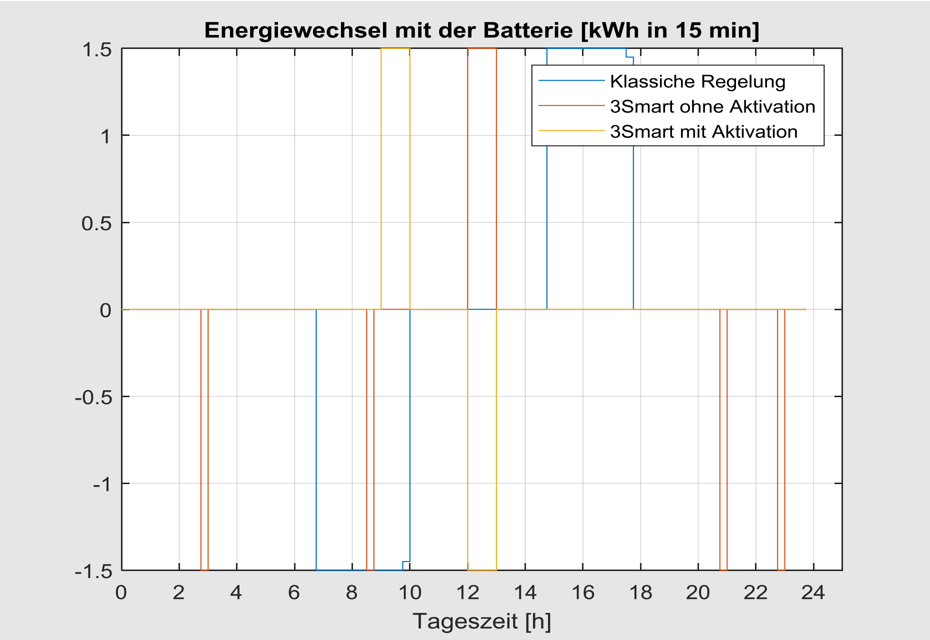

Figure 3.31. Battery system actuation on the retirement and care centre building.

The overall electricity consumption of the retirement and care centre building is provided in Figure 3.32.

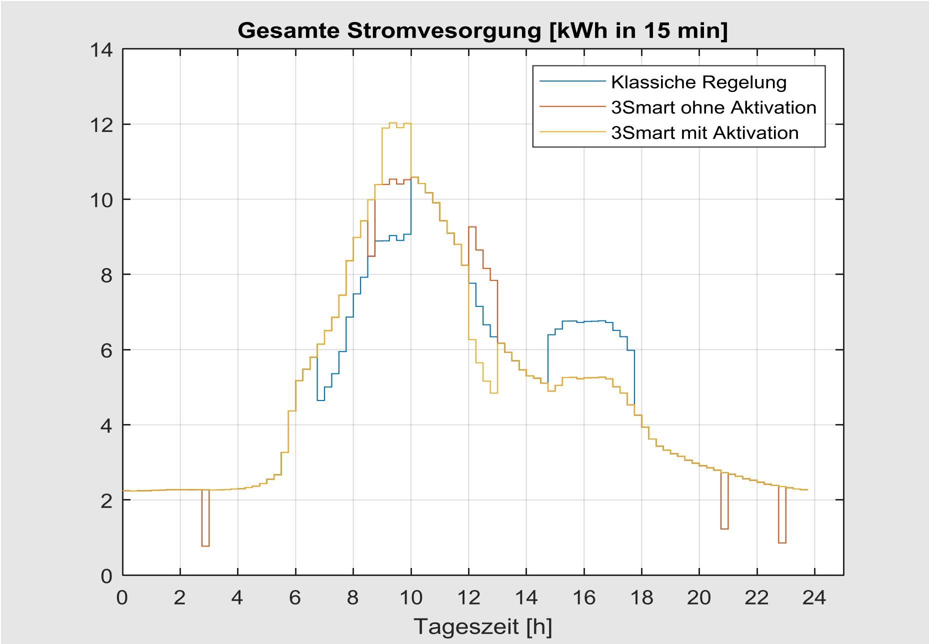

Figure 3.32. Overall electricity consumption profile of the retirement and care centre building.

The amount of flexibility exhibited by the 3Smart system is 13.3 kW. The overall costs on the side of building microgrid operation include battery degradation costs and the overall electricity costs. The classical control results in 25.70 EUR daily operational costs, 3Smart without activation in 20.82 EUR, and 3Smart with activation in 17.39 EUR.

The overall economical performance of the retirement and care centre building for the analysed day in heating is provided in Table 3.2.

Table 3.2. Comparative representation of daily financial performance of conventional control and 3smart controls for the retirement and care centre operation in a characteristic day in heating.

	Conventional control	**3Smart – w/o activation**	**3Smart – with activation**
Heating	110.35 €	110.94 €	
Electricity, microgrid operation, flexibility	25.70 €	20.82 €	17.39 €
Total	136.05 €	131.76 €	128.33 €

The overall economical benefit from 3Smart system operation on the retirement and care centre building for the analysed day in heating amounts 4.29 EUR without activation and 7.72 EUR with activation. Accounting that flexibility is called roughly in 50% of days, the daily benefit is estimated at the average, so at 7 EUR.

Bibliography

[1] D7.3.2 Integrated planned energy management modules on all the buildings and in the grid for the Austrian 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

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Hrpan