Comparison of a Centralized with Decentralized Heat Pump Systems in a Multi-Family Building

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Abstract

The goal of the project "HpCosy", from which the work presented here originates, is the development of decentralized heat pump systems, which are to be combined into a swarm for the optimal use of PV electricity. In order to be able to quantify the effects of this swarm control at a later stage, the first step was to compare one centralized with six decentralized heat pump systems in a multi-family home.

In a first step, the thermal load of the building was defined with the help of simulations using the program TRNSYS with its Type 56 building model. The internal load due to occupancy and user behavior as well as the domestic hot water profile is based on individual profiles generated with the program loadprofilegenerator. In the next step the heating system was calculated. These calculations were performed using a multidimensional performance model provided by the heat pump manufacturer. The calculation of the heat pump takes into account both the necessary compressor speed to cover the load and the required flow temperature depending on the outside temperature respectively the status of the storage tanks.

The calculations reveal an electric energy saving potential of more than 30% through the use of decentralized units for domestic hot water and space heating instead of central systems. The focus here is on domestic hot water circulation: The circulation required in multi-family home necessitates high setpoint temperatures in the storage tank. In addition, the ability to individually adjust setpoint temperatures for space heating also has a positive effect, as a single user cannot dictate inefficient operation for the entire building through high temperature demands.

Keywords: Heat pump, domestic hot water recirculation, space heating, energy savings.

1. Introduction

Heat pumps are a key technology for supplying buildings with domestic hot water (DHW) and space heating (SH). They will play a key role in an energy transition in which the geographical distribution of energy sources will increasingly be based on electrical energy. Hot water and the provision of cooling will become increasingly important due to better insulation of buildings, increased comfort requirements and, last but not least, advancing climate change. The obvious solution is to supply space heating, hot water and cooling with one device and, as much as possible, with locally produced PV electricity. In view of this development, the challenges facing system suppliers today no longer lie solely in the design and construction of a heat pump unit, but increasingly in system integration and control. What is needed are compact system solutions that are able to provide heating while at the same time reacting flexibly to the supply of photovoltaic electricity or to tariff incentives for load shifting (demand side management). In this paper, a comparison is made between flexible decentralized heat pump heating systems and a centralized solution for a multi-family home, in order to be able to compare the advantages and disadvantages without the influence of special control strategies.

doi:10.18086/eurosun.2022.08.04 Available at http://proceedings.ises.org

2. Procedure

2.1 Boundary conditions

A combination of building simulations using TRNSYS software and heat pump system calculations using spreadsheets was used to compare a centralized vs. decentralized heat pump systems in a multi-family home (MFH).

The modeling of the building was done with "Type 56" in the software TRNSYS(Klein et al, 2017; SPF-OST, 2021). It is a three-story renovated building consisting of six apartments: three on the east side and another three on the west side (Mojic et al., 2019). In the simulation model, the building is divided into eight thermal zones: six apartments, the basement, and the stairwell that connects to each apartment. Both, the internal loads of the apartments and the DHW demand are determined individually, with different occupant profiles. Details of the building and the load profiles are shown in Tab. 1. The occupant profiles are based on profiles from the tool loadprofilegenerator (Pflugradt, 2010). The naming of the profiles used is given in brackets.

The city of Zurich was used as the location of the building. The total heat demand of each apartment as the sum of SH at ideal heating with set temperature 21 °C and DHW can be seen in Fig. 1. In total, the heat demand adds up to 50 MWh for SH and 17 MWh for DHW.

Tab. 1: Details of the building and the residents.

	West	East
3. Floor	148.9 m^2 / 2 Persons (CHR55)[(B)]	167.8 m^2 / 4 Persons (CHR18)
2. Floor	148.9 m^2 / 4 Persons (CHR27)	167.8 m^2 / 2 Persons (CHS04)
1. Floor	148.9 m^2 / 2 Persons (CHR33)	167.8 m^2 / 4 Persons (CHR44)
Energy reference area	1'302 m^2	
Net floor area	1'103 m^2	
Specific heat demand	45 kWh/(m^2.a)	
Shape factor[(A)]	1.3	

[(A)] Shape factor = thermal envelope divided by energy reference area

[(B)] In brackets: Name of the household from the tool loadprofilegenerator.

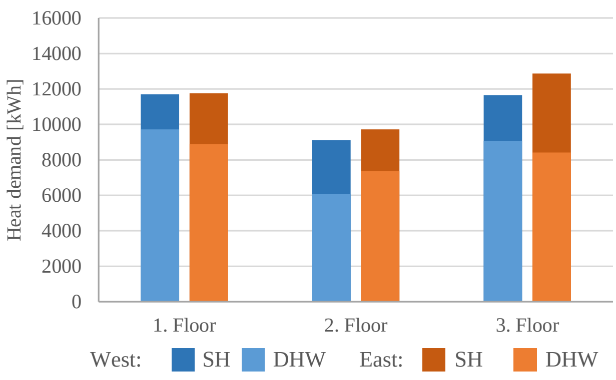

Fig. 1: Heat demand for SH and DHW per apartment.

2.2 Modelling and dimensioning of the heating systems

Centralized heating system

The main components of the centralized heating system are, in addition to the inverter-controlled 26 kW heat pump itself, two DHW tanks, each with a volume of 600 l, and a SH buffer tank with a capacity of 850 l. Fig. 2 shows the hydraulic scheme of the system. A central pump supplies the space heat distributor from which the individual apartment units are supplied. Each apartment is equipped with a room-temperature controlled thermostatic valve. An overflow valve is integrated into the heating circuit system to keep the pressure constant and prevent the pump from working against closed valves. The domestic hot water distribution is kept warm by hot-water (circulation).

It is worth mentioning that, in agreement with the Swiss standard SIA 385/1:2020 ("SIA 385/1: Anlagen für Trinkwarmwasser in Gebäuden - Grundlagen und Anforderungen," 2020), the hot water recirculation is calculated with 60/55 °C in flow and return, with the corresponding effects on the set temperature in the DHW storage tank. Because of temperature limitations of the heat pump, part of the heat must be supplied directly electrically by an electric heating element in order to reach the required 60 °C. The flow and return setpoint temperatures for space heating at reference conditions are 35/30 °C. The actual flow temperature set point for each hour of the heating season is calculated based on a heating curve that takes into account the ambient outside air temperature. Additionally, 2 K have been added to the central supply flow temperature setpoint in order to compensate for losses.

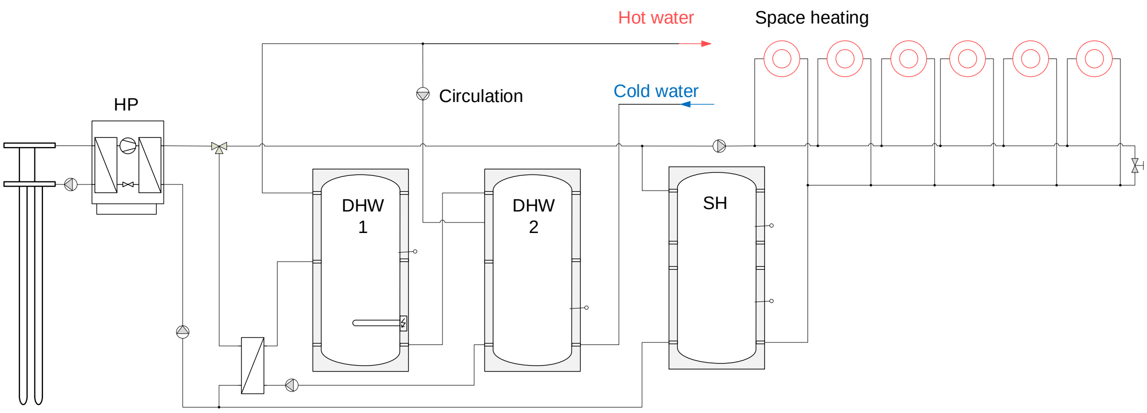

Fig. 2: Hydraulic scheme of the centralized heating system.

The dimensioning of the heat pump for the central heating system was based on the heat demand of the building described above. The aim of the design was a model that can cover the heat demand with 2500 full load hours. The total space heating demand (including losses) in the building is about 58 MWh. Considering the full load hours of 2500 for the heat pump operation, the heat pump capacity is 23.1 kW. The Optiheat Inverta 17e model from CTA AG with an output of 25.6 kW at a compressor speed of 70 rps was selected as the basis for the calculations. The COP of this HP as a function of the condenser outlet temperature and the compressor speed is shown in Fig. 4 on the left.

Decentralized systems

The decentralized systems were modeled as compact units with integrated DHW storage tanks (220 l) and direct connection to space heating without a SH buffer tank. The set temperature in the DHW tank is 55°C (SIA 385/1:2020 for systems without DHW recirculation), which can be achieved by the heat pump without the use of an electric heating element; the space heating curve can be set individually in each unit according to the preferences of the occupants and the heat loss rate of the apartment, which is higher for apartments just under the roof or in contact with the basement.

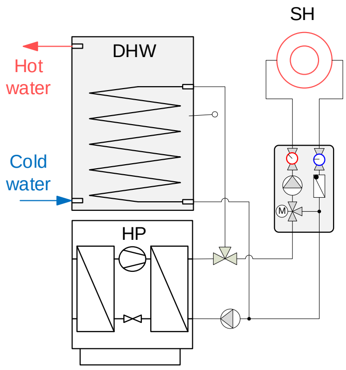

Fig. 3: Hydraulic scheme of a single decentralized unit.

The parameterization of the heat pumps, that determines the heating capacity and electric power consumption, was done according to the Optiheat Inverta 4esr TWW model of the company CTA AG: The COP of this HP as a function of the condenser outlet temperature and the compressor speed is shown in Fig. 4 on the right.

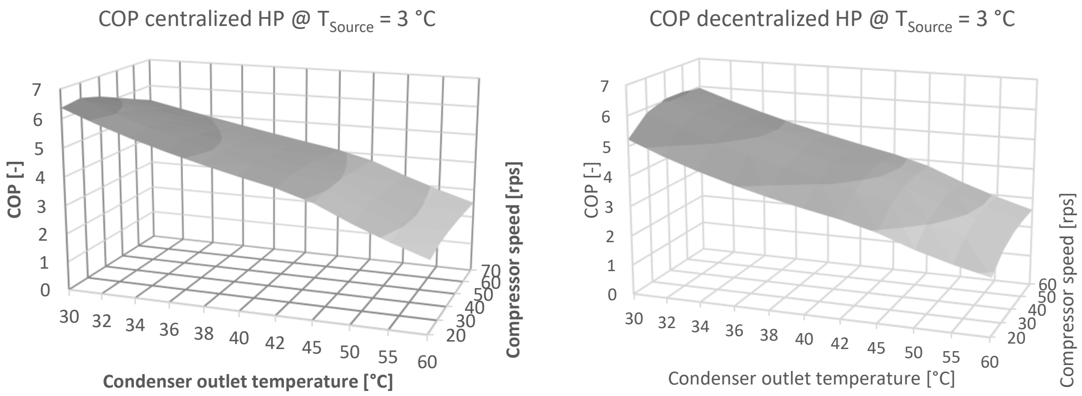

Fig. 4: COP of the central HP (left) and the decentralized HPs on the right as a function of condenser outlet temperature and compressor speed.

2.3 Variation of room set temperatures

A significant advantage of the decentralized systems is that different comfort requirements of the residents can also be served precisely. For example, a higher room temperature setpoint for one of the apartments on the upper floor does not lead to a general increase in the heating circuit flow temperature, since the other apartments can be served independently. Accordingly, it can be expected that the advantage of the decentralized systems will come into effect primarily when the demands on the room setpoint temperatures in the individual apartments differ significantly.

To investigate the influence of the room setpoint temperatures on the results, Monte Carlo simulations were performed in which different setpoint temperatures for the individual apartments were randomly assumed in the range 21 - 25 °C (in one-degree increments).

As described, the heating curve in the decentralized units was adjusted to the respective demand or the desired temperature, whereas the flow temperature supplied by the central system is determined by the apartment with the highest room setpoint temperature.

3. Results

3.1 Comparison with Identical Room Temperature Setpoints

Heat balance

The heat balance of the different versions is shown in Fig. 5. The total heat demand for SH and DHW is identical. The variants differ only in the heat losses via the storage tanks and the distribution and/or circulation:

Considering the DHW storage losses, two factors in particular have an influence. The six storage tanks together have a larger surface area than the two central storage tanks at a very similar storage volume. This fact leads to an increase of the DHW storage losses of the decentralized units. The temperature difference between the storage tanks and the environment speaks in favor of the smaller decentralized storage tanks: first, the temperature set point of the decentralized storage tanks is lower than in the central storage tanks, and second, they are located in a warmer environment. In the apartments the room temperature is 21°C, in the installation site of the central system a temperature of 15°C was assumed. In total, the heat losses of the six small DHW tanks are slightly higher than those of the two DHW tanks from the centralized system.

In addition to the storage losses, there are thermal losses in the decentralized system due to the pipes for distribution and circulation that are kept warm. With 4650 kWh, these losses are approx. 70 % higher than the storage losses.

The difference in the SH part is comparatively low. The storage tank losses of the buffer tank, that are small due to the small temperature difference to the ambient, and the losses for distribution of heat to the apartments amounts to approximately 3% of the heat demand. The decentralized systems have no losses at all, since they do not have a space heat storage and heat transfer from the pipes to the surrounding contributes to the heat the apartment and is therefore not lost.

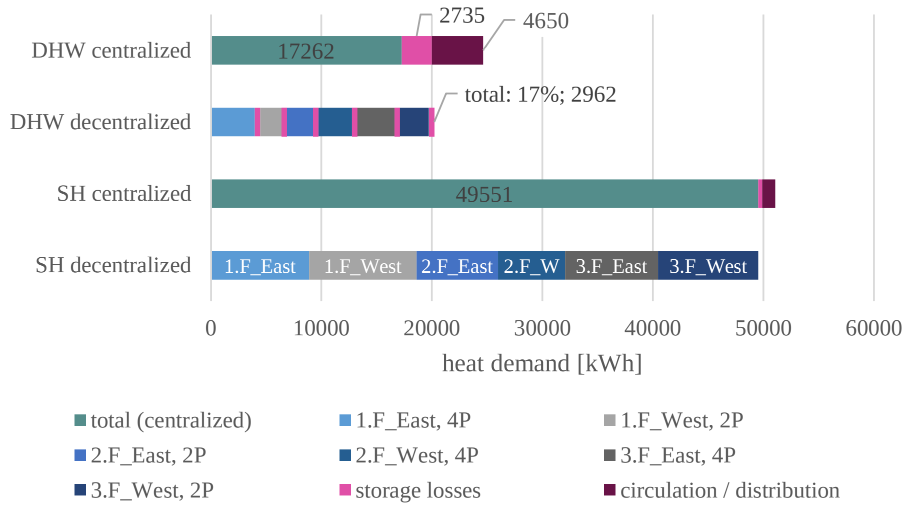

Fig. 5: Heat balance of the centralized / decentralized variants.

Electricity demand

Fig. 6 shows the total electric energy demand and the extra electric energy use that is needed for covering losses and inefficiencies (e.g. reduced COP of the heat pump or the use of electric heating elements instead of the heat pump at higher temperatures) for the centralized as well as for the decentralized system.

With a target room temperature of 21 °C in each apartment, the decentralized systems could save 12 % of the electrical energy used for space heating. Looking at DHW preparation only, the total electricity savings of the decentralized systems compared to the centralized is 53 %, which is a result of lower temperature setpoint requirement for storage tanks of decentralized systems without recirculation (55 °C vs. 60 °C), and spared losses of the recirculation itself.

The total saving of electric energy in the presented case is 28 %.

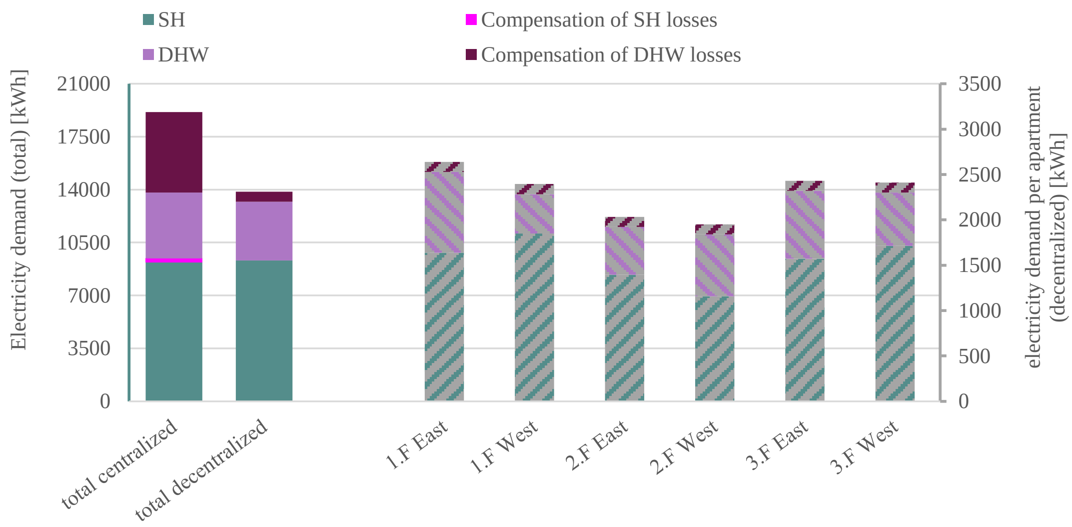

Fig. 6: Electricity demand to cover SH and DHW and the respective extra-electricity for covering losses and inefficiencies, for a centralized heating system compared to 6 decentralized systems.

Performance factors

The seasonal performance factors were calculated for different subsectors: for DHW, SH and for the total heat demand. In the case of the central system, Fig. 7 also lists the PF to cover the various losses. This illustrates above all the influence of the high temperature requirements of the circulation, which must be covered for the most part by heat provided directly electrically (supply 60 °C, return 55 °C).

The resulting SPF of the decentralized system is finally 4.0, while the decentralized systems each achieve an SPF of approximately 5.

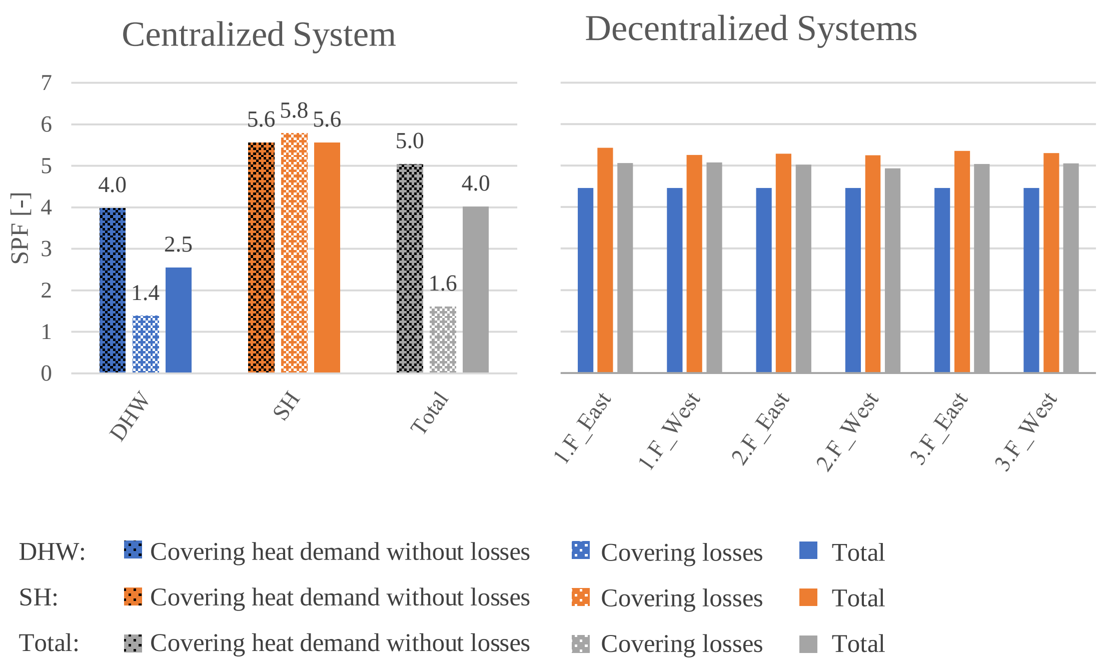

Fig. 7: Overall SPFs of the centralized and decentralized systems

3.2 Comparison with Individual Room Temperatures

As described above, a variation of randomly selected room set temperatures was calculated to investigate the influence on the overall systems. Fig. 8 gives an overview on the room temperature setpoints (in the graphic on top) and the achieved savings in electric energy in total (middle) as well as the difference in subsectors (bottom).

- The total savings differ between 25% and 31%.
- The lowest savings compared to the central system are achieved in the case where the majority of apartments request a high set point temperature in the apartment units (Tset2).
- The highest savings in percentage can be seen in the case, where the maximum set temperature in a single apartment is 23 °C.
- The highest savings in total (kWh) can be seen in the case with the largest difference between the maximum and the median set temperature (Tset1).

The difference in electricity consumption for DHW preparation is naturally very small, since the variation has no effect on the load to be covered. Nevertheless, there is a small difference to be seen. That is due to the influence of thermal losses: the higher the room set temperature, the lower the thermal losses of the distributed storage tanks. Since the storage losses were considered as passive gains in the apartment, this also changes the heat demand to be covered for space heating. Of course, the different room setpoint temperatures and also the interaction between the zones play a disproportionately larger role.

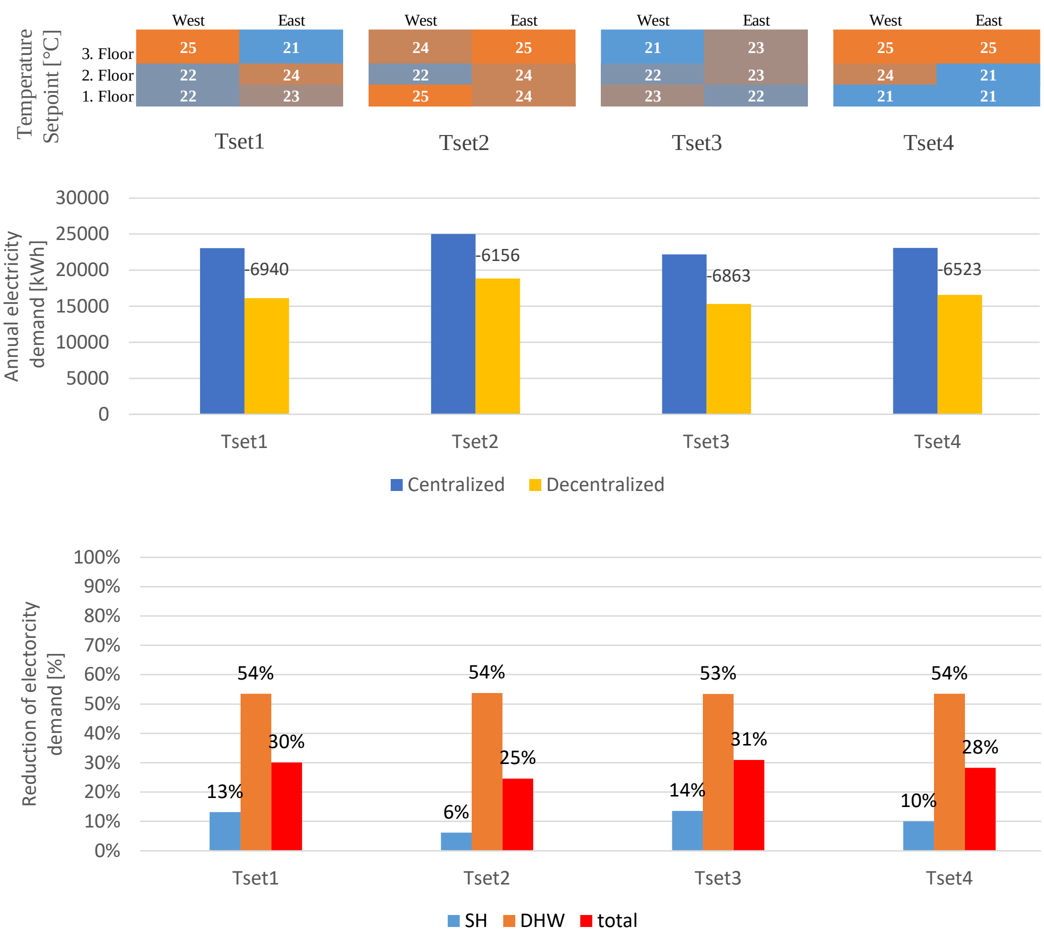

Fig. 8: Set temperatures in the apartments and the achieved savings in electric energy.

4. Summary

The comparison between a centralized and several decentralized heat pump systems clearly shows great advantages of the decentralized solutions, even in a purely demand controlled operation without taking PV electricity or swarm control into account.

The savings in the base case with a room set temperature of 21 °C are 28 % in electric energy. The variation of room set temperatures revealed that the savings could increase up to 31 % when only one of the apartments demands a high room temperature. However, the largest share of the energy saved is due to the elimination of DHW circulation.

5. Outlook

In a next step, the possibilities of a swarm control of the decentralized units will be investigated with the aim of using PV electricity as efficiently as possible. Here, too, various advantages of the decentralized solution are expected:

- The individual, power-controlled systems allow precise and finely graduated adjustment to the current PV yield.
- The individual hot water tanks are not subject to the restrictions of circulation with its high flow temperature, which must be guaranteed at all times. This means the timing of recharging can be coordinated with the availability of PV electricity.
- The individual systems allow individual decisions regarding the comfort criteria for room temperatures. In this way, it may be possible to better exploit the potential for storing heat in the thermal capacitance of the hydronic floor heating systems.

6. Acknowledgement

The authors would like to thank the Swiss Federal Office of Energy for supporting the project "HpCosy - Heat Pump Comfort System" under contract number SI/502088-01, the partners of the institute INEB at the University of Applied Sciences and Arts Northwestern Switzerland and the industry partner from the company CTA AG.

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