

High solar fraction by thermally activated components

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Abstract

Thermally activated building elements (TABs) are employed successfully in the building sector in recent years. From an energetic point of view, such low temperature systems are especially beneficial when combined with solar thermal installations or heat pumps. Within the scope of national funding programs and R&D projects the intensive use of thermally activated building elements is investigated, as main thermal storage in different buildings, with focus on the combination with solar technologies (thermal, photovoltaic) for energy supply. Investigations based on measuring data from realised buildings and on a theoretical approach, various technical system concepts with solar thermal or photovoltaic in combination with thermally activated components for single- (SFH) and multifamily houses (MFH) were analysed under technical, economic and ecological criteria. The results show that through the activation and use of the thermal storage potential contained in the building mass, high solar fractions up to 100 % of the building's heat demand can be achieved.

Keywords: high solar fraction, thermal activation, concrete slabs, technical economic and ecologic analysis

1. Introduction

The Renewable Energy Directive of the EU requires buildings to fulfill at least 20 % of its total energy needs with renewables by 2020. An efficient integration of fluctuating renewable energy from solar thermal and photovoltaic systems into the heating infrastructure of a building is a big challenge. However, compensating for these fluctuations with the assistance of batteries and big thermal storages at the level of the heat supply is very cost-intensive. On the other hand, thermally activated building systems (TABs) have been shown to enable an efficient and cost effective integration of renewable energy. With TABs, the large thermal capacities of the building structure – such as massive floors and ceilings – are used as heat storage and they are as such integrated into the overall energy system of the building. By absorbing heat from internal or external passive gains through radiation, conduction and convection or by releasing stored energy, the slabs provide respectively cooling and heating to the rooms. The thermal activation of the building mass enables it to store more heat, providing inertia against temperature fluctuations and allowing it to be heated or cooled in hours with renewable energy production. Moreover, the large areas of the thermo-active surfaces allow for substantial heat flux between room and structure, even with relatively low temperature differences. For these reasons, TABs are predestined for the application of solar thermal and low temperature heating sources, such as near-surface geothermal, ground water and outside air.

The goal of the research project solSPONGEhigh is the detailed analysis of this approach. On the basis of numerical models and several case studies the project and its results contribute to a better understanding of the energy-related processes in and the design of such systems.

2. Method

For two prototype buildings, a one-family house and an apartment building, different system concepts for heating and preparation of domestic hot water are being developed. In addition to small buffer storage tanks, the system concepts mainly include thermally activated components (story ceilings) as heat storage and heat dissipation system. The energy source is provided by building-integrated solar-thermal or solar-electric systems combined with heat pumps. The system concepts are numerically modeled in different configurations, supplemented with control strategies and used to cover the heat requirements of different heat demand levels of

the considered buildings.

In the first step, the single-family house (120 m² floor space) and the multi-family house (540 m² floor space), in each case with two different heat demand levels, were modeled in the simulation environment TRNSYS. The heat demand level "Low Energy Building" (LEB) meets the current state of thermal protection in new buildings in Austria and the heat demand level "Nearly Zero Energy" is equivalent to the heat consumption of a passive house. With regard to the four different heat demand profiles, different heat supply systems were developed in the second step (see chapter 3). The system A is supplied in a monovalent way via an air-water heat pump, the systems B, C, D are additionally equipped with building-integrated thermal solar systems and the systems E and F include a photovoltaic system. In addition, variations in the type of heat pump and the thermal charging of the story ceiling are defined and modeled in TRNSYS. In the case of "solar overheating", an increase of the upper temperature limit by 2 Kelvin is allowed in the component (Fig. 2). Systems B to F are equipped with three differently sized solar systems (SFH: 20 m² (a), 40 m² (b), 60 m² (c); MFH: 25 m² (a), 125 m² (b) 200 m² (c)).

Tab. 1: Overview of the established systems for the heat supply of the considered buildings

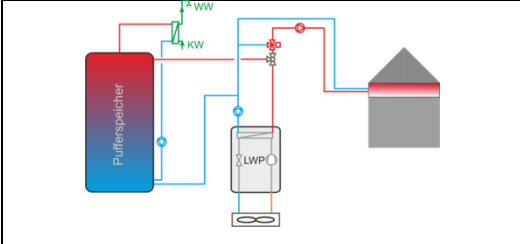
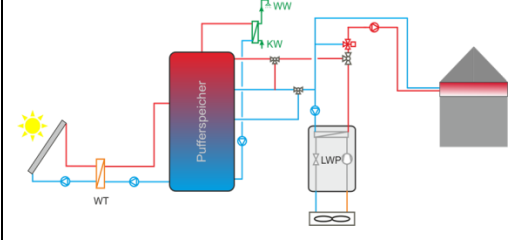
	solar plant	heatpump	storage tank	solar charging	activated structural elements
system A	-	air-water	domestic hot water	-	ceiling slab
system B	solar thermal	air-water	domestic hot water	-	ceiling slab
system C	solar thermal	air-water	domestic hot water	+ 2 Kelvin	ceiling slab
system D	solar thermal	soil-water	domestic hot water	+ 2 Kelvin	ceiling slab
system E	photovoltaic	air-water	domestic hot water	-	ceiling slab
system F	photovoltaic	air-water	domestic hot water	+ 2 Kelvin	ceiling slab

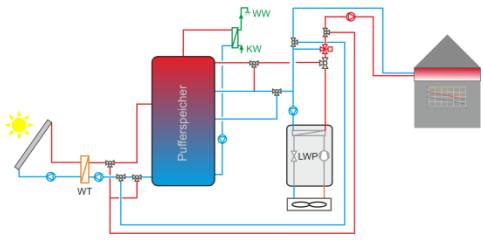
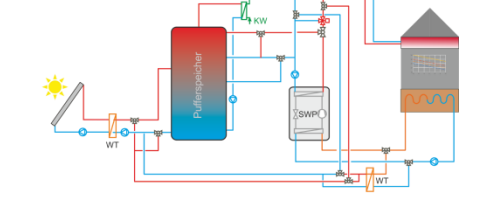
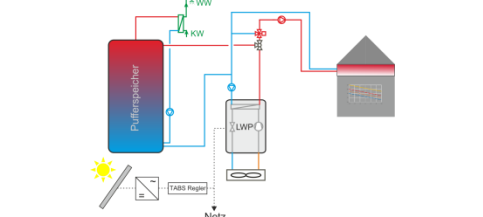
In the third step, the models of the systems (A to F) were combined with the building models in both heat demand levels, equipped with control systems and simulated as overall system models on an annual basis. Step four was the definition of characteristic figures for the assessment of the systems, with the aim of being able to assess both the energy-related performance, the economic and the ecological performance. In the fifth step, the simulation results were evaluated, compared and analyzed with regard to the defined energetic, economic and ecological assessment figures.

3. CONSIDERED SYSTEMS

At the start of the project, different heat supply concepts were defined to cover as much heat as possible through the solar thermal and solar electrical system by the additional activation of the storage mass in the building (primarily concrete). The considered Systems are described in Tab. 2.

Tab. 2: Considered systems for the heat supply of the buildings

	An air/water HP system (System A) was selected as the first heat supply system. In the case of the monovalent heating system, in the buffer storage only a hot water volume is available. Space heating can be directly done with the HP (without water storage). This means that for System A a volume is only available in the buffer store for DHW heating.
	In System B the HP is coupled to a solar thermal system, whereby solar heat is only stored in the buffer storage. With System B the building can be heated by the additional solar system with the corresponding temperature in the storage from the water storage or directly with the HP (if no solar heat is available).

	On the solar side of System C, different hydraulic connections are being considered in the case of the direct or indirect integration in the heat supply systems. This means the solar thermal heat can be stored in the buffer store or directly in the building (TABS), but also serial charging (water storage and TABS) is possible if the required temperature levels are available.
	In System D a soil-water heat pump with a soil storage under the building is coupled to a solar thermal system. In that case the solar thermal heat can be stored same as in System C and additionally regenerate the soil storage.
	System E and F is equal with to System A including an additional photovoltaic system. In System F the control strategy has been adapted, that depending on the heat pump design performance and the current photovoltaic power, the building mass is loaded to a higher temperature level (+2 Kelvin).

4. Building

Concerning the climatic conditions the city of Graz (Austria) was chosen for the building location. For the thermal building and system simulations a mean climatic data set (over 10 years) is used (T_{mean} ambient: 10.7 °C, heating degree days: 3102 Kd, global hor. radiation: 1206 kWh/m²a, diffuse hor. radiation: 616 kWh/m²a). The building designs (insulation standards) are based on the building guidelines OIB-RL 6 for the minimum requirement and for a very ambitious case a nearly zero energy building (including controlled ventilation with air heat recovery) was defined. The specific head demand of the two different considered buildings amounts for the low energy building (LEB) 37 kWh/(m²a) and for the net zero energy building (NZEB) 17 kWh/(m²a).

The dimensioning of the required heating capacity of the backup system was based on a heating load calculation. For the nearly zero energy building the same design criteria were chosen for the backup systems as for the low energy building. The dynamic heat load calculation (simulations in TRNSYS) for the low energy buildings for a room air temperature of 22 °C during the heating period are summarized in Tab. 2. Since the solar thermal systems are compared with an air heat pump system (System A), the backup system has to be dimensioned to ensure the coverage of the heat requirements for the DHW heating and space heating without solar support.

Tab. 3: Heating load of the LEB and heating capacity for heat pumps

LEB	Heating load	air-water heat pump (A-12W35)	soil-water heat pump (S0W35)
SFH	4.3 kW	5.4 kW	5.8 kW
MFH	20.4 kW	19.8 kW	-

In addition to the various heat-supply systems, the heat dissipation system is also considered and analyzed. The systems and ceiling constructions is shown in Fig. 1 for the ground floor of the building. The largest difference to an underfloor heating system (FH) is the positioning of the insulation layer. In the case of the underfloor heating system, the heat dissipation system is installed in the screed, and the concrete is separated by the insulation layer in order to limit its activation. If the building is heated through the ceiling (TABS), where the heat transfer system is installed directly in the concrete, more storage mass can be activated. The next difference is that the pipes of the heat dissipation system are positioned much deeper in the concrete in the TABS system

than in the FH system and the heat transfer coefficients of the heat output surfaces (ceiling or floor) are also be different and calculated through the building model in TRNSYS dependent on the room air temperature and the surface temperature of the heat transfer surface.

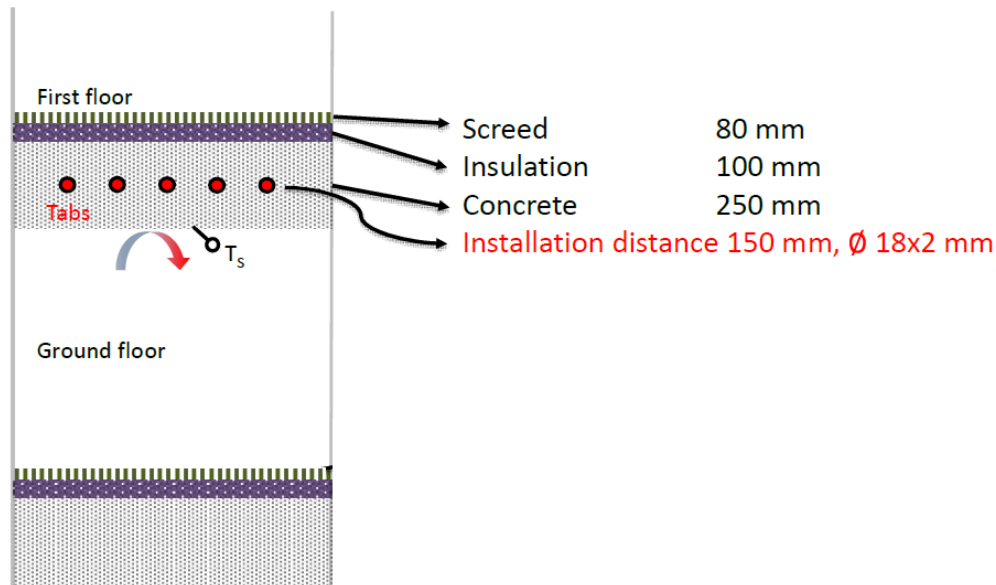


Fig. 1 Ceiling construction for the concrete core activation (TABS)

5. Control strategy

On the basis of the evaluations of the different simulation data of the various types of control temperatures that were tested, the surface temperature (T_s) was chosen for the control variable for the room heating. The building model of the considered building consists of multiple thermal zones. Each thermal zone can be charged independently of one another, whereby the control variable (surface temperature of the thermally activated component) is dependent on the outside air temperature. The required control surface temperature changes with the outside air temperature. In addition, depending on the heat source (solar or HP), the temperature hysteresis for the charge controller changes (Fig. 2). If heat is required to charge the thermal zone and no solar heat is available, the backup system is charging to a surface temperature hysteresis of 2 K (T_{surf} Heat ON, T_{surf} HP OFF). If solar heat is available, the hysteresis is increased by 2 K to 4 K, so that the storage mass is charged to a higher average temperature level.

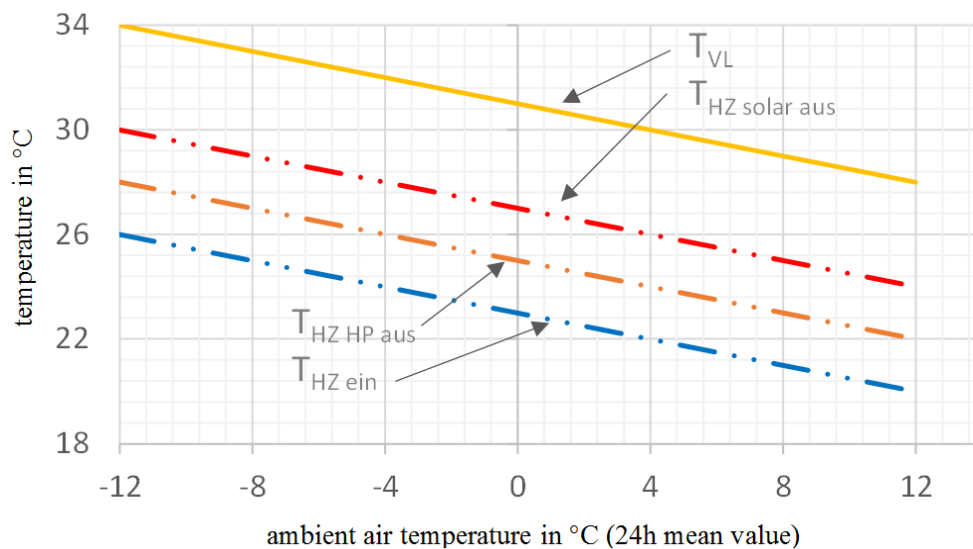


Fig. 2: Control strategy

6. Results

At the centre of the considerations is the question of the achievable degree of self-sufficiency with heat for the reference buildings. The solar coverage SD, as a measure of the self-sufficiency, depends both on the ratio of solar heat provided to the heat consumption, and on the possibilities for storing heat.

Due to the storage capacity of the story ceilings, a single-family house in low energy level can achieve a solar fraction of approx. $SD = 50\%$ even with the smallest considered solar thermal collector area 20 m^2 (a) and a small buffer storage (1.5 m^3). With using all considered possibilities for improvement, reduction of heat consumption to the level Nearly Zero Energy, plus solar overheating, plus use of the soil, plus covering of the entire roof area and the entire south façade with thermal collectors 60 m^2 (c), the solar coverage is $SD = 91\%$. Thus, over 90% of the heat demand in the assumed single-family home can be covered in a decentral way and the heat pump has to contribute only about 10% to a full thermal supply.

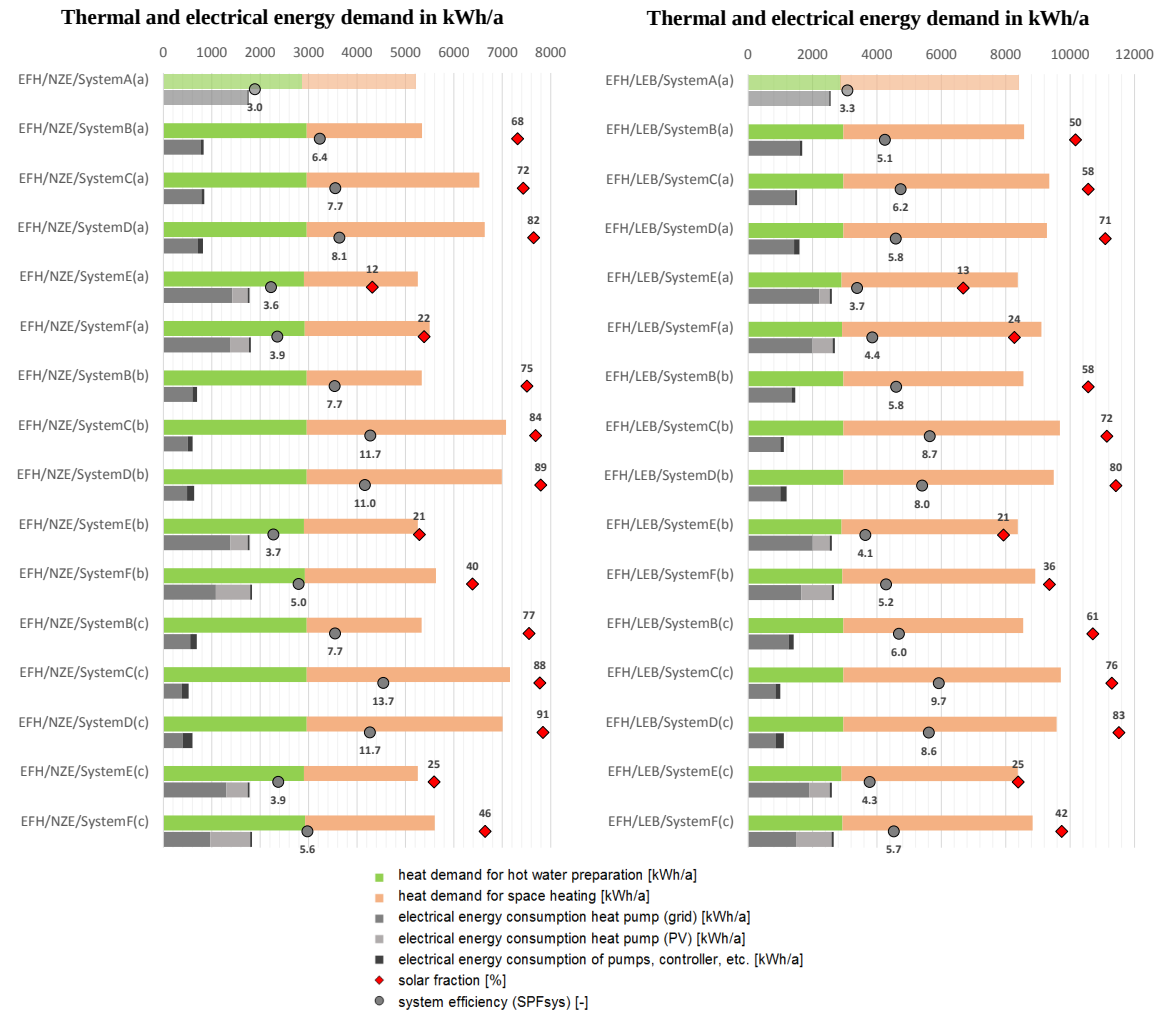


Fig. 3: Energetic results for the single-family house

For the multi-family building, the prerequisites for high solar fractions are less pronounced than for single-family dwellings. Due to the higher compactness of the building the specific heating demand is slightly lower, but in relation to the heated volume significantly less external surfaces are available for solar use. These circumstances are evident in the achievable solar fractions. In the heat demand level Low Energy Building with a compact energy storage (30 l/m^2 collector area) and with the smallest considered collector area of 25 m^2 , a solar fraction of approx. $SD = 25\%$ can be achieved. The full utilization of all examined possibilities of improvement leads to a maximum achievable solar fraction of approx. $SD = 75\%$.

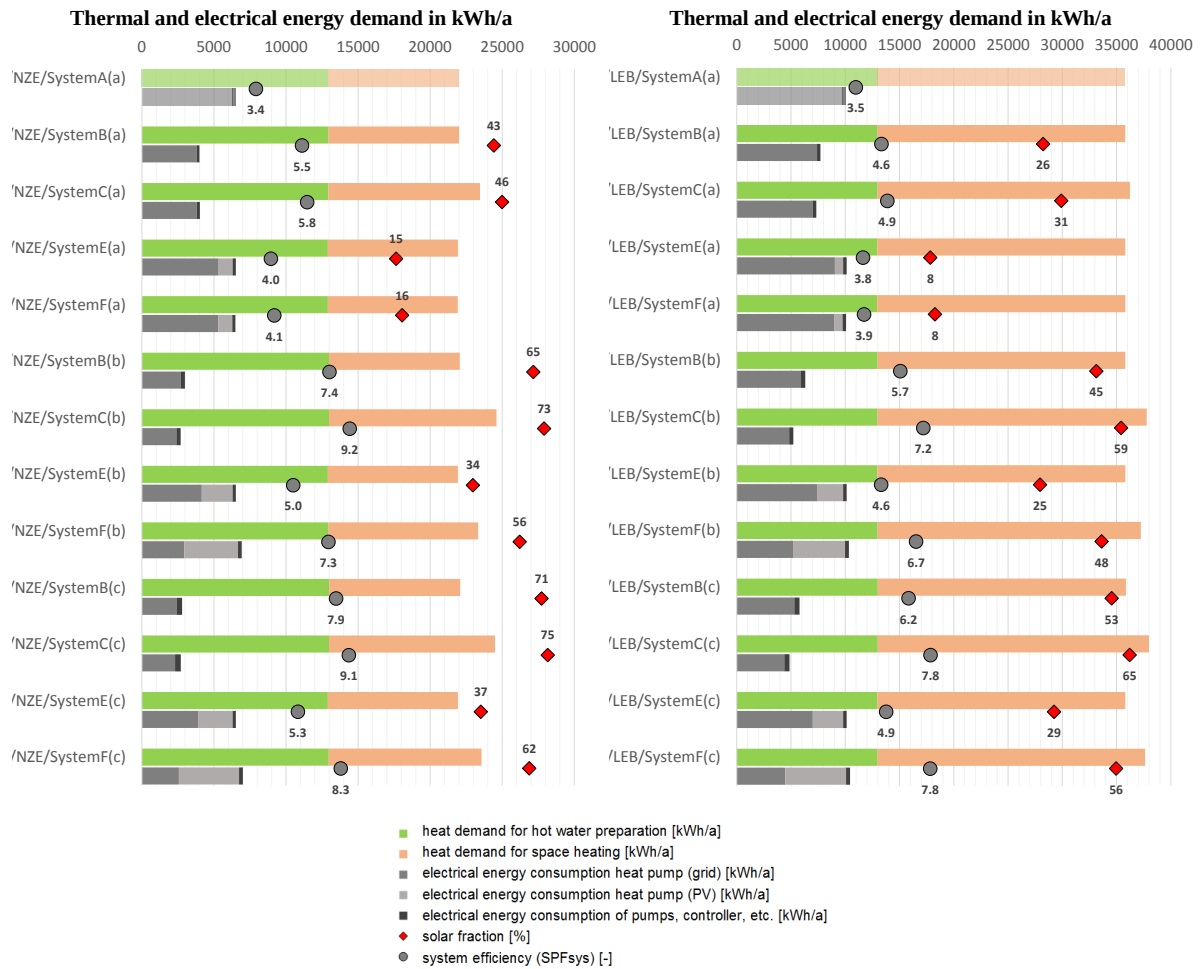


Fig. 4: Energetic results for the multi-family house

Besides the solar fraction a number of additional assessment parameters were analyzed for the considered scenarios. With regard to the costs of the energy concepts, it can be seen that the solar thermal concepts cause high additional investment costs. However, even small collector areas cause a significant reduction of the energy demand and thus also the operating costs. The solar-electric concepts have lower additional investment costs, whereby the solar electricity yields that cannot be directly utilized can be offset against the operating costs considering a feed-in tariff into the electricity grid.

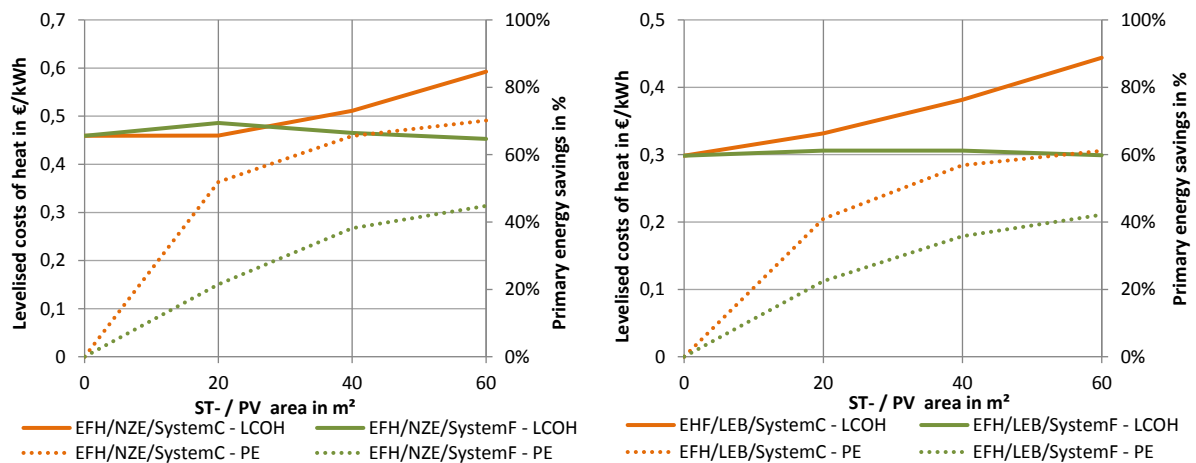


Fig. 5: Economical and ecological results for the single-family house

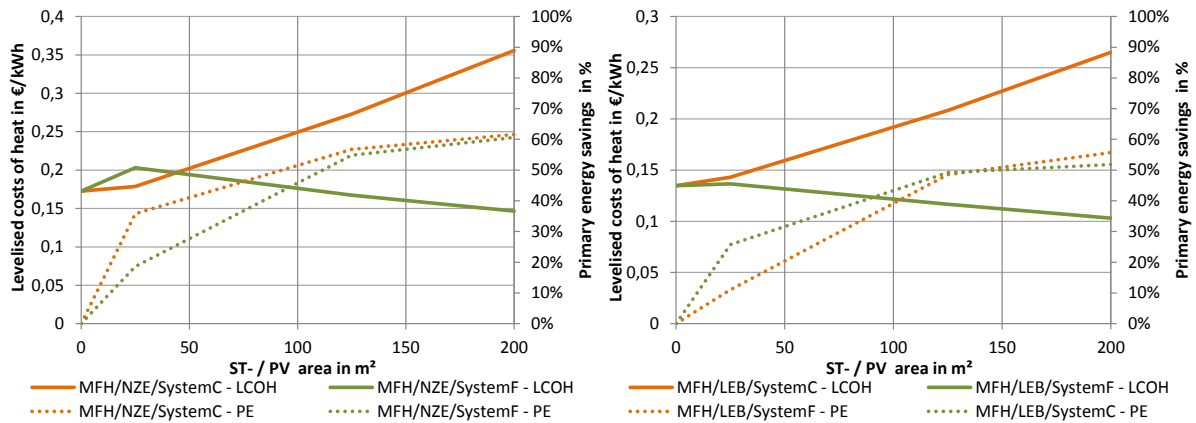


Fig. 6: Economical and ecological results for the multi-family house

When interpreting the presented results, it should be considered that the heat supply systems combined with the reference buildings are simulated using extensive and complex models based on a number of assumptions. The presented results are valid only in relation to these assumptions.

7. Acknowledgements

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8. References

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9. Conclusion

Due to the mismatch in time between the solar supply and the energy demand, usually only a part of the solar energy can be used to cover the energy needs of a building. The larger the solar energy system is dimensioned, the more important is the integration of an energy storage. In order to achieve high solar fractions, the short to medium term storage of larger amounts of heat is essential. This raises the question of alternative solutions for heat storage in buildings.

One way to increase the heat storage capacity of a building has been analyzed in the research project solSPONGEhigh. The thermal activation of solid components such as ceilings and foundations (used as sensible heat storage elements), with solar-thermal or solar-electric systems shows a huge energy saving potential. The results show that through the activation and use of the thermal storage potential contained in the building mass, high solar fractions up to 100 % of the building's heat demand can be achieved.

A general picture across the analysis of the different systems, buildings and insulation standards showed that that a solar thermal concepts shows a better system efficiency and thereby a higher primary energy- and CO₂-reduction potential in comparison with solar-electrical concepts but also higher levelised costs of heat for bigger collector areas. For solar thermal concepts it makes sense to realize rather small collector areas and for solar-electric concepts a larger solar-electric area should be preferred.

In general terms, it can be said that the use of renewable energy sources and the building as thermal storage makes heat supply systems with adequate investment costs, low operating costs, a significant reduction in the dependency.