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Annex 49

Design and Integration of heat pumps for nearly Zero Energy Buildings

Executive Summary

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IEA HPT Annex 49

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IEA HPT Annex 49 "Design and integration of Heat pump for nearly Zero Energy Buildings"

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1 Executive summary IEA HPT Annex 49

1.1 Political Background

In many countries worldwide, buildings contribute significantly to the primary energy consumption and the CO_2-emissions. In the EU, for instance, about 40% of the primary energy and 36% of the CO_2-emissions are due to building operation and buildings are the single largest consumers. Thus, energy efficiency in buildings is a major strategy to reach ambitious CO_2-reduction to fulfil climate protection targets. Current building energy demands in the new built sector are in the range of low energy buildings of a space heating demand around 50 kWh/(m^{2}yr). As next step Net or nearly Zero Energy Buildings (NZEB/nZEB) are envisaged as future building standards, which have an energy demand of almost (nearly) zero by including on-site renewable energy production. By these concepts building loads have to be reduced and building system performance increased to an extend that on-site production can meet the net zero balance. Thereby, the new built sector can become climate neutral or even turn to a net energy producer in the case of a plus energy balance. In order to reach these ambitious targets, building and system performance as well as on-site renewable production have to be integrated in optimised overall concepts.

1.2 Outline of IEA HPT Annex 49

Thus, high performance building technology for nZEB application is of high interest for the implementation of the nZE requirements in the new built sector. IEA HPT Annex 49 entitled "Design and integration of heat pumps for nZEB" is carried out in the Technology Collaboration Programme (TCP) on Heat Pumping Technologies (HPT) of the International Energy Agency (IEA) and deals with heat pumps as core component of the HVAC system for nearly or Net Zero energy buildings. Heat pumps are considered as ideal building technology for nZEB due to their unique features:

- Heat pumps are highly efficient generators at low temperatures differences to the conditioned space which is enabled by the high performance building envelope and low loads of nZEB
- In nZEB space heating loads are decreasing and different building loads have an equal impact on the overall energy performance. DHW can make up more than half of the total heat demand and cooling in Europe or an additional dehumidification in the USA and Asia get more prevalent. Heat pumps can serve multiple building services with high performance.
- System integration of multiple functions with the heat pump can unlock further performance increase, since a simultaneous production of different buildings services can enable internal heat recovery, e.g. for space cooling (or dehumidification) and DHW. Simultaneous operation yields higher performance due to multiple use of the electricity.
- Use of the same components for multiple building services can justify investment in high quality components (e.g. capacity-controlled components with inverter)
- Heat pumps are capable to transform electricity to heating or cooling energy, which offers energy flexibility for on-site generation or the electricity grids and unlocks additional storage capacities as thermal storage

Based on these features the combination of the heat pump and PV systems already established as archetype system technology for nZEB. On this background Annex 49 has been structured into the following Tasks

- Task 1: State of the art of heat pumps in nZEB in the participating countries
- Task 2: Integration options for multifunctional heat pumps in nZEB
- Task 3: Field monitoring of marketable and prototype heat pumps in nZEB
- Task 4: Design and control of integrated heat pumps for nZEB

Table 1 gives an overview on the participating institutions in Annex 49 and the national contributions. A strong focus of the Annex 49 contributions of the participating countries was on monitoring with no less than 15 projects in different types of nZEB with heat pump. Thereby, the focus was set on larger residential and non-residential buildings, which put higher challenges to achieve ambitious performance targets for the nZE or plus energy balance.

Table 1: Overview of contributions of the participating countries to Annex 49

Country/Institution	Contribution to IEA HPT Annex 49
Austria Unit EE building, Univ. of Innsbruck, IWT TU Graz, AIT, Vienna	• Monitoring & simulation of two nZEB passive houses for optimization • Development of a prototype of a façade integrated heat pump • Evaluation of larger nZEB buildings
Belgium Free Univ. Brussels	• Evaluation of heat pump in office nZEB with sewer heat recovery
Germany TH Nürnberg, IGS, TEB GmbH	• System integration, design and field monitoring of different nZEB • Development of control strategies for smart grid integration
Norway SINTEF, NTNU,Cowi AS	• Monitoring of nZE demonstration buildings in Norway • Evaluation and control of energy flexibility in nZEB
Sweden RISE	• Monitoring/Comparison of heat pump systems in two equal test houses, Evaluation of heat pump solutions for nZEB in Sweden
Switzerland IET HSR	• Integration and design options of solar and heat pump systems • Field monitoring of nZEBs with residential and office use • Investigation of design of speed-controlled heat pumps
UK Glen Dimplex	• Evaluation of design and control of nZEB model houses
USA ORNL, CEEE & City@UMD, Univ. of Maryland, NIST	• Field monitoring of integrated (IHP) heat pump variants • Technology testing/comfort evaluation in NZEB test facility (NZERTF) • Prototype development of a personal cooling device for NZEB offices

Furthermore, prototypes were developed and lab- and field-testing was performed. Moreover, some of the monitoring projects were accompanied with in-depth investigations by simulations. On the one hand, the objectives were to identify system optimisation potentials and verify the nZE balance. On the other hand integration options for the heat pump, in particular with storages to accommodate different required building services like space heating or cooling and smart controls to increase the self-consumption and grid-support were investigated.

1.3 Task 1: State-of-the-art of nZEB

In the EU, the time schedule for the introduction of the nZEB requirements is depicted in Figure 1 and stipulates the introduction of nZEB for all new buildings by January 1, 2021 according to the recast of the EU-Directive on the Energy Performance of Buildings (EPBD recast, 2018). The first step, the introduction for all new public buildings has already taken place by January 1, 2019. In other countries worldwide, e.g. in the USA and Canada as well as in Asian countries like Japan or China, the introduction is intended in the time frame between 2020 and 2030.

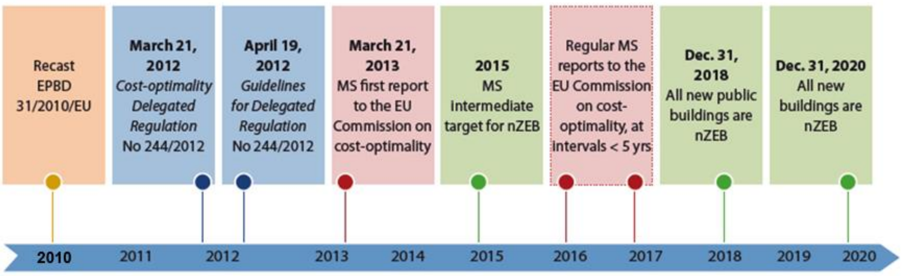

Figure 1: Time schedule for the implementation of nZEB in the EU member states (source: Atanasiu et al. 2013)

The state-of-the-art of nZEB in the different participating countries of the Annex 49 has been analysed. The intention of the EPBD recast (2010/2018) is to set higher objectives for building energy performance in new buildings in order to decrease energy use in buildings to nearly zero and thereby also promote renewable production at the building site or nearby. However, in the EPBD, only a vague outline of an nZEB as "a building with high energy performance" whose remaining energy demand shall be covered "to a large extent by renewable source on-site or nearby". The detailed definition are left to EU-member states (MS).

Despite different harmonisation initiatives, e.g. the collaboration of the Federation of European Heating, Ventilation and Air Conditioning Associations REHVA and the European standardisation organisation CEN to elaborate a common nZEB definition (Kurnitski et al., 2013) and a set of accompanying standards including the overarching standard EN ISO 52000-1 (ISO, 2017), resulting nZEB definitions in the EU MS vary in criteria, metrics and limits. In the USA, however, a similar definition to REVHA has been published in 2015 (DOE, 2015), so there is still a perspective of an internationally more harmonised definition to be introduced. An overview of the different definitions is compiled in BPIE (2015), JRC (2016) and IPEEC (2018). Moreover, despite the common CEN standards, which are currently elaborated also as ISO-standards, the different national definitions of nZEB are related to national rating procedures, which use national calculation methods to prove compliance with the nZEB requirement according to the national implementation. As a consequence, even with a common definition, the implementation in the individual countries would vary due to different national boundary conditions, climate data and calculation methods. Thus, it is hard to assess and compare the ambition level across the EU-MS. The ambition level denotes, how ambitious the national requirements are to derive a high energy performance of the nZEB implementation.

According to EU requirements the minimum ambition level for a national nZEB implementation shall be the cost-optimal level, i.e. the best energy performance at minimum cost. The EU has published guidelines (EC, 2012) how to perform the cost-optimality evaluation and obliged the EU MS to report in 5-year intervals on cost-optimal levels, see also time schedule in Figure 1. Moreover, in 2016 the EU has published recommendations for four European climate zones as orientation of the ambition level to be achieved by the national nZEB implementations for single family houses and office buildings (EC, 2016).

The ambition level of different countries can be shown either relative to each other (by normalizing the boundary conditions such as climate, internal gains, etc.) or with respect to an ambitious energy standard such as the widespread passive house. The comparison of ambition levels would be useful information for policy makers to set requirements for high ambition levels in the new built sector, as intended by the EPBD recast.

Therefore, in the Task 1 of Annex 49, a methodology to compare the ambition levels of different nZEB implementations has been elaborated. The method is based on simulations of the national implementation of the nZEB building at common boundary conditions. Thereby, a relative ranking regarding the ambition level is possible. The method has been tested for a single family building and the countries Austria, Germany and Switzerland, which covers central European climate with pronounced heating demand. The evaluation confirms that also the ambition level of the implementations strongly vary across the countries and do not fulfil EU recommendations in all countries.

Details on the background and state of the art of nZEB as well as the developed methodology to compare ambition levels of the EU nZEB implementation in participating countries of Annex 49 is found in the Report Annex 49 part 1 on the state of the art of heat pumps in nZEB.

1.3.1 Conclusion State of the art of nZEB

nZEB implementation in the EU has started with public new buildings in 2019 and is concluded with all new buildings by January 1, 2021 according the EPBD recast (2018). Other countries worldwide like the USA and Canada as well as Japan and China will follow in the time frame of 2020-2030. Current nZEB implementation, however, vary in terms of criteria, metrics and limits, and thus, the ambition level of the individual implementation are hard to compare.

A methodology elaborated in Annex 49 indicates that some countries set higher requirements to building performance, while other virtually stay on the same lower ambition level as before nZEB implementation. It also indicates that some countries are less ambitious than required by the EU recommendations. Therefore, a common methodology to assess ambition levels should be established and approved/recognized to entirely implement the EPBD.

The all electric building concept, as a combination of heat pump and PV, is an archetype for an nZEB implementation and already found often in realised nZEB. Thus, the introduction of nZEB for all new buildings could be a market driver for heat pumps due to the high performance requirements for the building technology.

1.4 Monitoring of nZEB with heat pumps

A focus of the work and national contributions in IEA HPT Annex 49 was the monitoring of in total more than 15 monitoring projects in nZEB with integrated and multifunctional heat pumps in residential, office and other non-residential use as well as in groups of connected buildings. The focus of the monitoring projects was on larger buildings, since the nZE balance is relatively easy to meet for smaller residential buildings, where building loads are limited with high performance building envelope and the outer building surface is large enough for on-site energy production. In larger residential and non-residential buildings, though, the ratio between building load and on-site energy production capability is shifted and achievement of ambitious nZEB or even plus energy targets is much more challenging than in smaller residential buildings. Actually, many projects set higher ambition in the project than would be required by the national legal requirements in the countries. Thereby, however, also the limits are partly much stricter and the design targets could not be achieved in all projects. On the other hand, by the stricter requirements, limitations become clearly visible and optimisation potentials can be assessed. Henceforth, some of the monitoring projects are also accompanied with in-depth investigations by simulations. Many of the projects also comprise long-term monitoring over several years, which enables to evaluate year-to-year changes in the system performance and to assess the energy reduction achieved by applied optimisation measures.
Thus, optimised building technology in combination with high performance buildings envelopes and optimised on-site energy production are a prerequisite to meet ambitious energy target for the future sustainable built environment. The detailed and long-term monitoring over a period of several years give valuable evaluation of real-world performance of nZEB with heat pumps and show typical optimisation potentials. On-site PV self-consumption is another aspect which is evaluated regarding load management with the heat pump and storage technology. Key performance indicators used for the evaluation of the on-site production and consumption of PV electricity are the load cover factor (LCF), which relates the on-site PV self-consumption to the total building energy demand and the supply cover factor (SCF), which relates the on-site PV self-consumption to the total PV-yield. Details on all monitoring projects in Annex 49 are found in the Report Annex 49 part 2 on Field monitoring.

1.4.1 Monitoring in residential nZEB

The focus on residential buildings were single family and multi-family buildings with high ambition level of a plus energy balance. Figure 2 depicts the monitoring projects of the residential buildings in Annex 49. The U-values are in the range of high performance building envelopes with values for the outer building surface components of 0.09–0.3 W/(m^{2}K) and for the windows of 0.8–1.1 W/(m^{2}K). Due to the high ambition level the space heating demand is with 11-30 kWh/(m^{2}a) in the range of ultra-low energy houses, while some buildings are explicitly designed as passive houses. All investigated buildings are equipped with a ground-coupled heat pump, except for one groundwater heat pump and one building equipped with solar-ice heat pump system, i.e. a solar absorber and ice-storage as heat source for the heat pump.

Figure 2: Monitoring projects of residential buildings in IEA HPT Annex 49

Results confirm that the single family can meet a plus energy balance, while not all multi-family building met a plus balance. A plus balance is harder to achieve in larger multi-family buildings with limited options for on-site production. Even if the façade is additionally used for energy production, the achievement of the positive energy balance can be challenging despite a good performance of the heat pump. Seasonal performance factors (SPF) are in the range of an SPF of 3-5, while for the lower SPFs, optimisation potentials could be identified. Evaluated PV-self-consumption in terms of the load cover factors (LCF)/supply cover factors (SCF) are in the range of 20-30%/30-50% for single family houses and in the range of 20-40%/50-70% for the multi-family houses. However, design of the PV systems and installed thermal and electric storage capacity differ among the buildings.

1.4.2 Conclusion of monitoring in residential nZEB

In conclusion of the monitoring experience in residential nZEB the following can be summarised:

- In smaller residential houses, a plus energy balance is reachable with a PV installation on the roof only. In general the building envelope offers enough space to reach a surplus energy in the annual balance, even in northern climates.
- In larger multi-family buildings of 3-5 storey of even higher, the achievement of an ambitious balance is more challenging, and normally the roof does not offer enough space, but the façade has to be additionally used for on-site energy generation. Thus, a high performance building envelope and an optimised system performance are a prerequisite to achieve ambitious nZE balance criteria.
- This also implies higher cost for a plus energy balance due to PV façade integration, but may also contribute to higher PV self-consumption due to shifted production of the façade.
- On-site PV self-consumption tends to be higher in multi-family buildings with differing occupancy and load structures of the inhabitants.

1.4.3 Monitoring in nZE buildings with office use and groups of buildings

Besides the residential applications also groups of residential/office buildings and buildings with mixed residential/office use were monitored. This comprises two buildings with retail/ offices on the ground level and flats in the upper storeys. A high-rise office building also contains retail on the ground floor. Moreover, two groups of residential buildings, one group with 8 single family houses and one group with 6 multi-family houses, and a group of five office buildings, where a new building supplies heat to the four older buildings, have been monitored. Figure 3 shows the monitored buildings with office use and the groups of buildings.

Figure 3: Monitoring projects with office use and groups of buildings in IEA HPT Annex 49

All buildings are equipped with ground source heat pumps, expect for the group of 6 residential buildings, which uses a combination of the ground, ground water, exhaust air and solar heat. However, for the building with cooling demand, also regeneration heat or waste heat is used as heat source. Installed capacities vary from 30 kW in the residential buildings to MW range in the high rise office building, reference areas range from 1,000–50,000 m^2. The space heating demand is in the range of 10–35 kWh/(m^2a), so independent of the use, high performance building envelopes are installed. In particular for the groups of buildings and the mixed residential and office use, also the integration of a cooling function is a focus in the system concepts in order to increase the heat pump performance by simultaneous heating and cooling, waste heat recovery and ground regeneration.

The monitored group of residential buildings and mixed residential and office use show high SPF values in the range of 5 and higher, which facilitates meeting the balance. For the single family house application, actually, a plus energy balance is reached. However, for the buildings with office use, ambitious balance target are still challenging, despite the good heat pump performance values, which are also due the integration of different building services with the heat pump, e.g. combined space cooling and DHW operation. For high rise office building, only information on the commissioning phase were available. The focus in the project was an integrated planning process for complex nZEB. The larger group of the multi-family and office buildings, only first year or commissioning data were available. The combination of the different heat sources showed a good availability and robustness, and the best available heat sources could be used depending on the season, i.e. the ground in winter operation and exhaust air and solar in summer operation. The group of office building yielded an overall SPF of 4.3 in the first year of operation, but investigation also indicated further optimisation potentials. Evaluated LCF and SCF are in the range of 25-60%/30-40% and tend to be higher with mixed use or in groups of buildings similar to multi-family houses.

1.4.4 Conclusion of nZEB with mixed use and groups of nZEB buildings

nZEB groups of buildings show positive monitoring experiences and reach high SPF, in the case of the 8 residential building houses an SPF of the central heat pumps above 5 and good load management options were found, see chap. 1.6. Also the combination of office use and residential use can have synergies by the different load structures, enhancing the heat pump performance. However, system complexity may also rise, but the connection of buildings hold the potential to recover waste heat by combined heating and cooling operation with the heat pump.

Regeneration of the ground source is applied in all projects, either by freecooling or by waste heat recovery. Result found in the monitoring are promising, and further investigations of the benefits by thermal and electric integration in groups of buildings should be performed in the future.

1.4.5 Monitoring in nZEB with other non-residential use

Also some projects with non-residential use other than retail/offices have been contributed to the Annex 49, namely two schools, a kindergarten, a large hotel and a supermarket. Besides the nZE balance these applications are not standard applications for heat pumps, yet. Thus, experience with the heat pump application could be gathered for these applications. However, some of the projects use also combinations with other heating systems and heat generators, e.g. fractions of space heating and DHW are covered by district heating and solar thermal collectors in the hotel application. Moreover, also quite different heat sources are used in the projects, e.g. energy piles and an agro-thermal ground collector in the school building and waste heat from the supermarket refrigeration for heating and ground regeneration. The reference areas range from 833-14'400 m^2. Installed heat pump capacities range from 19-200 kW and the space heating demand is in the efficient range of 19.2-32.1 $kWh/(m^2yr)$.

Figure 4: Monitoring projects of non-residential buildings in IEA HPT Annex 49

Performance values range from moderate to good performance, and SPF values of the heat pumps are in the range of SPF = 3-5 for the different applications. Another peculiarity is that the planning values are surpassed in most of the projects, i.e. the measured energy demand is partly double of the design values. However, even though the large secondary school reaches seasonal performance values of 4.7-5.2 over a four year monitoring, the intended plus energy balance could not be reached, but the energy demand was reduced from year to year. Other performance values were affected by differences to planning values. The primary school was equipped with a tailored CO_2-heat pump and adapted emissions system including radiators and floor heating, but DHW use was much lower than expected. Moreover, the CO_2-heat pump had a malfunction of the high pressure sensor. Thereby, only a moderate SPF of 3 was evaluated, but optimisation potential were already implemented.

1.4.6 Conclusion of nZEB with other non-residential use

In the non-residential application other than offices, larger deviation to planning values were observed in the monitoring. Thereby, the projected plus energy balance of the secondary school was not reached despite a good SPF of the heat pump in the range of 5, and also the other projects deviated from the expected performance values. In the other projects the heat pumps had moderate SPF in the range of 3, which was partly due to malfunctions detected in the first year of operation, but partly also due to the deviations of the load from the planning values. However, all projects with moderate performance also showed optimisation potentials, so better performance is expected in the future. Also in the non-residential application the integration of space cooling by the heat pump is of particular interest to recover waste heat and increase the performance by simultaneous operation or regeneration of ground sources.

1.5 Prototype developments for nZEB

In Annex 49, also new prototypes of heat pumps or chillers for nZEB application have been developed as highly integrated and compact units. Developed prototypes had also an emphasis on cooling, either as integrated or as main operation mode of the unit. Also new and existing prototypes have been further investigated by lab- and/or field testing. Details on the prototypes depicted in Figure 5 are contained in the Report Annex 49 part 4 on prototypes.

Figure 5: Prototypes and test sites in IEA HPT Annex 49

At **IWT of TU Graz**, a **façade integrated cooling device** with 2 kW cooling capacity has been developed by simulations, prototyping and monitoring. The prototype heat pump is covered by façade-integrated PV-modules, which are sufficient to cover the cooling demand of the adjacent room due to good load match. In space heating mode the unit can cover about 40-60% of the heating demand for Graz climate. Different operation modes like grid-independent and grid-coupled operation with and without battery storage as well as different cooling options by fan coils or thermally activated concrete ceiling have been investigated.

At the **HSR Rapperswil**, an **unglazed absorber** has been tested **for night time cooling application**. The component is already market available for space heating and DHW application, and the system shall be extended by an integrated freecooling function. Cooling capacities, though, are strongly depending on the weather conditions. At clear sky and moderate nighttime temperatures between 23-13 °C, cooling capacities of 175-250 W/m^2 have been measured, while for cloudy sky values are in the range of 75-100 W/m^2 were evaluated.

At the **CEEE of the University of Maryland**, a **roving comforter (RoCo) unit**, which is a personal-sized heat pump that cools indoor air to guarantee occupants comfort has been developed as several prototypes and is now in the market introduction. Energy analysis in office buildings for 9 climates revealed that RoCo can provide between 9-49% energy savings. Phase change material development was another focus of the project, both regarding good latent heat capacity and thermal conductivity. Field testing showed that RoCo can provide 10 W effective cooling, reducing body temperature by 1 K and heart rate by 9 BPM. Most people expressed a better thermal sensation with RoCo.

At the **ORNL** a long-term development of the **Integrated Heat Pump (IHP)** for space heating/cooling, DHW and dehumidification has been carried out. A ground-source and three air-source variants have been designed, lab-tested and simulated and subsequently field tested. Field tests results for the different prototypes variant are summarised with implications to market state and introduction. While the ground-source variant is already on the market for several years, for the gas-driven air-source variant, a value engineering is carried out in order to improve cost-competitiveness.

At **NIST** campus the **Net Zero Energy Residential Testing Facility** (NZERTF) has been designed and operated for several years. The test house with tunable loads is a testing platform for nZE technologies. As contribution to the Annex 49 two air-source heat pumps, a conventional ducted system and a small duct high velocity system have been extensively tested in space heating and cooling mode. Future testing will incorporate also the ground-source IHP.

1.5.1 Conclusions prototype developments

- All prototype developments in Annex 49 were dedicated to highly integrated units, both regarding integrated functionalities to cover all building services with one unit and regarding compact design, e.g. an integrated recooling storage or a compact façade integrated unit
- Prototype developments and testing had a focus on integrated space cooling operation, since with rising temperatures, the need for sustainable space cooling options increases
- Besides developments, also component and system testing of prototypes in the lab and in field testing has been contributed to Annex 49.

1.6 Accompanying investigations to heat pump application in nZEB

Besides the monitoring more detailed investigations on the integration, design or control of the heat pump for nZEB have been carried out partly linked to the monitoring. But also investigations apart from the monitoring projects have been contributed, e.g. the storage of heat in the building structure or a simulation study on the design of speed-controlled heat pumps. Details on the accompanying simulations are contained in the Report Annex 49 part 3 on simulation.

Figure 6: Monitoring projects for accompanying in depth analysis of integration, design and control

A focus of these accompanying investigations was set on smart integration of the heat pump with other building components, in particular thermal/electric storages for demand response.

- For the building **Berghalde**, a single family house with large PV installation, both self-consumption and grid support have been investigated by smart control as well as thermal and electric storage design. Electric storage can notably increase the self-consumption, but is currently not economically feasible. Moreover, control strategies and thermal storage up to 2,500 l have the potential to increase self-consumption. Design diagrams have been derived based on the investigations.
- For the group of 8 single family terraced houses in the **HerzoBase project**, rule-based control has been applied for load management by a central battery as well as central and decentralized thermal storages. Simulations confirm that grid load peaks could be reduced up to 24% in the winter month. While direct use of PV electricity could be increased up to 21%, grid feed-in could be reduced by 10% and battery charging by 11%.
- In **NTNU in Norway**, the load management has been assessed from the grid perspective. By the control of the heat pump the CO_2-balance of electricity use can be improved, but this may counteract with electricity pricing.
- At **UIBK**, two multi-family passive houses have been modelled in detail and validated with monitoring data of four years of measurements. The validated models have been used to perform detailed investigation on desuperheater use and system configurations and optimization potentials of the nZE balance. Results confirm that with extended PV-area instead of solar thermal (ST), an nZE balance can be reached. A desuperheater use at low heating demands does not promise high performance increase due to reduced running time.

Further investigations for heat pumps in nZEB have been carried out independent of monitoring

- At the **TU Graz**, the storage of solar heat produced by ST or solar PV in the building structure has been investigated. It was found that thermally-activated building system can offer a favourable option to reach high solar fraction both for PV and ST yield.
- At **HSR Rapperswil**, the design of capacity-controlled heat pumps for the application in nZEB has been investigated. It was found that a rather scarce design yield more part load operation at high COP values. Together with the NTNU, smart control has been tested. Results are ambiguous, since cost can be reduced, but energy use increases.

1.6.1 Conclusion of accompanying investigations by simulations

- Some of the monitoring projects were also used by for accompanying simulations
- Calibrated simulations proved to be a valuable means to identify optimisation potentials regarding the system configuration and integration as well as the design of components
- Load management options by the heat pump and thermal and electric storages confirmed the potential of the heat pump to significantly increase the on-site PV-self-consumption and grid support
- The building thermal mass can also by be beneficially used for load management and increase solar thermal of solar PV fractions
- Capacity-controlled heat pumps should be designed scarcely in order to maximize part-load operation at high COP values

1.7 Conclusions IEA HPT Annex 49 and Perspectives

The conclusions of the respective Tasks and work accomplished in the Annex 49 has already been given in the previous chapters. Further summarising conclusions and perspectives of the Annex work follow in this chapter.

1.7.1 Monitoring experience of heat pumps in nZEB

- In general the numerous long-term monitoring projects show a high performance of the heat pump operation in nZEB. However, most of the monitored buildings set higher targets for the ambition level than would be required by the national nZEB implementation in the building regulation, which could not be met in every project.
- These results underline, that in particular in larger buildings an ambitious nZE or plus energy balance remains a challenge despite the high performance of the heat pump, and requires optimised building envelope and system technology as well as large-scale integrated renewable production, which may be limited by the available building surface, though
- Therefore, due to the necessity for high performance, ambitious nZEB requirements can also be a market driver for heat pumps in larger buildings, since otherwise, ambitious nZEB targets may not be reachable
- First experience with nZEB with mixed use and groups of buildings/neighbourhoods show positive results regarding waste heat recovery and load balancing, which should be further investigated

1.7.2 Accompanying investigations by simulation on design and control

- Accompanying investigations were used to optimise the system configuration and the component design regarding the performance and the nZE balance as well as to investigate design and control of the heat pump and storages
- A smart heat pump operation and the demand response capability of heat pumps is a further unique selling point for heat pumps in nZEB and all electric building concepts
- Results from different projects in the Annex 49 confirm that adapted and advanced controls can increase self-consumption and unlock demand response potentials
- Based on the monitoring results and simulations design and control recommendations for integrated thermal and electric storages for increased on-site electricity self-consumption and grid supportive operation were derived. Thermally activated building components can also beneficially be used for load management.
- In some monitoring projects, an oversizing of the heat pump was observed. Also speed-controlled heat pumps should be designed to closely match the load to benefit from longer running time at good part load COPs. Since design standards are already on the safe side, a scarce design of the heat pumps is recommended.
- Control for peak shaving is relatively easy to develop, while price-based or CO_2-based controls are significantly more sophisticated as investigated at NTNU
- Price-based or CO_2-based controls require minimum fluctuations (volatility) of the penalty signal (i.e. price or CO_2-intensity of the electricity grid) in order to meet their control objectives.
- For the evaluation of control strategies, a detailed modelling of the heat pump system is required while simplified models may lead to incorrect conclusions (mostly overoptimistic).
- With increasing importance of energy flexibility, demand response capability may become a design criterion besides the current criteria mainly based on energy performance and cost. However, at current market conditions, investment in flexibility, e.g. by larger storage design or electric battery integration, is often not economically feasible and there is little incentive to unlock the energy flexibility potential. However, in some field, prices have decreased notably in recent years, e.g. for electric batteries due to increasing market diffusion of e-mobility, which may shift economic considerations also for stationary applications.

1.7.3 Perspectives

The following perspectives can be derived from the Annex 49 work

- With the background of rapidly progressing climate change, ambitious energy performance targets shall be a pursuit for the built environment as intended by the EPBD recast.
- Thus, a further harmonisation of nZEB implementations among the EU countries is recommended to support high ambition levels and facilitate standardised system solutions and technologies across European countries, which can further reinforce the good market position of heat pumps for nZEB applications
- From a general perspective the nZEB concept on annual energy balancing may be misleading due to load mismatch and seasonal effects (intermittent renewable energy production, overproduction in summer and lack of production in winter). Adequate Key Performance Indicators shall be further developed to entirely assess these concepts including grid-interaction effects in order to optimise local consumption and grid operation.
- Limitations to reach nZEB requirements, particularly in larger buildings, may be overcome by moving the boundary for nZEB rating from individual buildings to groups of buildings and neighbourhoods. Thereby, the ambition levels for individual buildings shall still be high, but load and on-site production profiles and balancing, both for thermal and electric loads, can be facilitated to reach ambitious targets. Research shall thus be extended to groups of nZEB and neighbourhoods.

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3 Abbreviations

Abbreviation	Meaning	Remark
BPIE	Buildings Performance Institute Europe	
CEN	Committee Europeen des Normalisation	EU Standardisation Body
CEEE	Center for Environmental Energy Engineering	
COP	Coefficient of Performance	
DHW	Domestic hot water	
DOE	US Department of Energy	
EBC	Energy in Buildings and Communities	IEA TCP
EC	European Commission	
EPBD	Energy Performance of Buildings	EU Directive
EU	European Union	
GS	Ground source	
HP	Heat pump	
HPT	Heat Pumping Technologies	IEA TCP
HSR	Hochschule für Technik Rapperswil	
HVAC	Heating, Ventilation and Air-conditioning	
IEA	International Energy Agency	
IHP	Integrated Heat Pump	
IPEEC	Intern. Partnership for Energy Efficiency Cooperation	
ISO	International Standardisation Organisation	
IWT	Institut für Wärmetechnik, TU Graz	
JRC	Joint Research Centre	
LCF	load cover factor	
MFH	Multi-family house	
MS	(EU) member state	
NIST	National Institute of Standards and Technology	
NTNU	Norwegian University of Science and Technology	
nZE	Nearly Zero Energy	
nZEB	Nearly Zero Energy Building	
NZEB	Net Zero Energy Building	
NZERTF	Net Zero Energy Residential Testing Facility	
ORNL	Oak Ridge National Laboratory	
PV	Photovoltaic	
REHVA	Federation of European HVAC associations	
SCF	supply cover factor	
SPF	Seasonal performance factor	
ST	Solar thermal	
TABS	Thermally activated building system	
TU	Technical University	
UIBK	University of Innsbruck, Building construction	
VSD	Variable speed drive	

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