# HPT Annex 50

# Heat Pumps in Multi-Family Buildings

## Task 2.1: Methodology for assessing the performance of combined systems

# Country Report

# *AUSTRIA*

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# Contents

# 1. Summary

The application of heat pumps in multi-family buildings face more challenges than their application in single-family houses, e.g. the restricted accessibility of heat sources, limitation concerning the (energetic) refurbishment of existing multi-family buildings due to the protection of historic buildings, etc. As this may jeopardize the energy efficiency performance of heat pumps in multi-family buildings, heat pump combinations with other Renewable Energy Sources (RES) are recommended. Unfortunately, standards or compact simulation tools that provide a method for the assessment of such heat pump combinations hardly exist. The already available calculation method regarding the so-called "Package Label", which was developed for installers, covers heat pump combinations with a solar thermal (ST) system but is based on a simplified method with respective inaccuracies.

Therefore, the aim of Task 2.1 was to develop energy efficiency assessment methods for heat pump combinations with a ST system and/or Photovoltaic (PV) system in multi-family buildings, which should then be used for ongoing standardization activities. The developed methods are based on existing standards using a method based on temperature-BINs according to ÖNORM EN 14825 (CEN 2018) and are in accordance with the ErP directive (2009/125/EC). The calculation results are SCOP values that can be directly transformed into the Seasonal space heating energy efficiency ($\eta_s$) values which define the energy efficiency rating on the Energy Label (e.g. A+++).

Finally, these developed energy efficiency assessment methods were implemented in an SCOP Excel Tool and evaluated within IEA HPT Annex 50 activities. In the framework of three Bachelor theses, various case studies were performed, where the calculation results from this enhanced SCOP Excel Tool were compared with Polysun® simulation results.

Further IEA HPT Annex 50 activities in Task 2.1 were performed regarding the economic and environmental assessment of heat pump combinations with a PV system:

- A Master thesis by Schreurs (2019) provides financial ratios, e.g. the Net Present Value (NPV) and Benefit Cost Ratio (BCR) regarding the replacement of a conventional gas-based heating system by a heat pump combination with a PV system. These financial rations were determined in various sensitivity analyses, which showed that the economic performance of a heat pump combination with a PV system highly depend on the assumed gas price development
- A compact Excel Tool for end users that provides a quick energetic and economic assessment of heat pump combinations with a PV system in the pre-planning phase, was developed by Klein (2020b) and validated with Polysun® simulations. The results of the compact Excel Tool, e.g. the PV yield and the heat pump’s electricity consumption, deviate up to 10 % from the more accurate Polysun® simulation results. As the tool is used in the pre-planning phase, these results are considered enough accurate.

The developed methods will be introduced into standardization activities as a basis for discussion.

# 2. Introduction

The application of heat pumps in multi-family buildings face more challenges than their application in single-family houses. One common obstacle is the restricted accessibility of heat sources. Therefore air/water heat pumps that have a lower energy efficiency than ground source heat pumps might be the only applicable heat pump type in a significant share of multi-family buildings, especially of existing buildings.

Furthermore, existing multi-family buildings cannot always be refurbished comprehensively, e.g. because of the protection of historic buildings. In such cases, the heat pumps must provide a higher heating capacity at higher supply temperatures, which is not the optimum heat pump configuration in terms of energy efficiency, especially where the only accessible heat source is air.

These disadvantages may be tackled by combining heat pumps in multi-family buildings with other Renewable Energy Sources (RES) but unfortunately, there are no standards providing adequate calculation methods to assess the energy efficiency of heat pump combinations with RES yet.

Therefore, the aim of Task 2.1 was to develop energy efficiency assessment methods for heat pump combinations with a solar thermal (ST) system and/or photovoltaic (PV) system in multi-family buildings, which should then be used for ongoing standardization activities. The subsequent sections present the development of these methods and their evaluation.

# 3. Development of an energy efficiency assessment method for Heat Pump combinations with a ST system and/or PV system

Prior to the activities in this IEA HPT Annex, an assessment method for heat pump combinations with ST systems had been developed by Köfinger (2013a). In the framework of this IEA HPT Annex, this assessment method has been further developed in order to extend it by the functionality of the assessment of heat pump combinations with a photovoltaic (PV) system (Zahradka 2017a).

## 3.1. Heat Pump combination with a ST system (previous research)

As the Energy Label is the most recognized and best known label in the field of energy efficiency and product quality, it was clear, that a new energy efficiency assessment method for Heat Pump combinations should be in accordance with the ErP directive (2009/125/EC) which would allow to "translate" the calculation results into the energy rating (e.g. A+++) that is found on the Energy Label, see Figure 1.

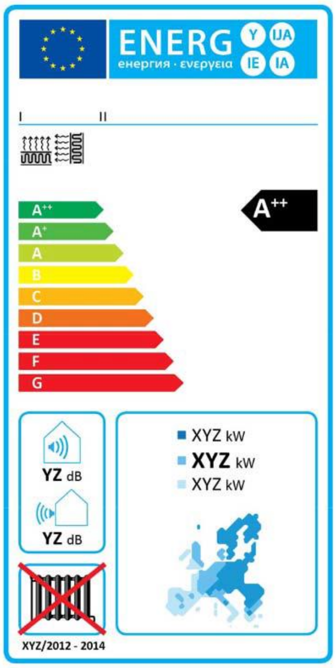



*Figure 1: Sample Energy Label according to ErP directive (2009/125/EC)*

A standard comparison showed that the standard ÖNORM EN 14825 (CEN 2018) would provide the most suitable calculation method for the energy efficiency assessment of heat pump combinations because it was in accordance with the ErP directive (2009/125/EC) and its calculation approach is compatible with the calculation approach provided in the standard ÖNORM EN 15316-4-2 (CEN, 2009) that is used for the energy efficiency assessment of ST systems. Both standards refer to clearly defined climate zones “cold”, “average” and “warm” climate derived from the climate in Stockholm (SE) resp. Helsinki (FL, “cold”), Regensburg (GE)/Strasbourg (FR, “average”) and Athens (GR, “warm”).

For Austria, both climate definitions “average” and “cold” apply depending on the geographical location of the building but “average” climate is the most common definition in Austria. As shown in Figure 2 the temperature BINs are slightly different between both standards but still close enough when relevant (heating conditions).

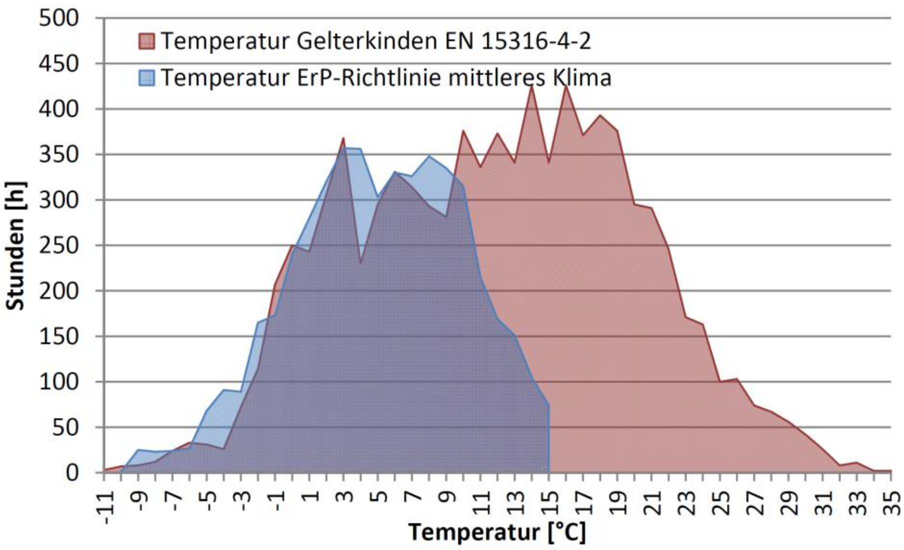



*Figure 2: Comparison of the temperature BINs in hours (German: Stunden) for average climate (German: mittleres Klima) stated in ÖNORM EN 14825 and ÖNORM EN 15316-4-2*

A crucial step in the development of the calculation method was it to merge the ambient temperature values and the corresponding global radiation values. The temperature values and the radiation values were created with the Meteonorm software (©Meteotest). For each ambient temperature value, a radiation value was allocated. Since in the BIN method each temperature can be used only once and since no distinction is made between day and night, mean values had to be created. These mean values are further transformed regarding the solar collector's orientation and tilt.

To calculate the overall efficiency of a heat pump combination with a ST system considering the energy, provided by the solar collector and storage heat losses, the formulas in EN 14825 for the calculation of the $SCOP_{on}$ resp. $SCOP_{net}$ values were modified as shown in formula (1) and (2). Via formula (3) and (4) the Seasonal space heating energy efficiency ($\eta_s$) is calculated which determines the energy efficiency rating of the overall system (see Table 1 and Table 2). To calculate the heat output of a ST collector ($P_{hKoll}$) and the heat storage losses ($Q_{Speicherverluste}$), which are required in formula (1) and formula (2), additional equations that are required (not included in this report). These calculations rely on the ambient temperature-dependent and global radiation-dependent collector efficiency and the global radiation allocated to each temperature BIN.

$$SCOP_{on} = \frac{\sum_{j=1}^{n} h_j \left[P_h(T_j) - P_{hKoll} + Q_{Speicherverluste}\right]}{\sum_{j=1}^{n} h_j \left(\frac{\left[P_h(T_j) - P_{hKoll} + Q_{Speicherverluste}\right] - elbu(Tj)}{COP_{PL}(T_j)} + elbu(T_j)\right)} \quad (1)$$

$$SCOP_{net} = \frac{\sum_{j=1}^{n} h_j \left[P_h(T_j) - P_{hKoll} + Q_{Speicherverluste}\right] - elbu(T_j)}{\sum_{j=1}^{n} h_j \left(\frac{\left[P_h(T_j) - P_{hKoll} + Q_{Speicherverluste}\right] - elbu(Tj)}{COP_{PL}(T_j)}\right)} \quad (2)$$

$$SCOP = \frac{Q_h}{\frac{Q_h}{SCOP_{on}} + H_{TO}\, P_{TO} + H_{SB}\, P_{SB} + H_{CK}\, P_{CK} + H_{OFF}\, P_{OFF}} \quad (3)$$

$$\eta_{s,h} = \frac{1}{CC} \cdot SCOP \cdot 100 - F(1) \quad (4)$$

| | |
|---|---|
| (j) | temperature step number/ BIN-Number |
| (n) | Number of temperature steps |
| ($P_h(T_j)$) | Heating load of the building at respective temperature Tj |
| ($P_{hKoll}$) | Capacity of solar thermal collector |
| $Q_{Speicherverluste}$) | Heat storage losses |
| ($h_j$) | Number of temperature steps / Bin-hours at the respective temperature Tj |
| ($COP_{PL}(T_j)$) | COP of the heat pump at the respective temperature Tj |
| ($elbu(T_j)$) | Required capacity of resistance heater at the respective temperature Tj |
| ($SCOP_{on}$) | Seasonal coefficient of performance of the heat pump system |
| ($SCOP_{net}$) | Seasonal coefficient of performance of the heat pump |
| ($H_{TO}$) | Number of hours in "thermostat OFF" mode |

| | |
|---|---|
| ($H_{SB}$) | Number of hours in "standby" mode |
| ($H_{CK}$) | Number of hours in "oil sump heater" mode |
| ($H_{OP}$) | Number of hours in "OFF" mode |
| ($P_{TO}$) | Power consumption in "thermostat OFF" mode |
| ($P_{SB}$) | Power consumption in standby mode |
| ($P_{CK}$) | Power consumption in operating state "oil sump heater |
| ($P_{OFF}$) | Power consumption in "OFF" mode |
| ($Q_h$) | Annual heating load |
| (SCOP) | Seasonal Coefficient of Performance |
| (CC) | Primary energy factor of electricity mix, currently 2.5 |
| (F(1)) | Lump-sum deduction for power consumption of the controller, always 3 % |
| ($\eta_{s,h}$) | Seasonal space heating energy efficiency |

*Table 1: Seasonal space heating energy efficiency classes of heaters, with the exception of low-temperature heat pumps and heat pump space heaters for low-temperature application (see Regulation (EU) 811/2013)*

| Energy efficiency rating | Seasonal space heating energy efficiency (ηs) |
|---|---|
| $A^{+++}$ | $\eta_s \geq 150$ |
| $A^{++}$ | $125 \leq \eta_s < 150$ |
| $A^{+}$ | $98 \leq \eta_s < 125$ |
| A | $90 \leq \eta_s < 98$ |
| B | $82 \leq \eta_s < 90$ |
| C | $75 \leq \eta_s < 82$ |
| D | $36 \leq \eta_s < 75$ |
| E | $34 \leq \eta_s < 36$ |
| F | $30 \leq \eta_s < 34$ |
| G | $\eta_s < 30$ |

*Table 2: Seasonal space heating energy efficiency classes of low-temperature heat pumps and heat pump space heaters for low-temperature application (see Regulation (EU) 811/2013)*

| Energy efficiency rating | Seasonal space heating energy efficiency (ηs) |
|---|---|
| $A^{+++}$ | $\eta_s \geq 175$ |
| $A^{++}$ | $150 \leq \eta_s < 175$ |
| $A^{+}$ | $123 \leq \eta_s < 150$ |
| A | $115 \leq \eta_s < 123$ |
| B | $107 \leq \eta_s < 115$ |
| C | $100 \leq \eta_s < 107$ |
| D | $61 \leq \eta_s < 100$ |
| E | $59 \leq \eta_s < 61$ |
| F | $55 \leq \eta_s < 59$ |
| G | $\eta_s < 55$ |

In order to validate the developed method for the energy efficiency assessment of heat pump combinations with ST systems, a comprehensive TRNSYS simulation was performed. Both, the TRNSYS simulation and the new calculation method were applied to cold and average climate. As seen in Figure 3, the difference between the calculated and simulated SCOP values concerning cold climate is 3 %, and 5 % between the calculated and simulated SCOP values concerning average climate. Both values are low and hence prove the accuracy of the newly developed method.

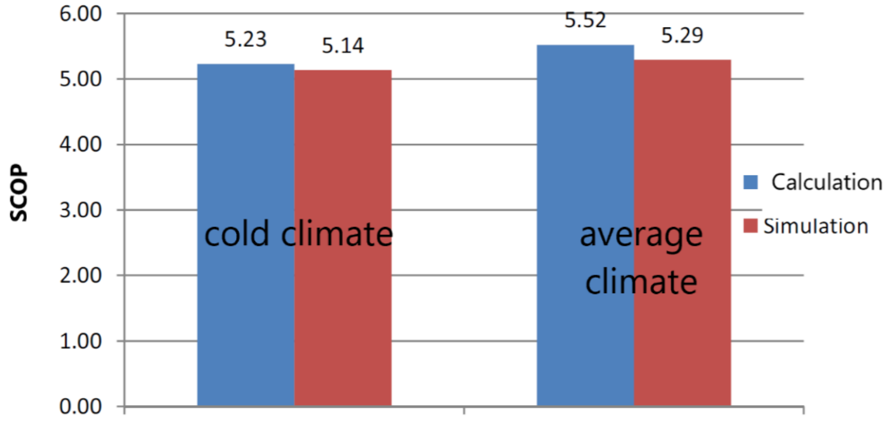



*Figure 3: Comparison of calculation and simulation results of heat pump combination with a ST system*

## 3.2. Heat Pump Combination with a PV system

In the framework of the activities in this IEA HPT Annex, the energy efficiency assessment method described in 3.1 has been further developed in order to include the energy efficiency assessment of heat pump combinations with PV systems (Zahradka 2017a).

For the integration of a PV system into the calculation method, the formulas in ÖNORM EN 14825 had to be extended by the module power analogously to Formula (1) and (2). The result of the extension can be seen in Formula (5) and (6). This extension reduces the electricity consumption of the heat pump which results in an increase of the $SCOP_{on}$ resp. $SCOP_{net}$.

$$SCOP_{on} = \frac{\sum_{j=1}^{n} h_j * P_h(T_j)}{\sum_{j=1}^{n} h_j * \left(\frac{P_h(T_j) - elbu(T_j)}{COP_{PL}(T_j)}\right) + elbu(T_j) - P_{hModul}} \quad (5)$$

$$SCOP_{net} = \frac{\sum_{j=1}^{n} h_j * P_h(T_j) - elbu(T_j)}{\sum_{j=1}^{n} h_j * \left(\frac{P_h(T_j) - elbu(T_j)}{COP_{PL}(T_j)}\right) - P_{hModul}} \quad (6)$$

($P_h$) Power output of PV module

This calculation method uses the same allocation method of the global radiation data to the temperature BINs as used in the energy efficiency assessment method of heat pump combinations with ST systems. The difference between the energy efficiency assessment method for heat pump combinations with a ST system and its pendant with a PV system lie in the calculation of the PV module's power output instead of the solar collector's heat output and that the PV power output reduces the heat pump's electricity consumption while the ST system's heat output reduces the building's heating energy demand which reduces the heat pump's operating hours. The power output of PV modules is calculated using the module's ambient temperature dependent efficiency and the global radiation (formulas not included in this report).

# 4. SCOP Excel Tool

The developed methods described above, were implemented in an Excel Tool that allows the calculation of SCOPs of heat pump combinations with a ST system and/or a PV system (Zahradka 2017b based on Köfinger 2013b). This Tool is subsequently called "enhanced SCOP Excel Tool".

Figure 4 shows the input screen of the enhanced SCOP Excel Tool. Figure 5 and Figure 6 show the design of the input parameter tab.

Calculation of energy efficiency - Average climate

| Product reference | |
|---|---|
| Manufacturer | |
| Product reference | |
| Type of heat pump | outdoor air-to-water |
| Operating mode | heating only |
| Temperature application | 55°C |
| Water flow | variable |
| Water outlet temperature | fixed |
| Capacity control | variable |
| Backup heater | electricity |

| Reference conditions | | |
|---|---|---|
| Climate | average | |
| Tdesignh | -10 | °C |
| Pdesignh | | kW |
| Tbiv | | °C |
| TOL | | °C |
| $H_{HE}$ | 2066 | hours |
| $Q_H$ | | kWh |
| Fossil fuel backup efficiency | | % |

Calculate

Reset

| Energy Efficiency | | | |
|---|---|---|---|
| SCOPon | SCOP | $\eta_s$ | $Q_{HE}$ (kWh) |
| | | | |

| |
|---|
| 11.46 |
| -6 |
| -10 |

| Performance data | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Condition | Outdoor air T°C | Part load ratio (%) | Part Load (kW) | Inlet / outlet water temperatures for testing | Declared Capacity (kW) | Declared $COP_d$ | $C_{dh}$ | CR | $COP_{bin}$ |
| **A** | **-7** | | | | | | | | |
| **B** | **2** | | | | | | | | |
| **C** | **7** | | | | | | | | |
| **D** | **12** | | | | | | | | |
| **E(TOL)** | | | | | | | | | |
| **F(Tbiv)** | | | | | | | | | |

| | | |
|---|---|---|
| 9.55 | 3.26 | 0.90 |
| 11.17 | 4.00 | 0.90 |
| 12.66 | 4.91 | 0.90 |
| 14.30 | 5.50 | 0.90 |
| 7.80 | 2.60 | 0.90 |
| 9.70 | 3.30 | 0.90 |

**Auxiliairy power consumptions**

**Operating modes for heating only**

| | Hours | Power input (W) | P * h (kWh) |
|---|---|---|---|
| Thermostat off | **178** | | |
| Stand by | **0** | | |
| Off mode | **3672** | | |
| Cranckase heater | **3850** | | |

**Operating modes for reversible units**

| | Hours | Power input (W) | P * h (kWh) |
|---|---|---|---|
| Thermostat off | **178** | | |
| Stand by | **0** | | |
| Off mode | **0** | | |
| Cranckase heater | **178** | | |

*Figure 4: Input tab of the enhanced SCOP Excel Tool*

| Kombination | Wert |
|---|---|
| ST | Climate |
| | $\eta_{0a}$ |
| | $a_{1a}$ |
| | $a_{2a}$ |
| | $t_m$ |
| | Kollektorfläche [m²] |
| | G* |
| | Storageefficiency |
| | $V_{sol}$ |
| | $U_{st}$ |
| | $\Theta_{setpoint}$ |
| | $\Theta_{a,average}$ |
| | T design [°C] |
| | T bivalent [°C] |
| | T OL [°C] |

*Figure 5: Required input parameters for the SCOP calculation of a heat pump combination with a ST system*

| Kombination | Wert |
|---|---|
| PV | Climate |
| | Modulfläche [m²] |
| | Eigenbedarfs-quote |
| | PV Effizienz |
| | T design [°C] |
| | T bivalent [°C] |
| | T OL [°C] |

*Figure 6: Required input parameters for the SCOP calculation of a heat pump combination with a PV system*

# 5. Evaluation of the energy efficiency assessment method for heat pump combinations with a ST system and/or PV system

To test the method explained above, comprehensive simulations of several building system models were performed in relation with the Bachelor theses by Eichhorn (2018), Haiderer (2018) and Hämmerle (2018) which are part of the activities in this IEA HPT Annex. Fictitious multi-family buildings were defined based on statistical data and the results of Task 1. The three building categories were “refurbished existing multi-family building”, “not yet refurbished existing multi-family building” and “newly constructed multi-family building”. The investigations were performed for the location Vienna/Austria which determines boundary conditions, e.g. weather data. The main properties of the three fictitious buildings are listed in Table 3. The buildings were simulated in combination with air/water heat pump models and eventually in combination with a ST system resp. a PV system by using the Polysun® simulation software.

*Table 3: Main properties of the buildings investigated in the course of the Bachelor theses*

| Building standard | Refurbished | Not yet refurbished | New construction |
|---|---|---|---|
| Bachelor thesis | Eichhorn | Haiderer | Hämmerle |
| Net floor area (m²) | 570 | 570 | 570 |
| Heating demand (kWh/m²) | 80 | 150 | 50 |
| Heating load (kW) | 30 | 57 | 19 |
| SH Supply/Return Temperature (°C) | 55/45 | 65/55 | 35/30 |

The next step was to calculate the system combinations using the developed method (SCOP) and to compare the results with the results from the Polysun® simulations (seasonal performance factor SPF). In this section, the three Bachelor theses and their main results are briefly presented. The Bachelor theses are in German, therefore, the German titles of the Bachelor theses in the titles below are translated into English. The original theses’ original titles are found in the Bibliography.

## 5.1. Bachelor thesis “Variant comparison of air/water-heat pump systems for space heating in a refurbished apartment building” (Eichhorn 2018)

The thesis documents the performed simulations of two different simulation models of air/water heat pumps including variants regarding heat pump combinations with PV and ST systems in a fictitious refurbished multi-family building located in Vienna/Austria. The properties of this reference building were defined in this work and shall represent a “typical” refurbished multi-family building in Austria. The main properties of the investigated fictitious multi-family building in comparison to the buildings investigated in the other two Bachelor theses are listed in Table 4.

The used calculation/simulation tools were Polysun® and the enhanced SCOP Excel Tool (Zahradka 2017b based on Köfinger 2013b).

*Table 4: Main properties of the investigated refurbished multi-family building in comparison to the buildings investigated in the other two Bachelor theses*

| Building standard | Refurbished | Not yet refurbished | New construction |
|---|---|---|---|
| Bachelor thesis | Eichhorn | Haiderer | Hämmerle |
| Net floor area (m²) | 570 | 570 | 570 |
| Heating demand (kWh/m²) | 80 | 150 | 50 |
| Heating load (kW) | 30 | 57 | 19 |
| SH Supply/Return Temperature (°C) | 55/45 | 65/55 | 35/30 |

The first heat pump model was generated by the Dymola (Dynamic Modeling Laboratory) simulations performed in Task 3.1, the second heat pump model (reference heat pump) is regarding a market available heat pump and was taken from the Polysun® data base resp. technical documentation. The used models and calculation/simulation variants are shown in Table 5.

*Table 5: Calculation/simulation variants*

| Variant | Simulation model | Configuration |
|---|---|---|
| 1 | Reference heat pump | HP only |
| 2 | Reference heat pump | HP-ST combination |
| 3 | Reference heat pump | HP-PV combination |
| 4 | Dymola heat pump | HP only |
| 5 | Dymola heat pump | HP-ST combination |
| 6 | Dymola heat pump | HP-PV combination |

The three main configurations “HP only”, “heat pump combination with a PV system” and “heat pump combination with a ST system” were illustrated using the system classification scheme developed in Task 1.2. An exemplary illustration of a heat pump combination with a ST system according to the IEA HPT Annex 50 system classification scheme is shown in Figure 7. The Polysun® system model of this heat pump combination with a ST system is shown in Figure 8.

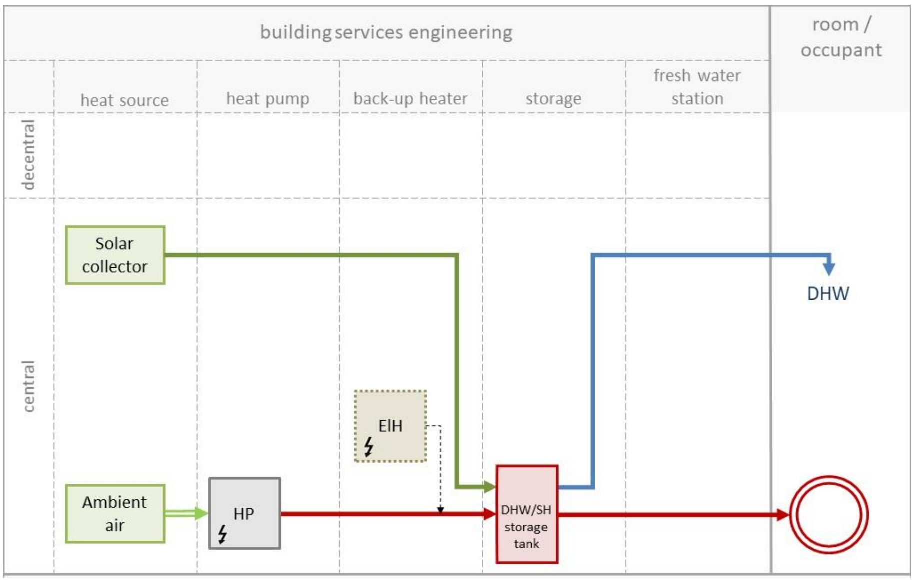



*Figure 7: Exemplary system diagram of heat pump combination with a ST system according to the IEA HPT Annex 50 system classification scheme*

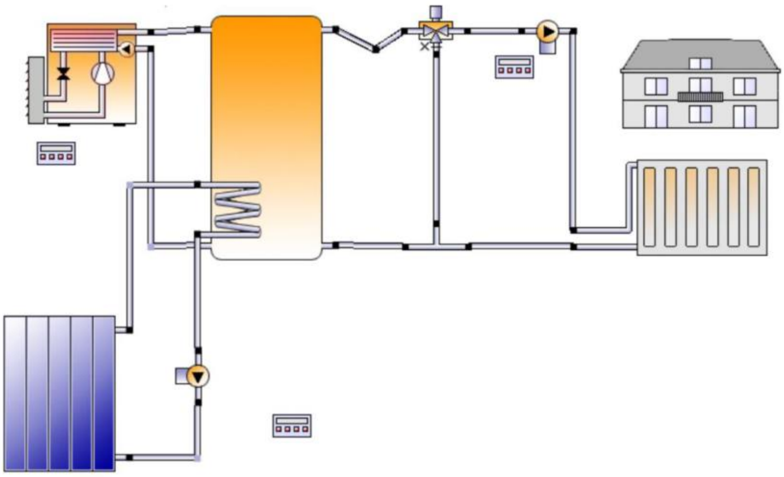


*Figure 8: Polysun® system model of heat pump combination with a ST system*

The desired output of these investigations was the SCOP values of the different heat pump combinations described above. For the calculation of a heat pump's SCOP, COP values at different heat source resp. heat sink temperatures are required. In a first step, Dymola simulation data of nine heat pump models was investigated in order to find the most suitable heat pump configuration for the investigated building standard (see Table 6). The models differ regarding the refrigeration circuit and regarding the refrigerant. The investigated refrigeration circuits were a single stage circuit, a refrigeration circuit with enhanced vapor injection (EVI) and a refrigeration circuit with an internal heat exchanger (iHx). As the EVI circuit in combination with R134a results in the highest SCOP (3.28), this Dymola heat pump model was used for further investigation. Table 7Table 6 lists the heating capacity and COP values of this Dymola heat pump model at five different ambient temperatures. These values were used in the enhanced SCOP Excel Tool (Zahradka 2017b based on Köfinger 2013b)

*Table 6: SCOP values of investigated Dymola heat pump models with different refrigeration circuits (Kreislauf) and refrigerants (Kältemittel)*

| **Kreislauf** | **Kältemittel** | **SCOP** |
|---|---|---|
| EVI | R1234ze(E) | 3,25 |
| EVI | R134a | 3,28 |
| EVI | R290 | 3,22 |
| iHx | R1234ze(E) | 3,09 |
| iHx | R134a | 3,12 |
| iHx | R290 | 3,06 |
| Single Stage | R1234ze(E) | 3,09 |
| Single Stage | R134a | 3,12 |
| Single Stage | R290 | 3,07 |

*Table 7: COP and heating capacity values at standard ambient temperatures ($T_{außen}$) from Dymola simulation data*

| Punkt | $T_{Außen}$ [°C] | $\dot{Q}$ [kW] | $COP_d$ |
|---|---|---|---|
| A | -7 | 26,40 | 2,31 |
| B | 2 | 16,20 | 3,39 |
| C | 7 | 13,28 | 3,85 |
| D | 12 | 15,64 | 4,96 |
| E ($T_{OL}$) | -10 | 30,07 | 1,96 |
| F ($T_{biv}$) | -7 | 26,40 | 2,31 |

In Table 8 and Table 9, input parameters for the enhanced SCOP Excel Tool regarding the heat pump combination with a ST system resp. a PV system are listed.

*Table 8: Input parameters for the SCOP calculation of the heat pump combination with a ST system with the enhanced SCOP Excel Tool (Kollektorfläche = collector area)*

| Kombination | Wert | Eingabe |
|---|---|---|
| ST | Climate | Average |
| | $\eta_{0a}$ | 0,753 |
| | $a_{1a}$ | 3,927 |
| | $a_{2a}$ | 0,017 |
| | $t_m$ | 50 |
| | Kollektorfläche [m²] | 60 |
| | G* | 900 |
| | Storageefficiency | 0,85 |
| | $V_{sol}$ | 3600 |
| | $U_{st}$ | 0,0096 |
| | $\Theta_{setpoint}$ | 50 |
| | $\Theta_{a,average}$ | 20 |
| | T design [°C] | -10 |
| | T bivalent [°C] | -7 |
| | T OL [°C] | -15 |

*Table 9: Input parameters for the SCOP calculation of the heat pump PV combination with the enhanced SCOP Excel Tool (Modulfläche = module area, Eigenbedarfsquote = share of own consumption)*

| Kombination | Wert | Eingabe |
|---|---|---|
| PV | Climate | Average |
| | Modulfläche [m²] | 99 |
| | Eigenbedarfs-quote | 25% |
| | PV Effizienz | 16% |
| | T design [°C] | -10 |
| | T bivalent [°C] | -7 |
| | T OL [°C] | -15 |

The simulations showed that the best results (SCOP value of 3.79) achieve the Dymola heat pump model in combination with a ST system (HP-ST combination). The results regarding the heat pump combinations with PV (HP-PV combination) were significantly lower (see Table 10). The good results of the Dymola heat pump model can be explained with the optimized refrigeration circuit and the fact, that the compressor is capacity controlled. The values of the seasonal performance factor (SPF) that were calculated with Polysun®, differ significantly from the SCOP values calculated with the enhanced SCOP Excel Tool. Regarding the heat pump combination with a PV system, the PV contribution could not be considered in the Polysun® simulation due to software restrictions. The reason for these and further deviations between the two calculation/simulation methods and the reason why the energy efficiency performance of the heat pump combinations with a PV system were less effective than those with a ST system, were not investigated in detail by Eichhorn (2018).

*Table 10: Results from the Polysun® simulations and the SCOP calculations for the different system combinations (refurbished multi-family building)*

| Variant | System | Heat pump model | SPF (Polysun®) | SCOP (EN14825) |
|---|---|---|---|---|
| 1 | HP only | Reference heat pump | 2.7 | 2.01 |
| 2 | HP-ST combination | Reference heat pump | 3.1 | 2.39 |
| 3 | HP-PV combination | Reference heat pump | 2.7 | 2.1 |
| 4 | HP only | Dymola heat pump | 3.3 | 3.28 |
| 5 | HP-ST combination | Dymola heat pump | 3.9 | 3.79 |
| 6 | HP-PV combination | Dymola heat pump | 3.3 | 3.52 |

## 5.2. Bachelor thesis "Assessment of the ecological application of an air/water heat pump in an existing multi-family building" (Haiderer 2018)

Analogously to Eichhorn (2018), this thesis documents the performed simulations of two different simulation models of air/water heat pumps including variants regarding heat pump combinations with PV and ST systems in a fictitious not yet refurbished multi-family building (defined in this work) that is located in Vienna/Austria as well. The main properties of the investigated fictitious multi-family building in comparison to the buildings investigated in the other two Bachelor theses are listed in Table 11.

*Table 11: Main properties of the investigated not yet refurbished multi-family building in comparison to the buildings investigated in the other two Bachelor theses*

| Building standard | Refurbished | Not yet refurbished | New construction |
|---|---|---|---|
| Bachelor thesis | Eichhorn | Haiderer | Hämmerle |
| Net floor area (m²) | 570 | 570 | 570 |
| Heating demand (kWh/m²) | 80 | 150 | 50 |
| Heating load (kW) | 30 | 57 | 19 |
| SH Supply/Return Temperature (°C) | 55/45 | 65/55 | 35/30 |

The illustrations according to the IEA HPT Annex 50 system classification scheme and the Polysun® models are  similar to those in Eichhorn (2018), see Figure 7 resp. Figure 8.

This work uses a similar approach as Eichhorn (2018) also applying the calculation/simulation tools Polysun® and the enhanced SCOP Excel Tool (Zahradka 2017b based on Köfinger 2013b). The main difference is the fact, that the investigated multi-family building is not refurbished and hence, has a higher heating load resp. requires higher space heating supply temperatures (65°C instead of 55°C). In addition to the approach of Eichhorn (2018), the seasonal space heating energy efficiency ($\eta_s$) values were derived from the SCOP values and the energy efficiency rating performed according to the ErP directive (2009/125/EC), see Table 1 resp. Table 2 in section 3.1.

Like in Eichhorn (2018), the first investigations were performed based on Dymola simulation data of the previously mentioned nine Dymola heat pump models in order to determine the most suitable system for the investigated multi-family building. Due to the higher supply temperatures, the calculated SCOP values are all below three (while the SCOP values in Eichhorn (2018) are all above three, see Table 6).

This investigation showed that also for higher temperatures the best SCOP values are achieved with refrigeration circuits with enhanced vapor injection (EVI). The EVI refrigeration circuits in combination with R134a and R1234ze(E) achieve the highest SCOP values (2.96). As R1234ze(E) has a lower GWP (Global Warming Potential), the Dymola heat pump model with EVI refrigeration circuit and R1234ze(E) was selected for further investigation.

Analogously to Eichhorn (2018), the main part of the investigations was the energy efficiency assessment of different heat pump configurations and heat pump combinations with a ST system resp. a PV system. The SCOP was calculated with the enhanced SCOP Excel Tool, the SPF is a result of the Polysun® simulations and the Seasonal space heating energy efficiency ($\eta_s$) was derived from the SCOP values. Finally, the energy efficiency rating was performed based on the space heating energy efficiency values. Some main properties of the ST system and the PV system simulated within this work are listed in Table 12. Table 13 lists the results of the Polysun® simulations (SPF) and the SCOP calculations of all calculation/simulation variants. The variants refer to the Dymola heat pump model and a reference heat pump model as well as to the different heat pump combinations.

*Table 12: Properties of the investigated fictitious ST system and PV system*

| System properties | ST | PV |
|---|---|---|
| Number of collectors/modules | 72 | 88 |
| Surface area of collector/module (m²) | 2 | 1.65 |
| Surface area of all collectors/modules (m²) | 144 | 145.2 |
| Volume of storage tank (m³) | 10 | - |
| Collector/module efficiency (%) | 49 | 16.34 |
| Peak capacity/power (kWp) | 63.5 | 23.76 |

*Table 13: Calculation/simulation results by Polysun® and the enhanced SCOP Excel Tool, the Seasonal space heating energy efficiency ($\eta_s$) and the resulting ErP rating (not yet refurbished multi-family building)*

| Vari-ant | System | Heat pump model | SPF (Polysun®) | SCOP (EN14825) | $\eta_s$ | ErP |
|---|---|---|---|---|---|---|
| 1 | HP only | Reference | 2.5 | 2.51 | 97 | A |
| 2 | HP-ST combination | Reference | 4.6 | 3.1 | 124 | A+ |
| 3 | HP-PV combination | Reference | 2.9 | 2.56 | 102 | A+ |
| 4 | HP only | Dymola | 3.0 | 2.96 | 115 | A+ |
| 5 | HP-ST combination | Dymola | 3.6 | 3.57 | 144 | A++ |
| 6 | HP-PV combination | Dymola | 3.2 | 3.04 | 122 | A+ |

The results in Table 13 show an improvement of the SCOP by up to 23 % for the variant with the reference heat pump and by up to 21 % for the variant with the Dymola heat pump model when the variants are combined with a photovoltaic or solar thermal system. Like in Eichhorn (2018), the heat pump combinations with a ST system achieved better results than the heat pump combinations with a PV system. In contrast to Eichhorn (2018), the Polysun® results (SPF values) for the heat pump combinations with a PV system are more realistic as these values were calculated manually based on Polysun® simulation results.

According to Haiderer (2018), the reasons for the decent results of the heat pump combinations with PV are the low ratio of own electricity consumption (10%) and the efficiency gap between PV modules and solar thermal collectors. This comparison seems to be ambiguous as these values do not reflect the efficiencies of the overall systems.

It can be seen, that in general, the calculation/simulation results from the used calculation/simulation tools differ significantly from each other. Haiderer (2018) targets these deviations more comprehensively than Eichhorn (2018) and provides some “theories” (e.g. differences in the use of global radiation data) that may (partially) explain the deviations but without proofs (which was not in the scope of this work).

As the Dymola heat pump model represents a highly optimized heat pump, the electricity consumption of this model is 16 % lower than the reference heat pump model’s equivalent. This is achieved by the compressor speed control, the EVI and the choice of a refrigerant that is most suitable for the given conditions (e.g. high supply temperature).

## 5.3. Bachelor thesis “Efficiency assessment and variant comparison of an air/water heat pump and air/water heat pump combinations in a new multi-family building” (Hämmerle 2018)

Analogously to the two previously presented Bachelor thesis (Eichhorn 2018 and Haiderer 2018), this Bachelor thesis documents the performed calculations resp. simulations and calculation/simulation results using similar sets of simulation variants. The approach is almost identical to the other Bachelor thesis. The main distinction to the other two Bachelor thesis is, that the investigated multi-family building is a new construction. The building, also located in Vienna/Austria, was defined in this work as well. Like Haiderer (2018) the energy efficiency rating was performed based on the Seasonal space heating energy efficiency ($\eta_s$) values which were derived from the calculated SCOP values. Table 14 lists the most important building properties of the investigated newly constructed multi-family building. The building properties of the multi-family buildings investigated in the other two Bachelor theses are indicated.

*Table 14: Main properties of the investigated newly constructed multi-family building in comparison to the buildings investigated in the other two Bachelor theses*

| Building standard | Refurbished | Not yet refurbished | New construction |
|---|---|---|---|
| Bachelor thesis | Eichhorn | Haiderer | Hämmerle |
| Net floor area (m²) | 570 | 570 | 570 |
| Heating demand (kWh/m²) | 80 | 150 | 50 |
| Heating load (kW) | 30 | 57 | 19 |
| SH Supply/Return Temperature (°C) | 55/45 | 65/55 | 35/30 |

The illustrations according to the IEA HPT Annex 50 system classification scheme and the Polysun® models are  similar to those in Eichhorn (2018), see Figure 7 resp. Figure 8.

Due to the lower system temperatures, the investigations based on Dymola simulation data were performed with different Dymola heat pump models than in the other two Bachelor theses: instead of nine model variants, six model variants were investigated (see Table 15). Like in the other two works, the model variants are distinguished by the refrigeration circuit (single-stage, iHx, EVI) and the used refrigerant (R290 and R410A). It can be seen, that the variants concerning the refrigerant differ from the set of variants in other works where the refrigerants R290, R134a and R1234ze(E) were investigated. The EVI refrigeration circuit in combination with R290 achieves the highest SCOP and $\eta_s$ values (3.62/142). Therefore, this Dymola heat pump model was selected for further investigation in this Bachelor thesis.

*Table 15: Comparison of Dymola heat pump models - SCOPs and Seasonal space heating energy efficiency ($\eta_s$) values*

| Variant | Refrigeration circuit | Refrigerant | SCOP | $\eta_s$ |
|---|---|---|---|---|
| 1 | Single-stage | R290 | 3.48 | 136 |
| 2 | Single-stage | R410A | 3.43 | 134 |
| 3 | iHx | R290 | 3.48 | 136 |
| 4 | iHx | R410A | 3.44 | 134 |
| 5 | EVI | R290 | 3.62 | 141 |
| 6 | EVI | R410A | 3.43 | 134 |

The results of the simulations resp. calculations regarding SCOP, SPF and the Seasonal space heating energy efficiency ($\eta_s$) of different heat pump combinations with a ST system resp. a PV system (see properties in Table 16) are listed in Table 17.

*Table 16: Properties of the investigated fictitious ST system and PV system*

| System properties | ST | PV |
|---|---|---|
| Surface area of all collectors/modules (m²) | 38 | 50 |
| Volume of storage tank (m³) | 3 | - |
| Collector/module efficiency (%) | 85 | 16 |
| Peak capacity/power (kWp) | 25 | 14 |

*Table 17: Calculation/simulation results by Polysun® and the enhanced SCOP Excel Tool, the Seasonal space heating energy efficiency ($\eta_s$) and its resulting ErP rating (new construction)*

| Variant | System | Heat pump model | SPF (Polysun®) | SCOP (EN14825) | $\eta_s$ | ErP |
|---|---|---|---|---|---|---|
| 1 | HP only | Reference | 3.4 | 3.3 | 128 | A++ |
| 2 | HP-ST combination | Reference | 4.3 | 4.2 | 166 | A+++ |
| 3 | HP-PV combination | Reference | 3.5 | 3.4 | 136 | A+++ |
| 4 | HP only | Dymola | 3.7 | 3.6 | 142 | A++ |
| 5 | HP-ST combination | Dymola | 4.6 | 4.5 | 178 | A+++ |
| 6 | HP-PV combination | Dymola | 3.9 | 3.8 | 153 | A+++ |

The comparison of the variants confirms the observation in Eichhorn (2018) and Haiderer (2018) that the variants regarding the Dymola heat pump model result in higher SCOP and $\eta_s$ values than the variants regarding the reference heat pump model.

The heat pump combinations with a photovoltaic system result in slightly higher SCOP and $\eta_s$ values compared to the heat pump only variants. Like in the other two Bachelor theses, Hämmerle (2018) attributes this small increase to the low rate of own consumption. He assumes that a battery energy storage system would lead to an increase in energy efficiency of the overall system, as less electricity would be fed into the grid while more electricity would be used directly by the heat pump when it is in operation. This would reduce the amount of electricity drawn from the grid, which in turn would result in higher SCOP and $\eta_s$ values.

The heat pump combinations with a ST system clearly stand out from the other variants. With a SCOP of 4.5, this variant achieves the highest SCOP values. The high characteristic values result from the fact that as soon as energy is available at the collector, it is charged into the storage tank. In this way the heating load can be covered without the heat pump being in operation. The heat pump is activated only when the heating load is not covered by solar energy anymore. Due to the reduced operating times of the heat pump, the electricity consumption is reduced. The deviations between the Polysun® simulation results (SPF) and the results from the enhanced SCOP Excel Tool are smaller than in Eichhorn (2018) and Haiderer (2018).

# 6. Economic and environmental assessment of heat pump combinations with a PV system

Additionally to the further development of the energy efficiency assessment method for heat pump combinations with a ST and/or PV system and the enhancement of the SCOP Excel Tool, research regarding the economic and ecological assessment of heat pump combinations with a PV system has been performed in course of the work on the Master thesis by Schreurs (2019) and a Bachelor thesis by Klein (2020a) .

## 6.1. Master thesis “Techno-economic assessment of combined heat pump and PV systems in Austria” (Schreurs 2019)

The research goal of this Master thesis has been to analyze the sensitivity of the net present value (NPV), benefit cost ratio (BCR) and internal rate of return (IRR) on different input parameters for the replacement of a conventional heating system in a multi-family house, by a heat pump combined with a PV system. A case study addresses the question, what input parameters influence the profitability of heat pump combinations with a PV system and to what extent.

The research was performed by creating an Excel model and performing simulations with the Building Model Generator (©AIT) software. The model was validated with the Polysun® software. The model regarding the Polysun® simulations combined with Excel calculations is shown in Figure 9. The model regarding the Building Model Generator (BMG) simulations combined with Excel calculations is shown in Figure 10. The system layout of the Polysun® model variant “air/water heat pump combination with a PV System is shown in Figure 11, its ground source heat pump pendant is shown in Figure 12 while the conventional space heating system with a gas boiler is shown in Figure *13*

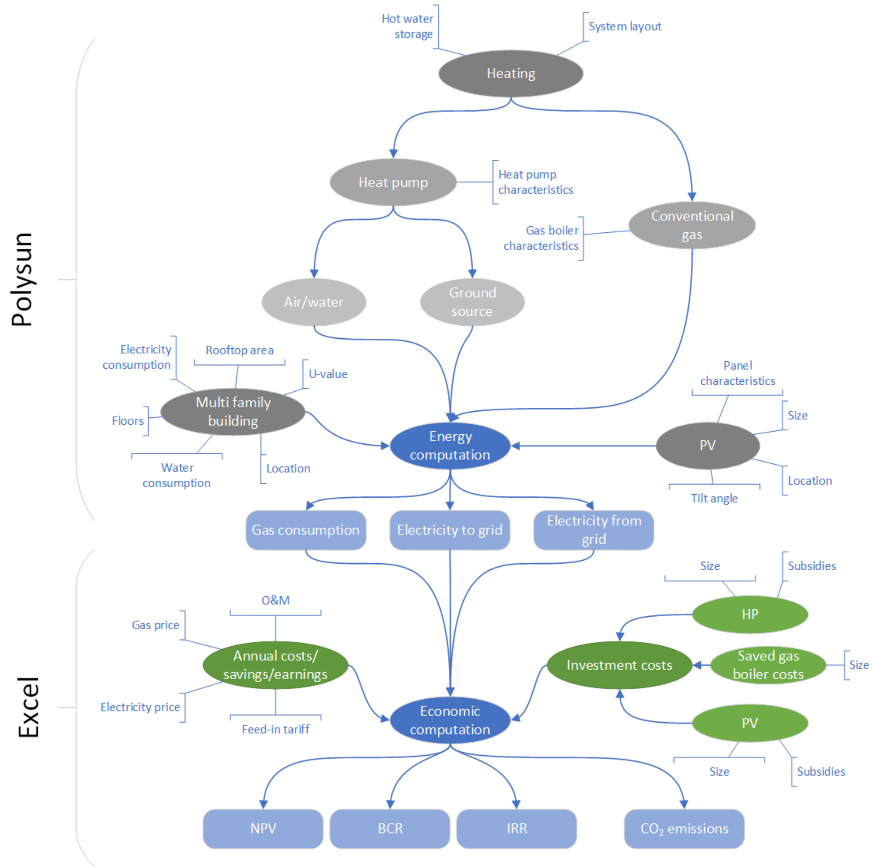



*Figure 9: Polysun®/Excel model with input parameters and outputs (Schreurs 2019)*

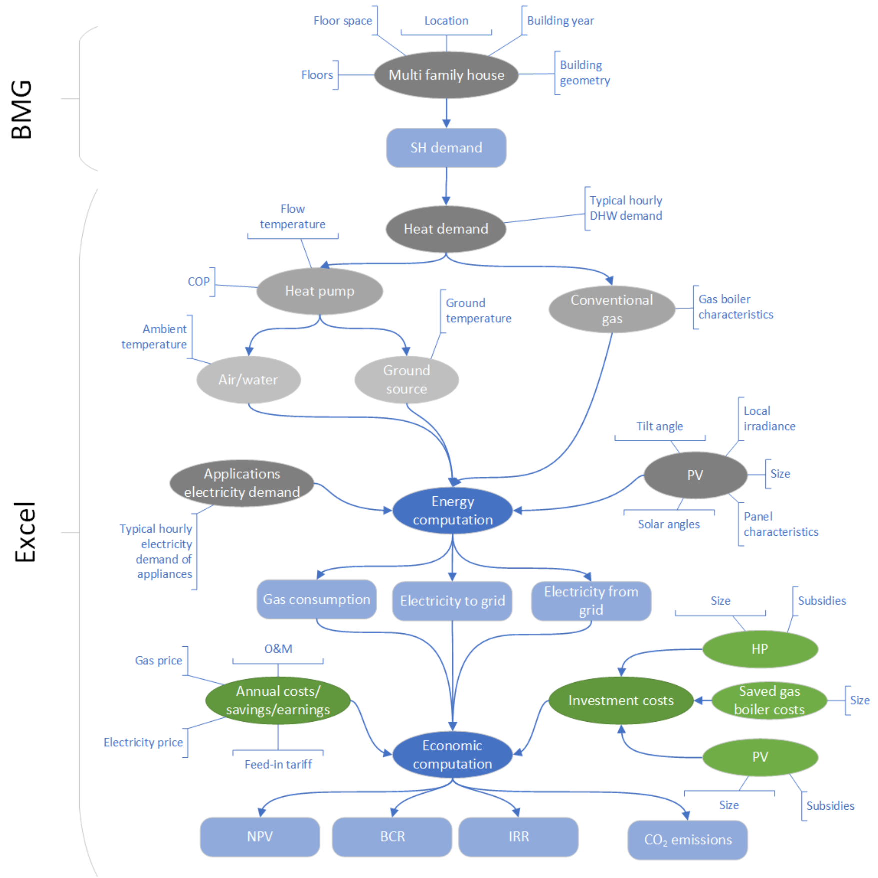



*Figure 10: BMG/Excel model with input parameters and outputs (Schreurs 2019)*

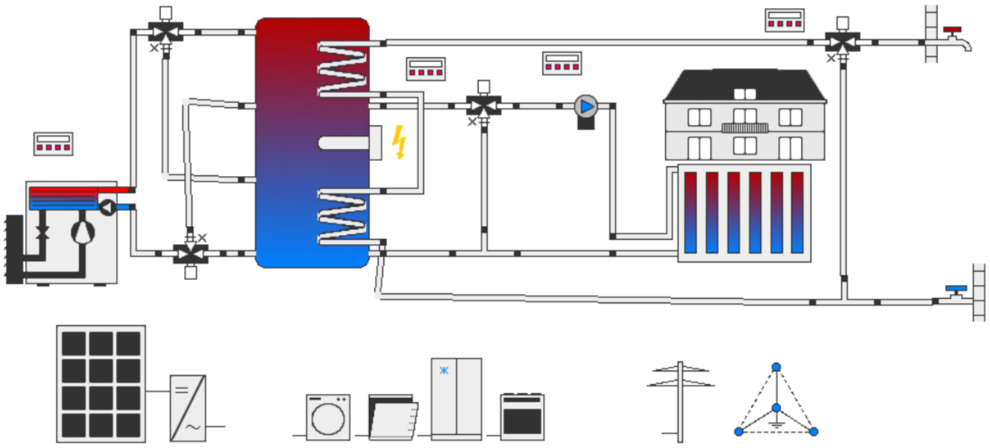


*Figure 11: Polysun® model layout of the air/water heat pump combination with a PV system (Schreurs 2019)*

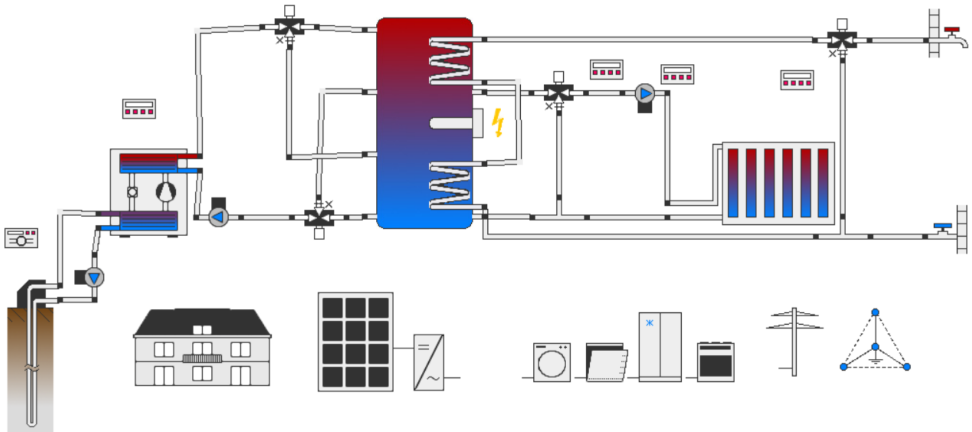


*Figure 12: Polysun® model layout of the ground source heat pump combination with a PV system (Schreurs 2019)*

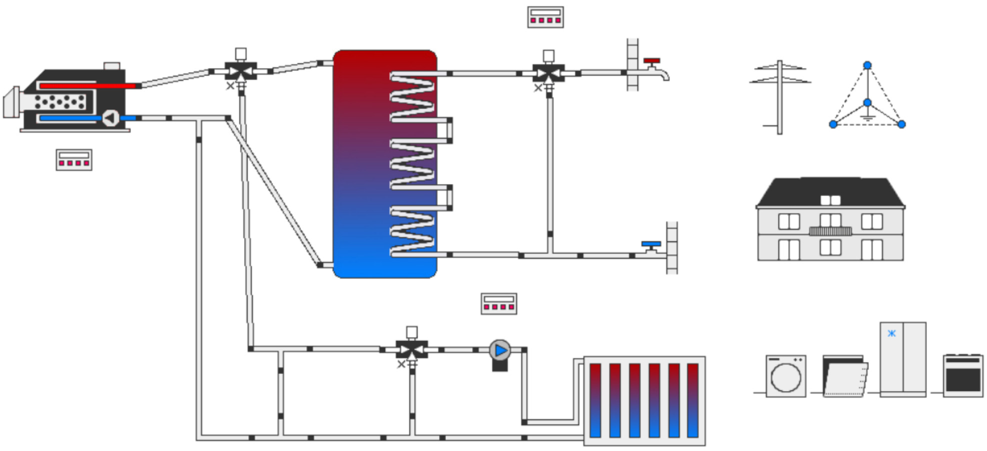


*Figure 13: Polysun® model layout of the conventional space heating system with a gas boiler (Schreurs 2019)*

The economic assessment showed that replacing a gas boiler by a heat pump combination with a PV system in a multi-family house would improve the NPV in comparison to installing the heat pump or PV system separately (see Figure 14). The BCR is greater than one for both the air/water heat pump combination with a PV system and the ground source heat pump combination with a PV system for the investigated input parameters.

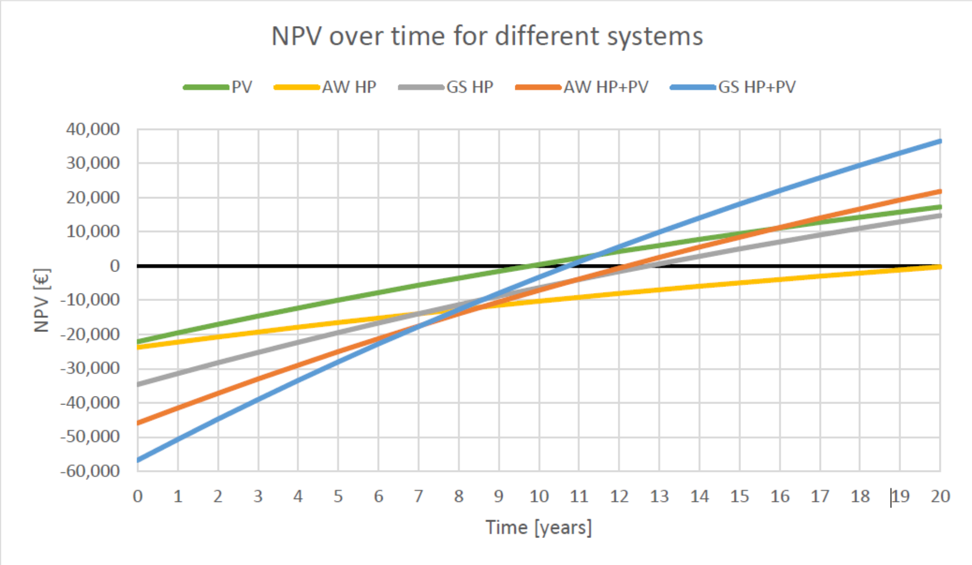



*Figure 14: NPV for the replacement of the gas boiler by an air/water resp. ground source heat pump combination with a PV system (AW HP+PV resp. GS HP+PV) and the NPV of the separate systems (Schreurs 2019)*

In Vienna/Austria (also in other federal states in Austria), subsidies influence the NPV and payback time of heat pump combinations with a PV system significantly. This applies more to ground source heat pumps due to higher investment costs and higher investment subsidies, see Figure 15. The economic assessment showed that the BCRs increase with the increasing PV area but the curves become flatter with the increasing PV area too, see Figure *16*.

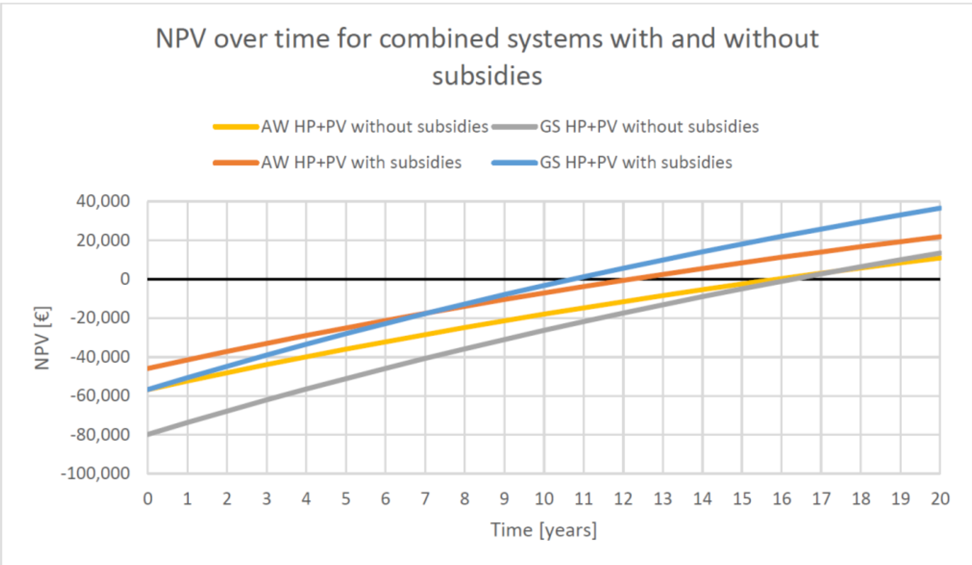



*Figure 15: NPV over the lifetime for the air/water resp. ground source heat pump combination with a PV system (AW HP+PV resp. GS HP+PV) with and without subsidies (Schreurs 2019)*

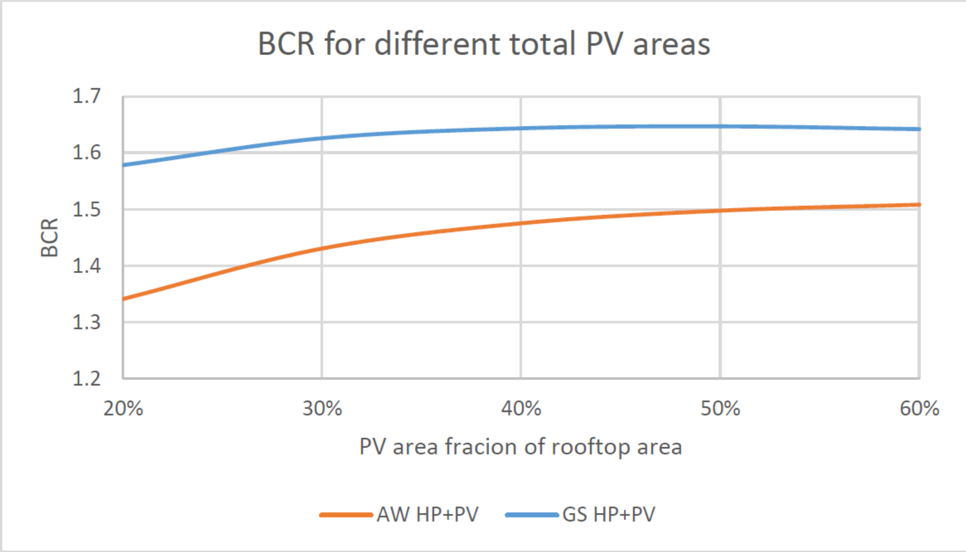



*Figure 16: BCR for different area sizes of the PV field for both heat pump systems (Schreurs 2019)*

The investment costs have a large influence: if these would decrease somehow by 50%, the NPV would double. This influence of the investment costs can be seen in Figure 17.

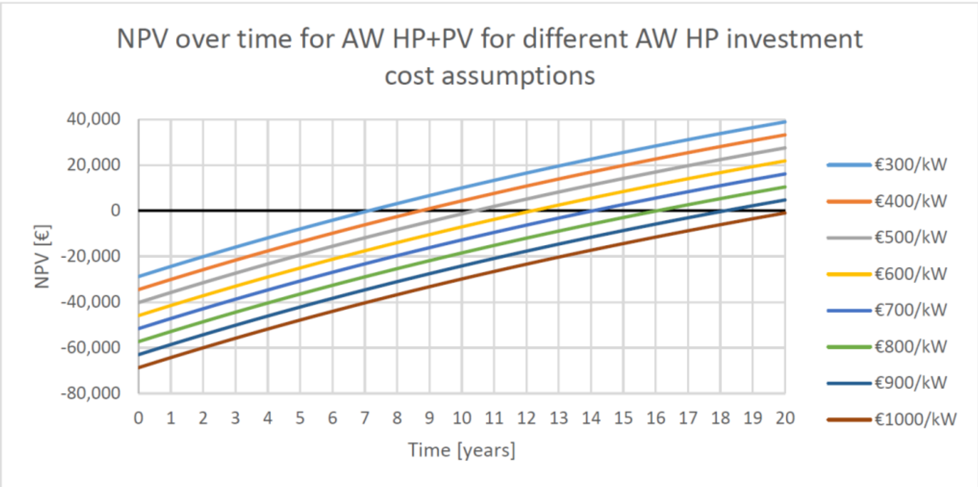



*Figure 17: NPV over the lifetime of the air/water heat pump combination with a PV system for different assumptions concerning the heat pump investment costs, ranging from €300/kW to €1000/kW (Schreurs 2019)*

The electricity price has a larger influence on the BCR than the feed-in tariff does. When the electricity price decreases, the BCR increases. It could be concluded from the sensitivity analysis that the gas price has the largest influence (see Figure 18). Because of this high dependency on the gas price, a gas price increase could even make subsidies redundant. Increasing the gas price could thus be the quickest way to stimulate the sales of heat pump combinations with a PV system.

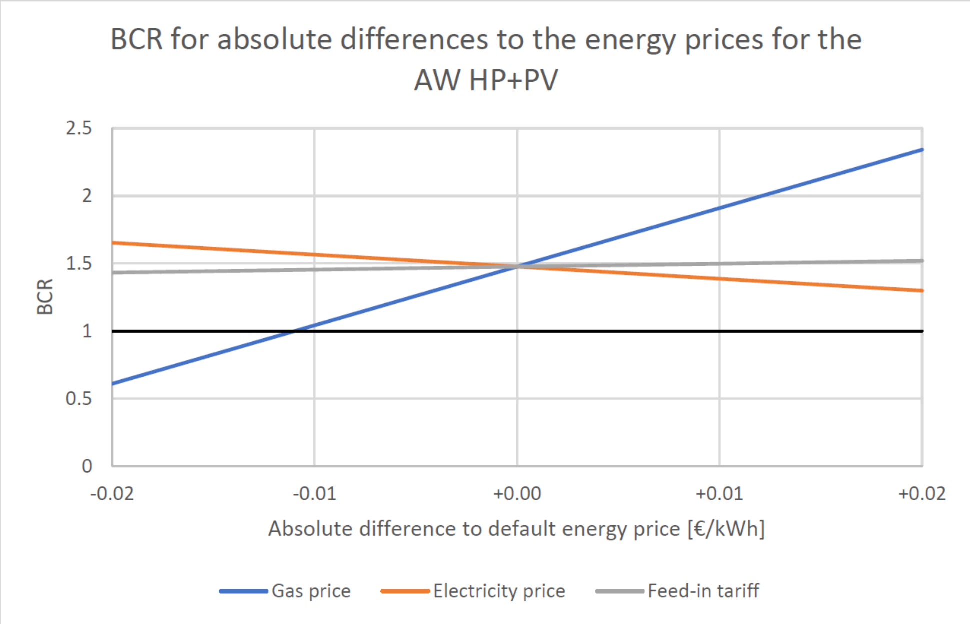



*Figure 18:* Influence of absolute changes to the gas price per kWh, electricity or feed-in tariff to the BCR of the air/water heat pump combination with a PV system. The default value of the gas price is €0.06/kWh, for the electricity price €0.17/kWh and for the feed-in tariff €0.0767/kWh *(Schreurs 2019)*

The environmental assessment showed that the replacement of a conventional gas-based heating system by a heat pump combination with a PV system would lead to a decrease in $CO_2$ emissions of approximately 45 % to 60%. The best result can be achieved by a ground source heat pump combination with a PV system (see Figure 19).

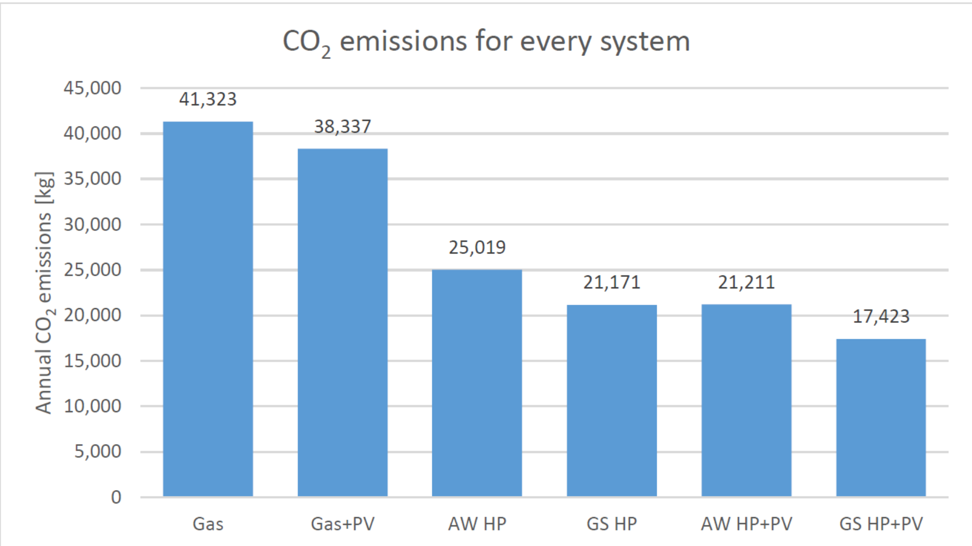



*Figure 19:* $CO_2$ emissions of the conventional gas system with and without PV, the air/water heat pump with (AW HP+PV) and without PV system (AW HP) and the ground source heat pump with (GS HP+PV) and without PV system (GS HP) *(Schreurs 2019)*

The assessment of the costs resp. benefits of the reduction of $CO_2$ emissions show that replacing the conventional gas-based heating system by an air/water heat pump (without PV) would result in costs of €0.02 per kg of $CO_2$ that is saved. The replacement by a ground source heat pump would result in net cost savings of €0.72 per kg of saved $CO_2$ emissions. The air/water heat pump combination with a PV system would result in cost savings of €1.07/kg and the ground source heat pump combination with a PV system would result in the highest benefit: €1.51 per saved kg $CO_2$ emissions (see Figure 20).

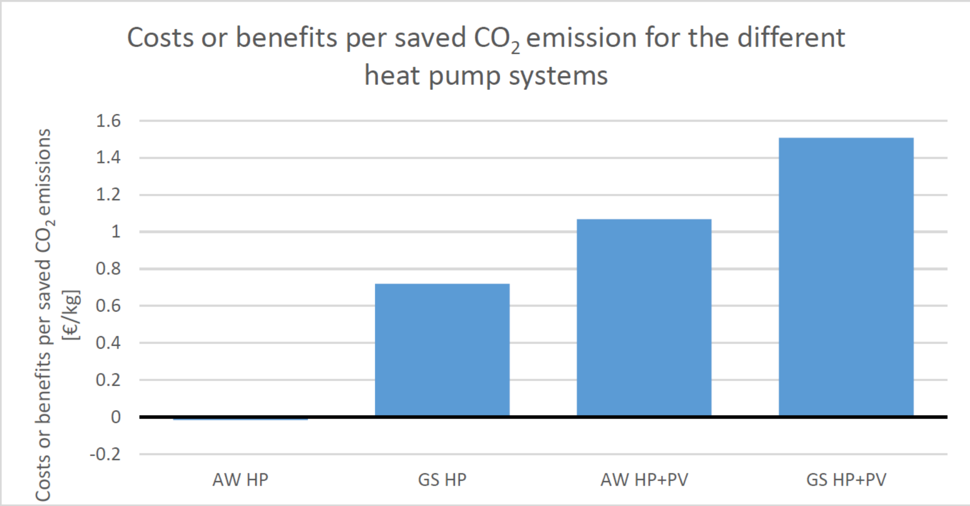



*Figure 20:* Costs or benefits of $CO_2$ emission reduction for both heat pump types with and without PV system *(Schreurs 2019)*

## 6.2. Bachelor thesis "Calculation tool for the energetic and economic assessment of a heat pump-photovoltaic combination" (Klein 2020a)

In the framework of this Bachelor thesis, which is in relation with the Master thesis by Schreurs (2019), an Excel calculation tool for the energetic and economic assessment of heat pump combinations with a PV system (Klein 2020b) was developed which addresses end users.

The Excel tool counts with embedded characteristic building data of the three building categories "passive house (heating demand: 15 kWh/m²a), "standard" (50 kWh/m²yr) and "refurbished existing building" (150 kWh/m²yr). The user can select one of these building categories or enter any heating energy demand manually.

Further input data concerning the building's energy consumption are the number of inhabitants and the DHW consumption per inhabitant. Characteristic data of a standard ground source heat pump and an air/water heat pump is also embedded in the Tool. The user can choose between these two heat pump types.

The required input data for the calculation of the PV yield, is the total PV module surface area. The weather data for all Austrian federal states and standard properties of the PV system (e.g. PV system efficiency) are embedded in the Excel Tool as well.

For the economic assessment, investment and operating costs as well as subsidies need to be entered by the user manually. Figure 21 shows the input screen of the assessment Excel tool (German only)

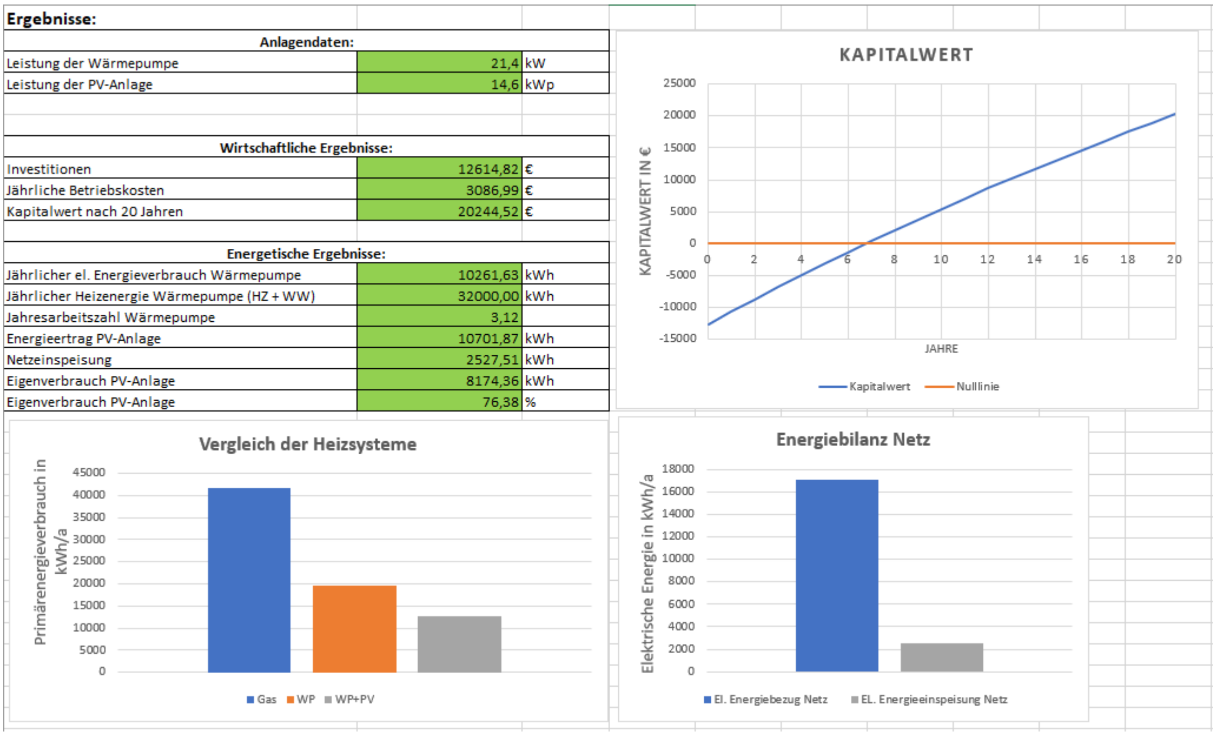
| Eingaben: | | |
|---|---|---|
| Bundesland auswählen | Wien | |
| Gebäudetyp wählen | Eigene Eingabe | |
| spezifischen Heizwärmebedarf eigeben | 50 | kWh/(m²*a) |
| Konditionierte Heizfläche | 400 | m² |
| Anzahl der im Gebäude lebenden Personen | 12 | |
| Warmwasserverbrauch | Standard Profil | |
| Warmwasserverbrauch für das gesamte Gebäude | | kWh/a |
| Heizungsabgabesystem auswählen | Fußbodenheizung | |
| Wärmepumpensystem auswählen | Luft/Wasser | |
| Jährlicher elektrischer Energieverbrauch | 15000 | kWh/a |
| Verfügbare Fläche PV-Anlage 1 (Strang 1) | 40 | m² |
| Ausrichtung PV-Anlage 1 | West | |
| Neigung der PV-Anlage 1 | 30 | ° |
| Verfügbare Fläche PV-Anlage 2 (Strang 2) | 40 | m² |
| Ausrichtung PV-Anlage 2 | Ost | |
| Neigung der PV-Anlage 2 | 30 | ° |
| Neubau oder Bestandsgebäude | Bestandsgebäude | |
| Zusätzliche WP-Förderungen eintragen | | € |
| Zusätzliche PV-Förderungen eintragen | | € |
| Bestehendes Heizungssystem auswählen | Gas | |
| Erdgaspreis eintragen | 0,058 | €/kWh |
| Ölpreis eintragen | 0,077 | €/kWh |
| Strompreis eintragen | 0,18 | €/kWh |
| PV-Einspeisetarif eintragen | 0,06 | €/kWh |
| PV- Anlage vorhanden | JA | |

*Figure 21: Input tab of the Excel Tool for the energetic and economic assessment of heat pump combinations with a PV system (Klein 2020b)*

In order to test the developed assessment Excel tool, a case study concerning a fictitious building with a heat pump combination with a PV system was performed. The reference system is a gas-based heating system.

The case study shows that the utilization of a heat pump combination with a PV system results in significant energy savings compared to the reference system. The primary energy consumption is approximately a third less than the primary energy consumption of the conventional gas-based heating system.

The economic analysis showed that the investment in the replacement of the conventional reference system by a heat pump combination with a PV system pays off after approximately 11.5 to 15 years. An exemplary screenshot of the result tab with charts regarding the NPV (Kapitalwert) over the assessment period, the annual primary energy consumption (Primärenergiebedarf) and the electricity supply from the grid resp. electricity fed into the grid (Energiebilanz Netz) is shown in Figure 22 (results not representative for the case study undertaken in course of this thesis).



| Ergebnisse: | | |
|---|---|---|
| **Anlagendaten:** | | |
| Leistung der Wärmepumpe | 21,4 | kW |
| Leistung der PV-Anlage | 14,6 | kWp |
| **Wirtschaftliche Ergebnisse:** | | |
| Investitionen | 12614,82 | € |
| Jährliche Betriebskosten | 3086,99 | € |
| Kapitalwert nach 20 Jahren | 20244,52 | € |
| **Energetische Ergebnisse:** | | |
| Jährlicher el. Energieverbrauch Wärmepumpe | 10261,63 | kWh |
| Jährlicher Heizenergie Wärmepumpe (HZ + WW) | 32000,00 | kWh |
| Jahresarbeitszahl Wärmepumpe | 3,12 | |
| Energieertrag PV-Anlage | 10701,87 | kWh |
| Netzeinspeisung | 2527,51 | kWh |
| Eigenverbrauch PV-Anlage | 8174,36 | kWh |
| Eigenverbrauch PV-Anlage | 76,38 | % |



*Figure 22: Result tab of the Excel Tool for the energetic and economic assessment of heat pump combinations with a PV system (Klein 2020b)*

Finally, the assessment Excel tool was validated with a Polysun® simulation which showed that the PV yield calculated with the Excel tool is approximately 10 % lower than its pendant calculated in Polysun®. This deviation is due to the differences in the used calculation/simulation methods. As the tool is used in the pre-planning phase, the calculation method is considered enough accurate.

# 7. Conclusion

The energy label provides consumers with a simple method of comparing different products of individual manufacturers. It is also applicable to different heating systems such as heat pumps, oil and gas boilers etc. to compare their efficiency. The system is simple and refers to primary energy consumption. It offers energy efficiency ratings from A++ to G, which is stated on the Label, attached to the device.

In Task 2.1, the further development of the existing approach based on ÖNORM EN 14825 and ÖNORM EN 15316 was successful, the enhanced SCOP Excel Tool (Zahradka 2017b based on Köfinger 2013b) that uses these methods now fulfils the functionality for the performance of energy efficiency assessments of heat pump combinations with other RES.

The investigations using the new methods resp. the enhanced SCOP Excel Tool showed that heat pump combinations with a ST system have better energy efficiencies than the heat pump combinations with a PV system. Haiderer (2018) and Hämmerle (2018) explain this by with lower rates of own consumption of the PV systems due to missing energy storage, compared to ST systems. A different setup of the ST/PV calculation/simulation models (e.g. a larger heat pump storage tank) might result in better efficiencies. Furthermore, the investigations indicate that deviations between the Polysun® simulation results (SPF) and the results from the enhanced SCOP Excel Tool are more significant in Multi-family buildings of a lower building standard but almost not significant in newly constructed Multi-family buildings of a high building standard.

This observation would indicate, that the energy efficiency assessment methods, described in this report, are suitable for heat pump combinations in newly constructed multi-family buildings of a high building standard and less suitable for Multi-family buildings of lower building standards. This statement has yet to be proved by further research.

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