HEATING OF A CASTLE WITH AIR-TO-AIR HEAT PUMPS

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Abstract: In order to allow a use of heritage buildings during the cold season heating is needed for a rather long period in Austria. However, the installation of a heating system in such buildings holds some challenges. A major issue is the required modification of the building structure if a heating system is installed because of historic preservation. That is why such buildings are most commonly equipped with electric heaters.

This paper deals with an alternative heating system suitable for heritage buildings: Air-to-air heat pumps installed at Castle Rabenstein (Burg Rabenstein) located in Austria. The castle with a gross floor area of ca. 2500 m^2 is equipped with several air-to-air heat pumps with variable refrigerant flow and a heating capacity of ca. 500 kW.

For the analysis of possible operation modes a thermal building simulation of a selected area of the castle – which is mainly used for events – was performed by means of TRNSYS. Different heating strategies were investigated with respect to the heating energy demand for maintaining a comfortable indoor climate. In this context, the reduced room temperature – when no event takes place – and the preheating time in combination with the air supply temperature of the indoor devices are of special interest.

In order to determine the energy efficiency of the heating system a monitoring concept was established, and the measurement system is in operation since December 2013.

Key Words: Burg Rabenstein, thermal building simulation, heat pump monitoring, initial measurement results, TRNSYS

1 INTRODUCTION

Austria has a continental climate with low temperatures in winter and relatively high temperatures in summer. The climatic conditions in the populated areas can be described as follows: heating degree days ca. 3500 Kd/a (basis: room temperature 20°C, heating limit: 12°C), design ambient temperature for heating systems ca. -10°C, average temperature during the heating season ca. 2°C. In such a climate heating is required for a rather long period (ca. 200 days). However, while for residential buildings continuously heating is necessary in the cold season, the heating of a castle is typically limited to selected days and rooms. Of course, this depends strongly on the usage of the castle's rooms.

With respect to the installation of a (new) heating system in a castle various criteria have to be met, e.g. historic preservation, prestige, low cost, etc. According to Rabenstein (2014), the final report of the EREC (European Renewable Energy Council) project "New4Old" estimates a total of 18 000 castles and palaces in Europe which either have no heating system or should switch to an energy efficient system. At Castle Rabenstein (Burg Rabenstein) an air-to-air heat pump has turned out to be the preferred solution. Similarities of the 18 000 objects with the Castle Rabenstein especially in terms of age, condition of the building and topography suggest the air-to-air heat pump as an advantageous heating system. A market observation estimates approximately 25 % of the mentioned objects requiring a new heating system. This leads to a target market of 4500 objects among castles and palaces in Europe. Due to the fact that energy efficient heating is not only an issue for castles and palaces but for every protected building, the market potential encompasses a few hundred thousand buildings. Relevant buildings are manor and estate houses, historical residences in cities, museums, churches and monasteries to mention but a few.

Since only few realized heat pump installations in heritage buildings can be found, the aim of the present project is to collect data required for the dimensioning of new air-to-air heat pump applications in castles. Further aims are to determine the energy demand depending on the heating strategy (key words: non-permanent heating and operative room temperature), the efficiency of a real application, and finally, based on this data, to demonstrate the feasibility of an innovative heating system for heritage buildings.

2 CASTLE RABENSTEIN AND ITS HEATING SYSTEM

The Castle Rabenstein (Figure 1) is located around 25 km north from the city of Graz, Austria. The castle is situated on a rock close to the river Mur at an elevation of about 445 m above sea level. First parts of the castle were erected in the 12th century and it was continuously extended and modified afterwards. Since 2005 the castle has been owned by Werner Hochegger and he renovated the building and installed an air-to-air heat pump.

Figure 1: Photo of Castle Rabenstein taken from the north (http://www.stmk.wifi.at)

The castle has a gross floor area of about 2500 m² and consists of the following major “wings”:

Castle Wing (“Schlosstrakt”): It was built in the 16th and 17th century and it represents the “heart” of the castle. Following rooms belong to this wing: knight’s hall (Rittersaal), a library, the “Japanese room”, and a bar.

Meeting Wing (“Konferenztrakt”): it is located in the western part of the castle and comprises a chapel, the planetary room („Planetensaal”), a tavern, and a business lounge.

North Wing („Nordtrakt“): this part of the castle is of special interest; it comprises a restaurant (“Gewölbe“), the “Rittinger bar”, and a room for lectures and concerts (“Concert Hall”).

The heating system at Castle Rabenstein is basically a multi-split air-to-air heat pump with variable refrigerant flow and direct evaporation & condensation. Multi-split air-to-air systems are typically used for cooling purpose. However, at Rabenstein this mode is primarily used for defrost operation. The most important facts of the heating system are summarized in Table 1.

Table 1: Technical data of the heating system

Gross floor area	ca. 2500 m²
Number of refrigerant circuits	11
Number of indoor units	72
Overall heating capacity	546 kW [1)]

[1)] Indoor air temperature 20°C DB, Outdoor air temperature 7°C DB/6°C WB

The main purpose of the heating system is an on-demand variation of the indoor temperature in the cold season, because the energy consumption for heating should be minimized. This requires that only selected areas have comfortable room temperatures during times of events taking place in selected rooms of the castle. In this context, the "operative room temperature" – which corresponds approximately to the average of room air temperature and surrounding wall temperatures – plays an important role (see below).

The heating system of the castle consists of 11 refrigerant circuits. One circuit comprises several indoor units connected to a corresponding outdoor unit. An outdoor unit consists of – at least – one outdoor coil (working as refrigerant evaporator in heating mode) and two compressors. A layout of the heating system is depicted in Figure 2.

In heating mode the indoor units operate as refrigerant condenser rejecting heat to the indoor air via forced convection. The heating capacity of an indoor unit can be controlled by means of the refrigerant mass flow rate. Since all indoor units can be controlled in this manner, the room air temperature in different rooms can be controlled independently. Figure 3 shows indoor units located in the "Bar" and the "Concert Hall", both rooms are situated in the North Wing of the castle.

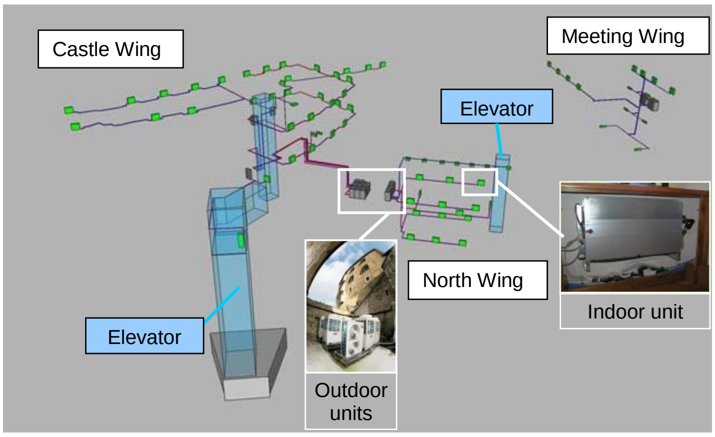

Figure 2: Overall scheme of the heating system
(http://www.burg-rabenstein.at/; modified by IWT)

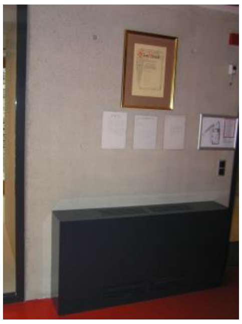


Figure 3: "North Wing" – Pictures of indoor units ("Rittinger Bar" (left) and "Concert Hall")

The following chapters contain detailed information about the building simulations carried out within this project, and report on initial measurement results.

3 THERMAL BUILDING SIMULATION

The aim of the thermal building simulations within the present study was on the one hand the determination of the heating energy demand according to the standard ÖNORM B 8110-5:2010 (based on standardized conditions), and on the other hand the determination of the heating demand under "real" conditions occurred in the year 2011. In this context, the consequences of a reduced room temperature (before an event takes place) and different pre-heating times have been analyzed with respect to the heating energy demand and comfort criteria. Up to now the focus of the investigations was laid on the "North Wing", because this part of the castle was especially adapted for events (e.g. concerts, celebrations, etc.).

The following sections describe the boundary conditions for the simulations carried out with TRNSYS (2013), the simulated heating energy demand of the building, and the analysis of different heating strategies (Tockner 2012).

3.1 Boundary Conditions

3.1.1 Climate and geologic data

For the simulations under the climate conditions of year 2011, the hourly data of the weather station „Frohnleiten" (located about 1 km from the castle) was used (ZAMG 2011). In comparison to the climate data of the period 2000 – 2009, 2011 was an "average" year: the average ambient temperature was 9.7°C, and the overall solar irradiation was about 1150 kWh/(m^2 a) of which about 50% was diffuse irradiation. The coldest month was January with an average temperature of -0.5°C, while the coldest hourly value (-10.9°C) was measured in February. The highest hourly temperature (32.3°C) was measured in August with an average monthly value of 19.4°C.

The ground below Castle Rabenstein consists mainly of carbonate quartzite with a thermal conductivity of ca. 1.3 W/(m K), a specific heat capacity of ca. 0.96 kJ/(kg K), and a density of ca. 2100 kg/m^3 (compare ÖNORM ON V31:2001).

In order to take into consideration the heat exchange of the cellar walls and the floor of the restaurant „Gewölbe" with the underground, the ground temperature in different depths (0.6, 1.8, and 3 m) was calculated according to the theory of Kasuda (1965).

3.1.2 Building data (North Wing)

A geometric model of the North Wing was set-up in SketchUp (Trimble 2010) and the thermal building simulation with seven thermal zones was carried out with TRNSYS (2013).

As one can see from Figure 4, the building has large windows on the south façade and small roof lights as well as small windows to the north. The lower part of the building on the south is situated below ground level (indicated in the figure with three segments, corresponding to the surrounding of the zone "Gewölbe"). On the west and east façade in total four doors are installed.

For the construction of the walls, floors, and ceilings several assumptions were necessary. Table 2 summarizes the most important data of the thermal zone "Gewölbe" (restaurant). For simplification the strongly varying thicknesses of the different layers in this old building were approximated with average thicknesses. The U-values in Table 2 are based on assumed heat transfer coefficients on the inner and outer surface (7.7 W/(m^2 K) and 25 W/(m^2 K), respectively).

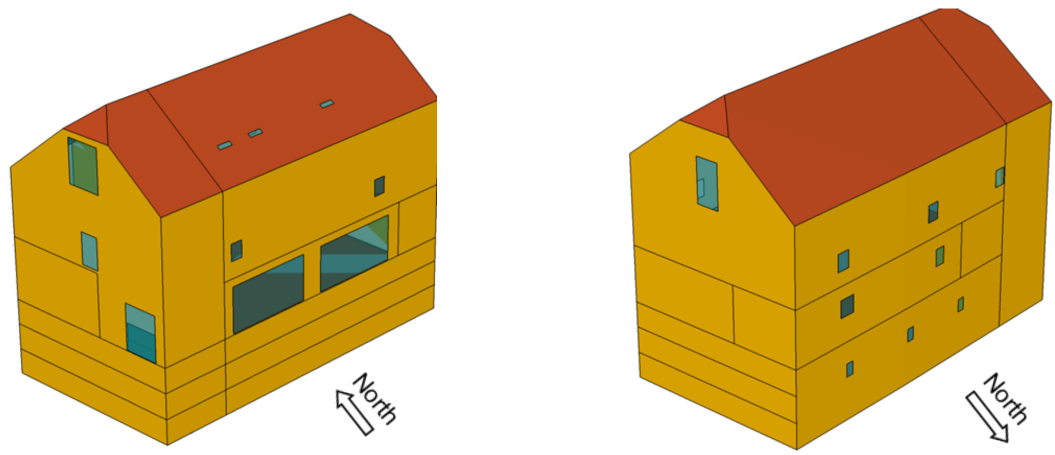

Figure 4: North Wing – left: from south-west, right: from north east (Tockner 2012)

Table 2: “North Wing” (thermal zone “Gewölbe”) – wall construction, specifications and U-values

Wall Type	Material	Area [m²]	Thickness [m]	Density [kg/m³]	heat conductivity [W/mK]	heat capacity [J/kgK]	U-Value [W/m²K]
North Wall	Lime Cement Lime Stone	49.5	0.015 1.066	1800 2600	3.13 2.94	1000 840	1.82
South Wall	Lime Cement Lime Stone	48.9	0.015 1.120	1800 2600	3.13 2.94	1000 840	1.77
East/West Wall	Lime Cement Lime Stone	32.4	0.015 1.040	1800 2600	3.13 2.94	1000 840	1.89
Partition Wall staircase	Concrete	26.5	0.200	2200	2.1	1000	3.77
Ground Floor insulated	Screed PE-Foil XPS PE-Foil Leveling	83.8	0.070 0.001 0.180 0.001 0.090	2000 40 1700	1.4 0.04 0.83	1000 1470 840	0.21
Ground Floor	Lime Stone	36.7	0.900	2600	2.94	840	2.10
Vaulted Ceiling dir. Ground Floor	Screed PE-Foil EPS PE-Foil clinker brick	120.5	0.070 0.001 0.080 0.001 0.380	2000 40 2200	1.4 0.04 4.32	1000 1470 1000	0.42

For the retrofitted wooden frame windows a U-value of 1.4 W/(m^2 K) was assumed, which is close to the actual state-of-the-art. On the other side, although the exterior walls of the building are enormous thick, their U-values are high (up to 1.2 m and 1.9 W/(m^2 K), resp.).

3.1.3 Infiltration, ventilation and internal gains

Infiltration: the air exchange rate owing to leakage was assumed to be moderate (0.1 h^{-1}), because of the rather tight windows.

Ventilation: the thermal zones „Gewölbe“ and „Rittinger Bar“ are equipped with a ventilation system incl. heat recovery, which is in operation for 1 hour 3 times a day. Electrical heaters are installed in order to prevent freezing of the heat recovery system and to increase the temperature of the supply air at very low ambient temperatures.

Air exchange between thermal zones (via open doors): an average air velocity of 0.1 m/s was assumed for the calculation of the air exchange between the zones. The corresponding flow rate is up to 500 kg/h and leads to an air exchange rate between 0.2 and 1.0 h^1 in the different zones.

Internal gains: The most important sources are lighting, persons, and electrical devices. The thermal load due to lighting and persons were taken into consideration according to the guideline VDI 2078 (2004). In total, lamps with an electrical power consumption of about 10 kW are installed in the North Wing (of which 3.8 kW belong to the Concert Hall). In the year 2011 different events took place. The thermal load of the persons assumed for the simulations varied accordingly, between 3.6 and 7.4 kW. Finally, the thermal load caused by electrical devices (coffee makers, refrigerators, etc.) was assumed between 0.6 kW (standby) and almost 6 kW when all kitchen appliances are in operation.

3.2 Heating Demand of the North Wing and the Overall Castle

The determination of the heating demand according to the standard ÖNORM B 8110-5:2010 implies several simplifications: internal loads 3.75 W/m^2, room air temperature 20°C, no air exchange between the thermal zones, ambient climate 2011.

The heating demand of the North Wing (which is partly renovated, i.e. insulated floor and roof) was determined in detail. However, in order to get an impression about the heating demand of the overall castle, the North Wing was simulated again but neglecting the insulation of the floor and roof.

Table 3 summarizes the simulation results. For the partly renovated (insulated) North Wing the specific heating demand is ca. 204 kWh/(m^2·a) and for the fictive non-insulated North Wing a value of 256 kWh/(m^2·a) was calculated. For the heating demand of the North Wing this results in an annual consumption of 68.7 MWh and for the overall castle about 611 MWh/a can be estimated.

Table 3: Heating demand of the North Wing and an estimation of the castle's overall heating demand (calculation acc. to ÖNORM B 8110-5:2010; ambient climate: 2011)

	Gross area	spec. heating demand renovated (basis: North Wing as is)	spec. heating demand not renovated (basis: North Wing without insulation)	Heating demand
	[m²]	[kWh/m²a]	[kWh/m²a]	[MWh/a]
North Wing	337	204		68.7
Rest of the Castle (estimation)	2120		256	542.7
Total	2457	249		611.4

3.3 Optimized Heating Strategies and Comfort Analysis

By means of thermal building simulations the heating demand has not only been determined according to the standard ÖNORM B 8110-5:2010, which is based on synthetic boundary conditions (see 3.2), but also for “real” conditions. In this context, “real” means especially a varying usage profile for the rooms, i.e. a non-comfortable set-back temperature in the rooms in periods of non-use and pre-heating in order to achieve a comfortable temperature when it is required.

As an example, Figure 5 shows the ambient temperature as well as the simulated operative room temperatures for the thermal zones Concert Hall, Rittinger Bar, and Gewölbe for the year 2011 in which 8 events took place (either in the Concert Hall, in the Rittinger Bar, or/and in the Gewölbe). In the following sections the “Event” marked with a rectangle in the figure (March 28, 2011, corresponding to the peak at approximately 2070 hr) is discussed a bit more in detail.

As one can see, the operative temperature in the 3 zones (Gewölbe, Bar and Concert Hall) is partly below 10°C, although the heating system ensures a minimum air temperature in the zones of 10°C (= "setback temperature") because the wall temperature may drop far below 10°C. Before every event the heating system increases the air temperature to a value of 24°C for 12 hours in order to achieve a comfortable indoor climate (operative temperature) during the event. (Remark: the operative temperature can be approximated as the average of air temperature and surrounding wall temperature.)

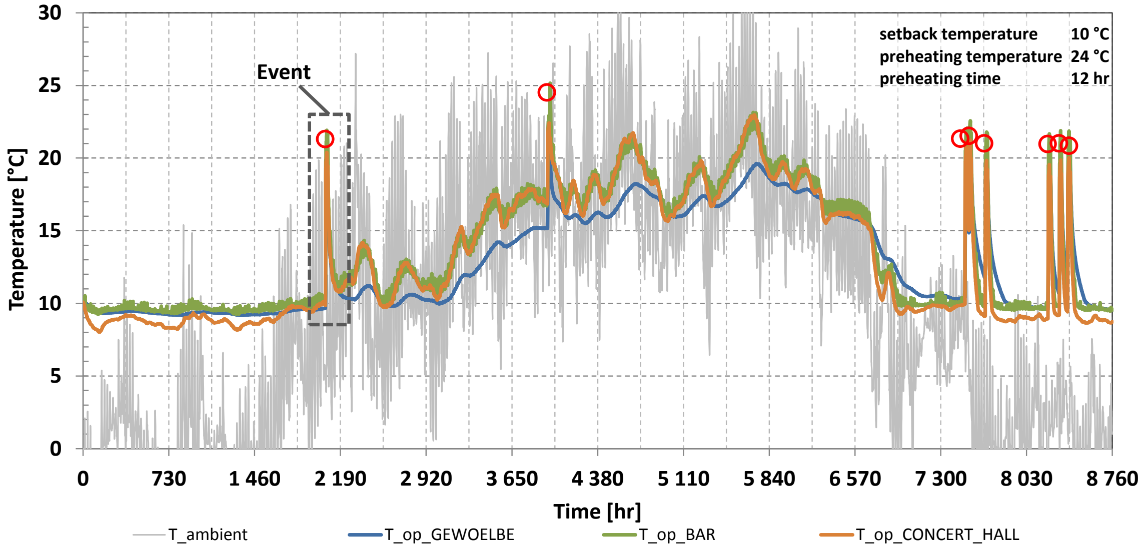

Figure 5: Ambient temperature and simulated operative temperatures in the North Wing in the year 2011 (8 events marked with circles)

Different strategies exist for achieving a comfortable operative room temperature during the time of an event: e.g. the air temperature during pre-heating and/or the pre-heating time can be varied (see Figure 6).

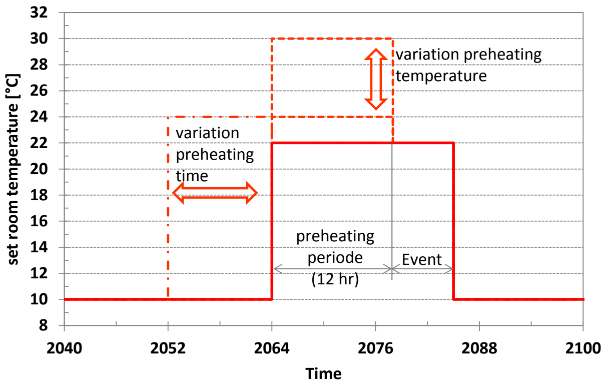

Figure 6: Variation of pre-heating temperature and/or time

Figure 7 shows the simulation results for two different strategies: as one can see from the left diagram, pre-heating for 12 hours at 24°C results in an operative temperature of ca. 19°C at the beginning of the event (which lasts for ca. 6 hours). Regarding the required heating load which has to be covered by the heat pump, it can be concluded that the heat pump must deliver the maximum possible capacity ($\dot{Q}_{heat,Gewölbe}$ = ca. 48 kW) for approximately 2 hours. Afterwards, the capacity can be reduced to ca. 20 kW in order to ensure 22°C air temperature in the room. From the moment on when the event starts, the internal loads ($\dot{Q}_{gain,Gewölbe}$ = ca. 12 kW) cover almost entirely the required heating demand.

For the second example, pre-heating is assumed for 24 h at 30°C (see right diagram in Figure 7). In this case the operative temperature is between 24 and 22°C during the event. Although the operative temperature corresponds to a comfortable indoor climate (according to EN ISO 7730:2006), during the event the temperature difference between air (30 to 26°C) and surrounding wall is high. This is caused by the high U-values and large thermal masses of the walls. However, the location of the indoor coils close to the surrounding walls may compensate their cold surface temperature.

If one compares the heating energy demand for these two pre-heating strategies, approximately twice of the energy is needed for the strategy 24 h / 30°C (696 kWh vs. 342 kWh for 12 h / 24°C).

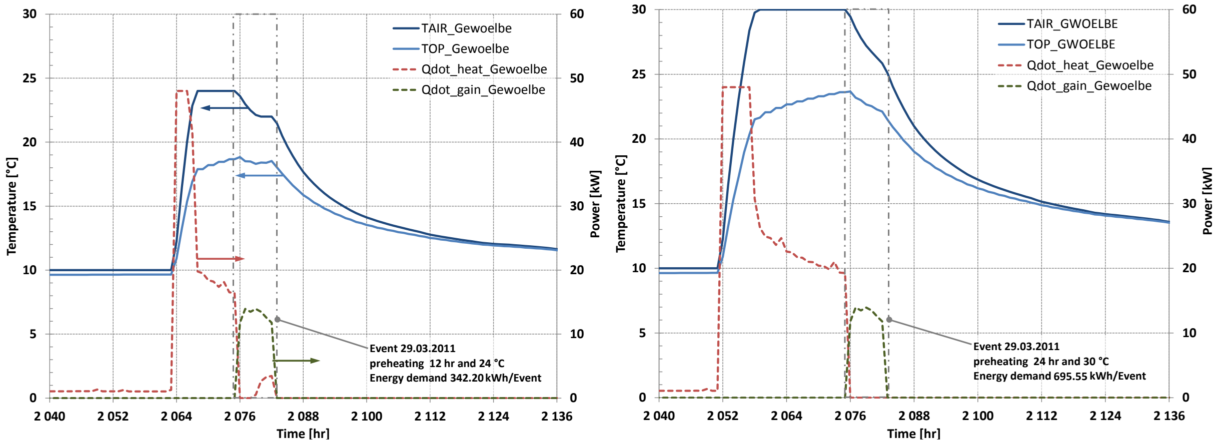

Figure 7: Thermal zone „Gewölbe“ – air & operative room temperature, heating capacity and internal loads for different preheating time / temperature (left: 12 h / 24°C, right: 24 h / 30°C)

If one compares the simulated operative room temperatures during all events of the year 2011 with the requirements of the different comfort “Classes” defined by EN ISO 7730:2006 it can be seen, that the strategy 24°C for 12 hours leads to unsatisfying operative temperatures in the room: almost non of the events can take place at recommended temperatures required for a “Class C” indoor climate (Class C is defined with a Predicted Percentage of Dissatisfied (PPD) < 15%). On the other side, in case of the strategy 24 h / 30°C the majority of operative temperatures complies with “Class A” (PPD < 6%).

Table 4 summarizes the simulated heating energy demands of the North Wing with different heating strategies: For two of them continuous heating is assumed in order to achieve a room air temperature (T_room_set) of 10 or 20°C. For the other variants, pre-heating for 12 or 24 hours at different air temperatures (24, 26, 28, or 30°C) is assumed. During the events the air temperature is 22°C, while during the rest of the year the heating system keeps a minimum room temperature of 10°C only.

As can be seen, the reduced air temperature (10°C instead of 20°C) results in a very low annual heating energy demand (25 MWh @ 10°C vs. 69 MWh @ 20°C). The simulated energy demand of the other variants is between 29.1 and 30.5 MWh. An interesting conclusion is, that a Class A climate ($t_{operative}$ > 21°C) during the events can either be achieved with 12 hours pre-heating at 28°C or 24 hours at 26°C.

Table 4: North Wing – heating demand and operative room temperature (zone Gewölbe) for different heating scenarios (Basis: 8 events in 2011)

	North Wing - Burg Rabenstein	space heating demand [kWh/a]	spec. space heating demand [kWh/m²a]	T_op Event Gewölbe [°C]
	T_Room_set: 20 °C	68748	204.0	19.5
12 hr	preheating temperature: 30 °C; T_Room_set: 22 °C	30504	90.5	21.9
12 hr	preheating temperature: 28 °C; T_Room_set: 22 °C	30012	89.1	20.9
12 hr	preheating temperature: 26 °C; T_Room_set: 22 °C	29539	87.7	20.1
12 hr	preheating temperature: 24 °C; T_Room_set: 22 °C	29112	86.4	19.3
24hr	preheating temperature: 30 °C; T_Room_set: 22 °C	33564	99.6	23.4
24hr	preheating temperature: 28 °C; T_Room_set: 22 °C	32667	96.9	22.3
24hr	preheating temperature: 26 °C; T_Room_set: 22 °C	31809	94.4	21.2
24hr	preheating temperature: 24 °C; T_Room_set: 22 °C	31006	92.0	20.1
	T Room set: 10 °C	25090	74.5	11.9

4 MONITORING OF THE HEAT PUMP

As mentioned above, the overall heating system consists of 11 refrigerant circuits. 3 of them have been equipped with measurement sensors, and a data logging system collects their data every second. Two of these measured refrigerant circuits (“AG8” and “AG9”) are responsible for the heat delivery to the North Wing of the castle. In total 21 indoor units are installed in this part of the castle.

The monitoring system is in operation since December 2013 and here follows a description of the measurement concept and preliminary measurement results.

4.1 Measurement Concept

Figure 8 shows the simplified refrigerant circuit of the air-to-air heat pump supplying heat to the North Wing of the castle. The outdoor unit basically consists of two sub units (the master “AG8” and the follower “AG8/1”), and the indoor unit consists of 21 indoor units. Each of the R410A hermetic twin rotary compressors can be speed-controlled in a range from 900 to 9000 rpm. For details see Toshiba (2012).

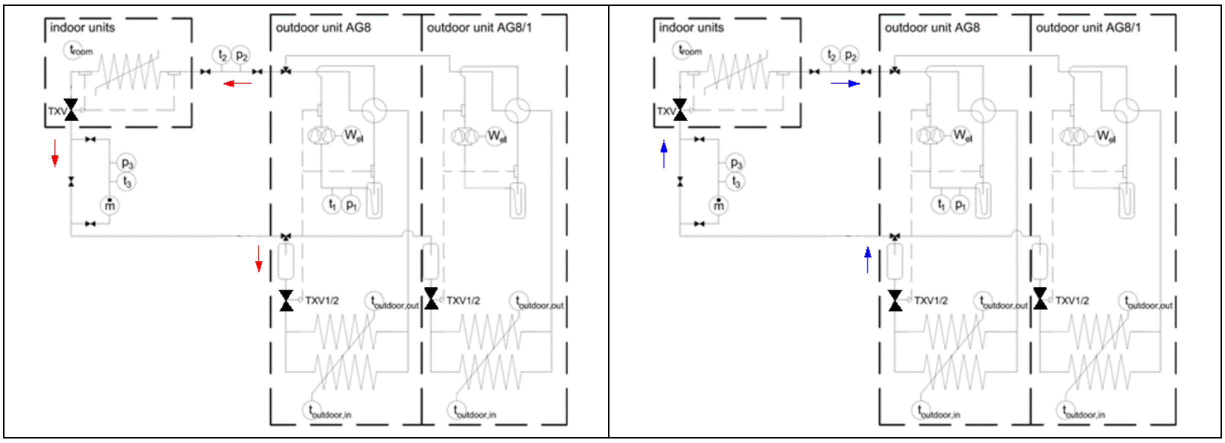

Figure 8: Schematic of the refrigerant circuit of the heat pump AG8 (master) & AG8/1 (follower) supplying heat to the North Wing (left: heating mode, right: defrost mode)

In **heating mode** the pressure and temperature sensors at point 2 (p2, t2) measure the refrigerant state at the compressor outlet. For a variation of the heating capacity, the mass flow rate through each indoor coil is controlled via the valve TXV. Point 3 represents the throttling valve inlet (TXV 1/2 controls the super heat at the evaporator outlet), and at this position the pressure (p3), the temperature (t3), and the mass flow rate ($\dot{m}$) of the sub-cooled refrigerant are measured. The pressure and temperature sensors at point 1 (p1, t1) are used to determine the state of the superheated refrigerant vapour at the compressor inlet. For the determination of the heating capacity the enthalpy difference of the refrigerant between point 2 and 3 is used (see Eq 1). Of course, this procedure assumes negligible heat losses between compressor discharge line and indoor coil as well as between indoor coil and measurement point 3.

$$\dot{Q}_h = \dot{m}_{(ref)} \cdot (h_{ref,2} - h_{ref,3}) \qquad \text{Eq 1}$$

The mean electrical power consumption of the heat pump in a certain measurement interval (P_{el}; overall electricity consumption of the circuit excl. indoor fans) can be determined via kWh-meters (see W_{el} in Figure 8). The Coefficient of Performance of the heat pump (COP_h) can then be calculated according to Eq 2.

$$COP_h = \dot{Q}_h / P_{el} \qquad \text{Eq 2}$$

For **defrost mode** (“cooling mode”) the refrigerant cycle can be reversed by means of a 4 way valve (see Figure 8). In this mode the refrigerant flows directly from the compressor outlet to the outdoor coil, where it delivers the heat required to remove the frost. After passing point 3, the throttle (TXV) reduces the refrigerant pressure and heat is absorbed from the thermal masses of the indoor units and the indoor air. It should be mentioned, that in defrost mode the indoor air flow rate is reduced to an “ultra low” value in automatic mode or even to zero in manual mode. However, the evaporated refrigerant leaves the indoor units at point 2 in a super-heated state, and finally it enters the compressor (point 1). The capacity extracted from the indoor air ($\dot{Q}_c$) can be determined via the refrigerant mass flow rate and its state in point 2 and 3 (assuming an adiabatic throttling process from p3 to p2). With respect to the efficiency of the heating system, the heat extracted from the indoor air during defrost operation reduces the net heat delivered by the heat pump. I.e., for a certain period of time (τ) the Seasonal Performance Factor (SPF_h) of the heat pump is defined by Eq 3.

$$SPF_h = (\int \dot{Q}_h \, d\tau - \int \dot{Q}_c \, d\tau) / \int P_{el} \, d\tau \qquad \text{Eq 3}$$

In order to allow an interpretation of the monitoring results it is required to know the indoor air temperature (represented by t_{room} in Figure 8) and the ambient temperature ($t_{outdoor,in}$), which is measured at the inlet to the outdoor coil. Additionally, the outlet temperature of the air from the coil is measured ($t_{outdoor,out}$).

<u>Remark</u>: only the outdoor unit “AG8” is equipped with a pressure and temperature sensor at the compressor inlet. However, the heat rejected from the refrigerant to the indoor air during heating mode and absorbed during defrost mode can be determined in any case via the measurement equipment installed at point 2 and point 3.

4.2 Initial Measurement Results

As mentioned above, the measurement equipment has been in operation since December 2013. Since that time the heating system has been operated for test reasons, therefore only examples of measurement results can be reported here.

4.2.1 Temperature/enthalpy diagrams of selected operating points

Figure 9 shows one “typical” temperature/enthalpy diagram of the refrigerant cycle during heating mode and one during defrost mode derived from measured data (see above). As can be seen by the heating mode chart, the evaporation temperature (ca. 0°C) fits well to the ambient temperature (t_{source} = ca. 7°C), while the condensation temperature is rather high (ca. 42°C) in comparison to the room temperature (t_{room} = ca. 28°C). Taking a look on the heating capacity shown in Figure 10, one can see that the heat pump AG8 delivered about 27 kW to the building at this time.

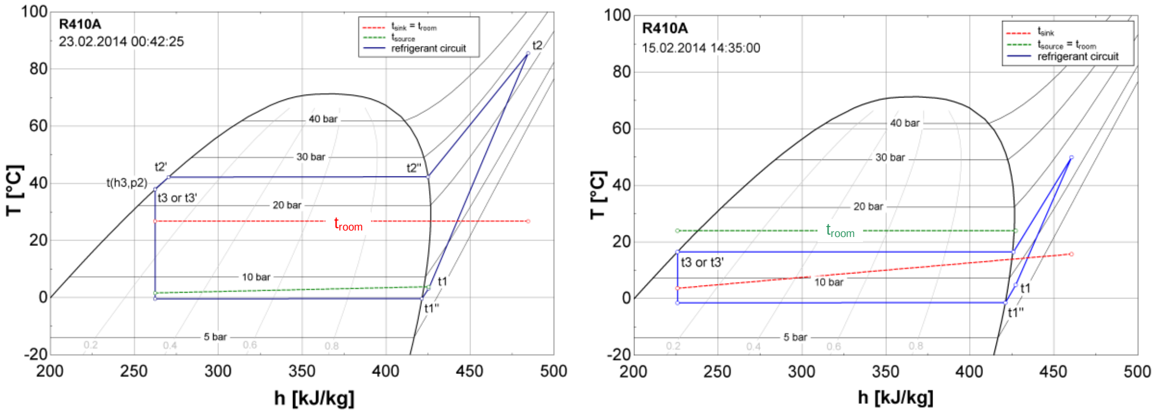

Figure 9: Examples of temperature/enthalpy diagrams
left: heating mode, right: defrost mode

It should be noticed that the condensation temperature is not only determined by the room temperature (measured at a certain point in the room), but by the mass flow rate of the heat sink in combination with its condenser inlet temperature.

In defrost mode, the refrigerant cycle looks like it can be expected at the end of a defrost cycle: Heat is absorbed from the indoor air at an evaporation temperature of ca. -1°C and rejected to the heat sink (ambient air) with a large glide ($t_{sink,in}$ = ca. 4°C, $t_{sink,out}$ = ca. 17°C).

4.2.2 Examples of capacity profiles

For test reasons the heat pump circuits AG8 and AG9 were operated in the period Feb. 20 – 24, 2014. Figure 10 shows the ambient temperature, the measured room air temperatures, as well as the heating capacities of the two circuits. According to these diagrams, the ambient temperature varied between ca. 0 and 8°C, while the room temperatures was between ca. 17 and 28°C. The corresponding heating capacities varied between ca. 7.5 and 30 kW when the heat pump operated. Since the diagrams show average values for one hour, some lower values can be seen. Furthermore, the heat extraction during defrost mode is taken into consideration as well.

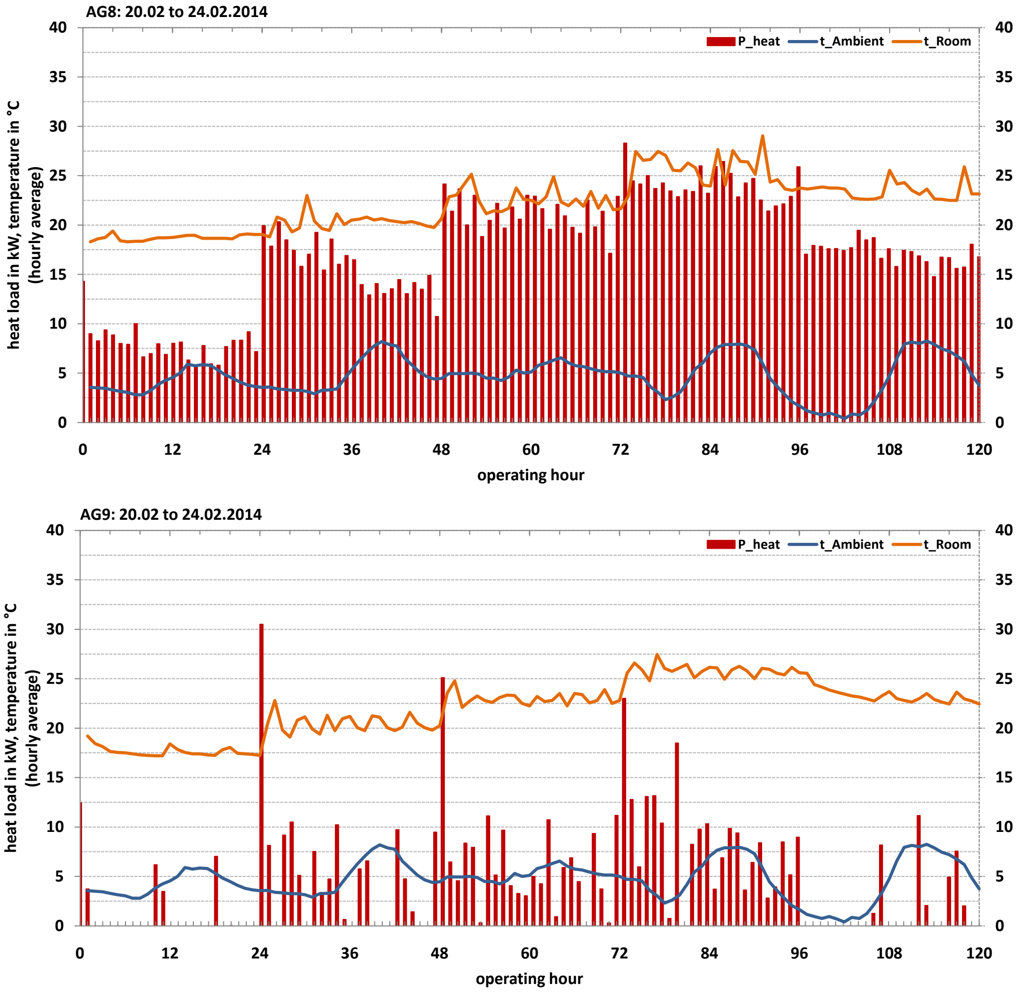

Figure 10: Heating Capacity, room and ambient temperature in the period Feb. 20 – 24, 2014 upper diagram: rooms „Gewölbe and „Bar" (refrigerant circuit AG8) lower diagram: Concert Hall (refrigerant circuit AG9)

At the moment the monitoring system is being extensively tested within a Master thesis (Gründhammer 2014), and the system should collect reliable data in the next heating period for the refrigerant cycle, heating capacity delivered to the building, and heat pump efficiency.

5 CONCLUSIONS AND OUTLOOK

Heating of heritage buildings by means of heat pumps represents an interesting market for air-to-air heat pumps. However, the rooms in such buildings are typically not in use all heating period long, and a reduced room temperature in periods of non-use – combined with pre-heating at an adequate temperature before usage – offer a large energy saving potential. In this context, the operative room temperature plays an important role. As shown by thermal building simulations for selected events in the North Wing of Castle Rabenstein, a pre-heating time of 12 hours seems to be too short as long as the pre-heating temperature is lower than 28°C, while 24 hours pre-heating at 26°C is sufficient in order to achieve a “Class A” climate.

For the determination of the energy efficiency of the heat pump installation at Castle Rabenstein, a monitoring system has been installed. It is in operation since December 2013. At the moment the measurement system is being tested. The experimental data gathered with the system will then be used for the verification of the building simulations and, finally, to show the advantages of heat pumps with respect to energy efficiency and environmental concerns.

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