SUMMER PERFORMANCE OF RESIDENTIAL HEAT RECOVERY VENTILATION WITH AN AIR-TO-AIR HEAT PUMP COOLING SYSTEM

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ABSTRACT

Increasing airtightness and isolation of residential buildings in today's climates cause challenging situations for the summer indoor climate. In combination with ventilation for fresh air, it calls for intelligent control of passive cooling when available, and active cooling when needed.

The combination of heat recovery ventilation and an air-to-air heat pump cooling system is a solution to these challenging situations. With the exhaust air heat pump cooling system, heat is transferred from the supply air (which is getting colder) to the exhaust air (which is getting warmer).

Such a ventilation system is monitored throughout the summer for an actual installation in The Netherlands. The control of such a system depending on the actual indoor and outdoor conditions is explained in a control diagram.

Correlation diagrams show how the ventilation supply air temperature and humidity varies with outdoor temperature in accordance with the passive or active cooling mechanism. It has been shown that the sensible cooling can be doubled with active cooling when compared to passive cooling. The total (sensible + latent) cooling of the air-to-air heat pump amounts up to 1100 W with 150 m^3/h and up to 1700 W with 270 m^3/h.

Limitations of the technology are explained with diagrams for conditions where the condenser gets too hot. For these situations the ventilation air flow rate is first automatically increased to allow the condenser to cool. If necessary, the heat pump is shut off intermittently to prevent damage to the condenser.

KEYWORDS

Residential ventilation, indoor air quality, ventilative cooling, air-to-air heat pump

1 INTRODUCTION

Increasing airtightness and isolation of residential buildings in today's climates cause challenging situations for the summer indoor climate. In combination with ventilation for fresh air, it calls for intelligent control of passive cooling when available, and active cooling when needed.

The combination of heat recovery ventilation and an air-to-air heat pump cooling system is a comprehensive solution for bringing fresh air into a residential building for a good indoor air quality. More than only bringing fresh air, the heat recovery saves energy for heating the ventilation demand in the cold season. In the warm season, the addition of the air-to-air heat pump gives top cooling and dehumidification via the supplied fresh air. The working principle and the practical performance are reported in this article.

2 HEAT RECOVERY WITH AIR-TO-AIR HEAT PUMP COOLING

The working principle of heat recovery ventilation with an air-to-air heat pump cooling system is explained using fig. 1. A fan is extracting air from the building (ETA) through a heat exchanger that is transferring the heat (in winter) or the cold (in summer) to the supplied fresh air. Under favorable conditions, the extracted air is bypassing the exchanger when heat recovery is not needed. The extracted air is leaving the building as exhaust air (EHA).

Another fan is bringing fresh outdoor air (ODA) into the building through a heat exchanger where it is transferring heat (in winter) or cold (in summer). Before this so-called pre-supply air (P-SUP) is supplied in to the rooms, it can be cooled by the air-to-air heat pump. This heat pump brings energy from the supply air (which gets colder) to the exhaust air (which gets warmer). Eventually the fresh air is supplied to the rooms (SUP) in a comfortable way.

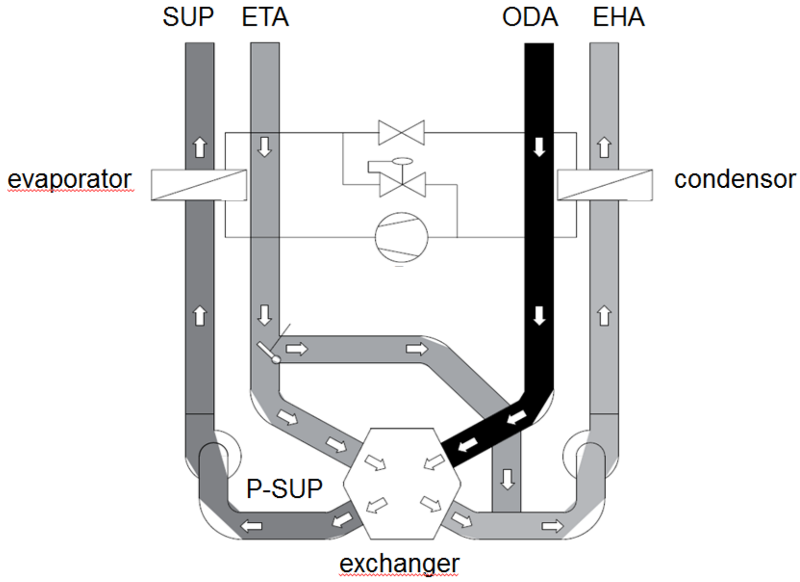

Figure 1: Schematic working principle with outdoor air (ODA), pre-supply air (P-SUP), supply air (SUP, extract air (ETA) and exhaust air (EHA).

The various states that this ventilation system can take are explained using the state control diagram in fig. 2. Depending on the outdoor temperature and indoor temperature (as measured in the outdoor air ODA and the extracted air ETA, respectively) and the setting of the comfort temperature, a specific state (expressed in colors) is entered. Example values of temperatures are given in italics for better understanding. The bypassing of the heat exchanger (to switch off heat recovery) is expressed by BP and the air-to-air heat pump is expressed by CC.

With low outdoor temperature (typically below 13 °C), the bypass is always closed, even when the indoor temperature is higher than the comfort temperature. This is to prevent that very cold air flows through the supply air ducts and produces condensation on the outside of the ducts in the house[1]. Above 13 °C outdoor temperature, and when the indoor is above the setting of the comfort temperature, first the bypass is opened to allow the cool fresh air to enter the building. When the outdoor air is not sufficiently cool anymore with respect to the

[1] Although ventilation systems with air-to-air heat pump cooling have insulated supply air ducts, this is the standard algorithm for products without heat pump cooling.

comfort temperature, the air-to-air heat pump is automatically switched on to provide cooling of the fresh air.

When the outdoor temperature is higher than the indoor temperature, the bypass is always closed to take benefit of the lower indoor air. Therefore, heat recovery (or in this case: cold recovery) precools the incoming fresh air to a level close to the indoor air temperature. When the indoor air temperature gets too warm, i.e. above the setting of the comfort temperature, the air-to-air heat pump is automatically switched on to further cool the supply of fresh air.

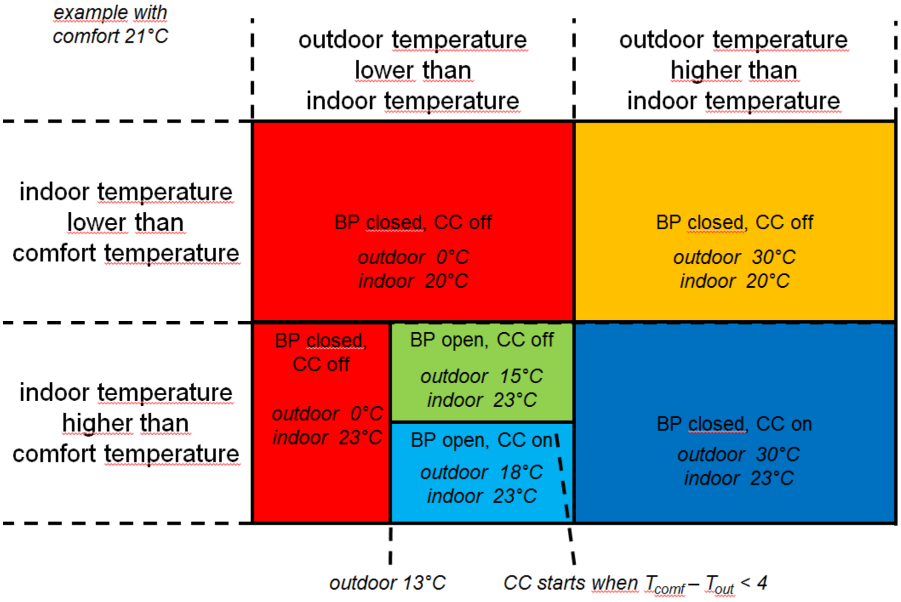

Figure 2: State control diagram

3 MONITORING OF SUPPLY AIR

During the summer of 2012, from the end of July until the beginning of October, a monitoring campaign was held in a house in Emmeloord, The Netherlands. The heat recovery ventilation system combined with an air-to-air heat pump cooling system was mostly used in middle fan speed or high fan speed, with fresh air flow rates 150 m^3/h and 270 m^3/h respectively. The setting of the comfort temperature was initially set to 23.5 °C, but the residents varied the setting during the monitored period between 23 and 24 °C according to their own needs.

The temperatures of the air streams ODA, P-SUP, SUP, ETA and EHA are measured internally in the ventilation unit. Additional Sensirion humidity sensors were added in the ducts to record the humidity of the air streams ODA, P-SUP, SUP and ETA. Fan percentages, the setting of the comfort temperature and the state of the ventilation system was also recorded internally on the PCB of the unit. The recordings were saved at an interval of 5 min and afterwards transformed into 1 hour average values for further analyzing.

Figure 3 shows a correlation diagram between the temperature of the supply air SUP and the temperature of the outdoor air ODA. The hour average values appear in the chart as groups of points that are indicated in accordance with the various states of the ventilation system from the state control diagram.

With closed bypass and outdoor temperatures below indoor temperature, the supply air temperature is at a comfortable level between 16 °C and 23 °C, in relation to the actual indoor air temperature because of the heat recovery. The average practical heat recovery efficiency based on the supply air temperature during the monitoring period is 87%. The heat recovery in this period saves heating energy for the central heating system of the house, indicated as avoided heating.

With closed bypass and outdoor temperature above indoor temperature, the supply air temperatures are also held close to the indoor air temperature because of the heat (cold) recovery. This gives a comfortable supply of fresh air and reduces the heat load for the building. This state is however not occurring often as the indoor air temperature rises to a level above the comfort temperature where the air-to-air heat pump is started.

When the indoor air temperature rises above the comfort temperature (and outdoor air temperature is above 13 °C), cooling is requested. With enough cooling capacity with the outdoor air, passive cooling is started (bypass open, heat pump off), resulting in supply air temperature 1 to 2 °C above the outdoor air temperature. The small rise in temperature is the effect of heat gains in outdoor air ducts and heat dissipation by the supply fan.

If the outdoor air itself had not enough cooling capacity, the air-to-air heat pump is started with open bypass to give a supply air temperature ranging between 10 °C for relatively low outdoor temperature to about 16 °C for outdoor temperature close to indoor air temperature. In this state, the ventilation system is giving passive cooling and active cooling at the same time, resulting in comfortable cooling throughout the house with the minimum of cooling energy.

When the outdoor air temperature is above the indoor air temperature, the bypass closes so that the incoming fresh air is first reduced in temperature by heat (cold) recovery and afterwards by the air-to-air heat pump. This results in supply air temperatures ranging from 12 °C to 22 °C depending on outdoor air temperature.

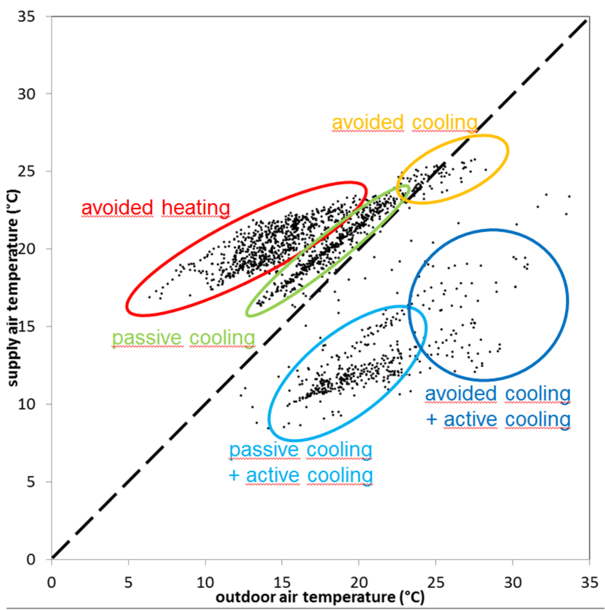

Figure 3: Monitoring results of supply air vs. outdoor air.

Figure 4 shows the correlation between the supply air and the indoor air, both in terms of temperature and absolute humidity. The sensors for this graph are positioned at another place as the internal sensors, so the values differ slightly. Without any cooling, the supply air is close to the indoor air, thanks to heat recovery. With passive cooling (heat pump off), the fresh air is supplied with a temperature 1 to 6 °C lower than the indoor air temperature. With active cooling (heat pump on), the fresh air is supplied with a temperature 6 to 12 °C lower than the indoor air temperature. Therefore, one could say that the sensible cooling power for the indoor air with active cooling can be doubled when compared to passive cooling.

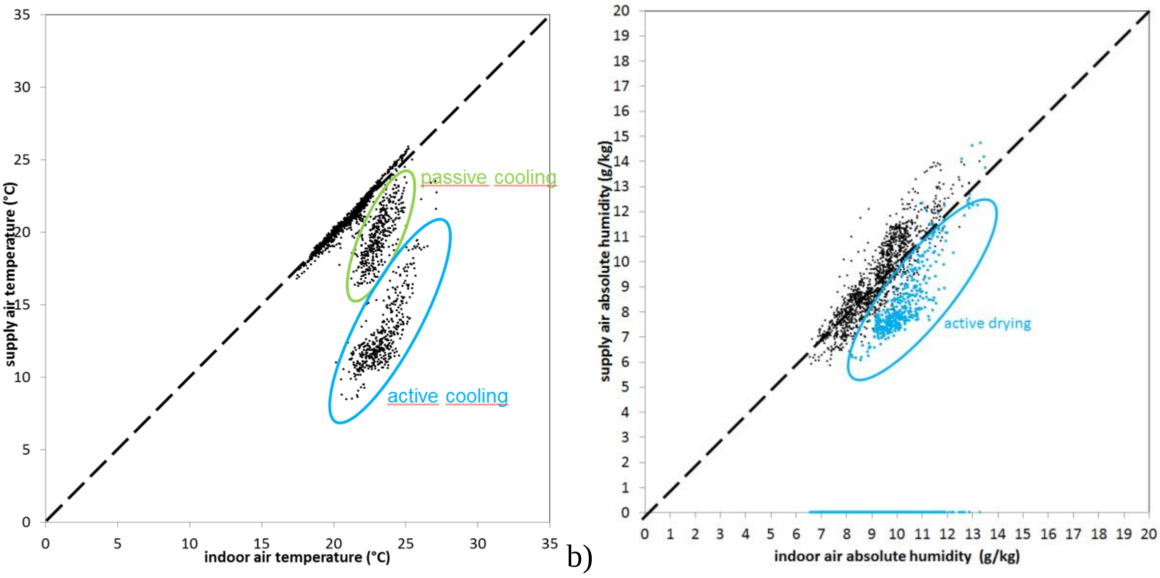

Figure 4: Monitoring results of supply air vs. indoor air: a) temperature, b) absolute humidity.

Figure 4b shows the absolute humidity of the indoor air and the supply air. When the heat pump is on, the dots are colored blue. It is obvious that the air-to-air heat pump is also supplying the fresh air with lower humidity than the indoor air (difference up to 3.5 g/kg), maintaining comfortable summer humidity levels in the house.

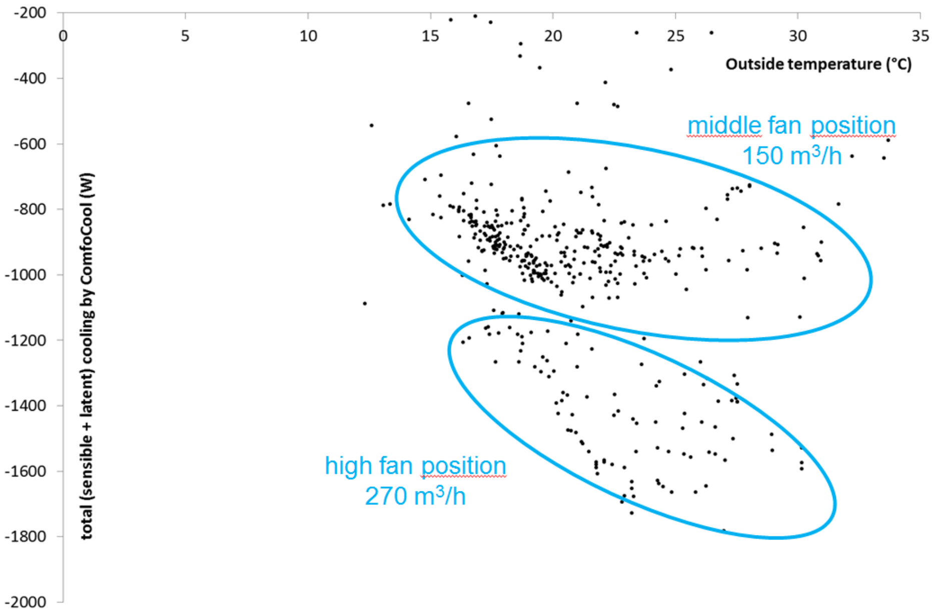

Figure 5: Total cooling power

The total cooling power (sensible + latent) of the heat pump has been calculated for the air-to-air heat pump by the difference in conditions in front of the evaporator (P-SUP) and after the evaporator (SUP) of the heat pump. Figure 5 shows the total cooling power in relation to the outdoor air temperature. Depending on actual temperature and humidity conditions, the total cooling power ranges between 700 and 1100 W for middle fan position (150 m^3/h) and ranges between 1200 and 1700 W for high fan position (270 m^3/h). The power consumption of the system was not monitored in this project. According to the specifications of the product, the heat pump has a power consumption of 800 W when active.

With the help of this cooling system, comfortable fresh air is supplied into the rooms, keeping the indoor temperatures throughout the whole house at a maximum of 26 °C as indicated by figure 4a.

4 WORKING AREA

A technical limitation of the air-to-air heat pump is to prevent damage to the condenser when it gets too hot. If the condenser temperature is reaching a safety limit, the fresh air flow rate is first increased to the maximum. If the safety limit is reached with maximum air flow rate, the heat pump is shut off intermittently to allow temporary cooling down of the condenser.

This effect is shown in figure 6 where the condenser temperature is shown in relation to the outdoor air temperature. With the heat pump shut off, the condenser is close to the outdoor air temperature. When the heat pump is on, the condenser takes temperatures roughly between 35 °C and 57 °C for outdoor air temperatures ranging from 15 °C to 30 °C. For outdoor temperature above 30 °C, the hourly values of the condenser temperatures start decreasing because of intermittent switching on and off of the heat pump.

Although the monitoring period did not show very warm periods, extrapolation of the monitoring data indicates that for high outdoor temperatures the air-to-air heat pump will not be active anymore. The combination of heat recovery ventilation and air-to-air heat pump cooling system is therefore intended for climates where the summer outdoor air temperatures are not often above 32 °C. This limitation holds only for the selected refrigerant and heat pump parts in the product used in this monitoring study.

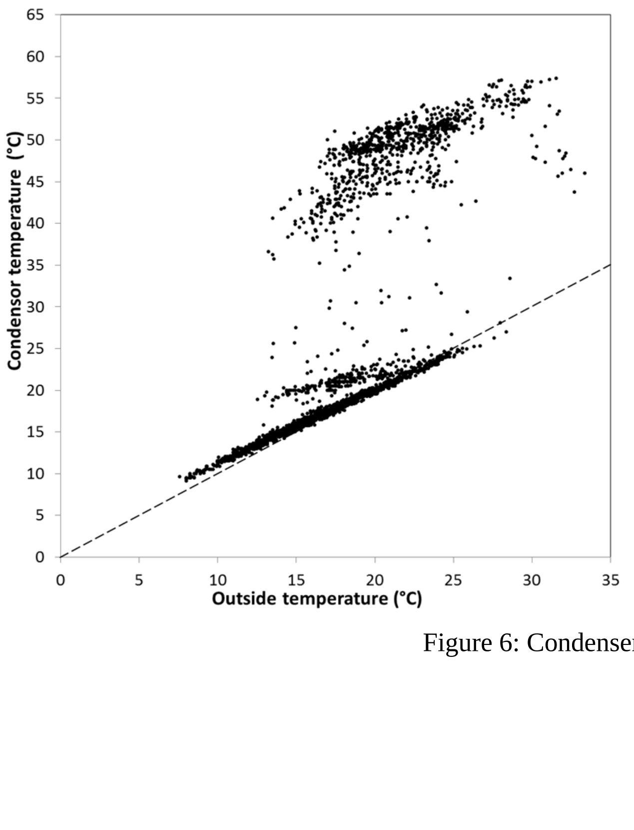

Figure 6: Condenser temperature

5 CONCLUSIONS

The heat recovery ventilation system in combination with an air-to-air heat pump cooling system is investigated by a summer monitoring period in a house in Emmeloord, The Netherlands. The ventilation system can act in various states that are explained by a state control diagram.

The monitoring results show that the various states produce a comfortable supply of fresh air throughout the whole building. When cooling is requested, the system automatically enters the optimal cooling strategy: passive cooling when possible, and active cooling when necessary.

The active cooling strategy can double the sensible cooling power for the house when compared to the passive cooling strategy, and it can be used in a wider range of conditions. The total cooling power of the air-to-air heat pump cooling system can reach up to 1100 W at 150 m^3/h and up to 1700 W for 270 m^3/h.

The total ventilation and cooling system has proven to provide a comfortable summer indoor climate with indoor air temperatures at maximum 26 °C for outdoor air temperatures up to 30 °C.

Opposite to circulation air-conditioning units, this ventilation/cooling combination not only brings fresh air to the house, but also provides comfortable indoor climate in all of the ventilated rooms in the house.