Moisture-proof Control of Balanced Ventilation Systems with Rotary Wheel Heat Recovery in Single Family Detached Houses

Svein Ruud[1*]

[1]RISE Research Institutes of Sweden, Energy and Resources, Box 857, SE-501 15 Borås, Sweden

Abstract. Single family houses with balanced ventilation have become more airtight, heat recovery efficiency has increased, and rotary heat exchangers have become the most common. All these changes combined increase the risk of moisture convection damage when it is very cold outside. However, theoretical studies have shown that it is possible to control airflows and rotor speed, in such a way that the risk of moisture damage is minimized. In collaboration with the ventilation industry, this project has developed a dynamic method of testing, in a controlled laboratory environment, how air handling units control systems can handle realistic variations of internal moisture generation in a moisture-proof way. The methodology means that an air handling unit with its control system is connected to a hardware-in-the -loop test facility that can in real time simulate an installation corresponding to a real house with different outdoor temperatures and internal moisture generation. The output from the test is how the moisture content varies in different rooms, extract air and supply air, as well as the variation of supply and extract air flow rates. Ventilation with different control strategies have been tested. In the project it has also been studied how the moisture recovery in rotary heat exchangers with different moisture-recovering properties varies depending on rotational speed, airflow, and outdoor temperature. It has then also been possible to verify previous theoretical calculations. The main conclusion is that by controlling the rotor speed and the air flows, the moisture contents in the indoor air can be controlled during periods of high moisture load.

1 Introduction

When introducing proven technology into new contexts, it is important not to cause unwanted effects such as moisture damage on the building envelope. Compared to the 1980s, Swedish single-family buildings with mechanically balanced ventilation systems have become more airtight, heat recovery efficiency has increased, and rotary wheel heat exchangers have become the most common. All these changes combined increase the risk of moisture convection damage when it is very cold outside [1]. The reason is that with balanced supply and extract air flow rates and at low outdoor temperatures, significant transfer of moisture from extract to supply air can take place in a rotating heat exchanger. If the building envelope is also very airtight, the infiltration and mixing of outdoor air with a low moisture content will be small. This means that the moisture content of indoor air can reach very high levels even at rather normal moisture release from the residents and their activities, e.g. showering and cooking. It can then for long periods greatly exceed the Public Health Authority's general advice that the increase of moisture content of indoor air during the winter season should not regularly exceed 3 g/m^3 [2, 3]. If at the same time, due to the thermal buoyancy effect, an over pressure occurs between the inner ceiling and the attic space, then a moisture convection damage is almost unavoidable. This because even very airtight building envelopes are not completely airtight.

During the last 25 years, Swedish single-family houses have mainly been equipped with exhaust air ventilation in combination with an exhaust air heat pump. In low-energy buildings of the passive house type, bi-directional air handling unit with heat recovery has been used for approximately the same period in very airtight and well-insulated houses.

The first Swedish passive houses were completed in 2001 in Lindås Park south of Gothenburg. They were carefully examined after 10 years in operation and no damage to the building envelope could be found [4]. In Lindås, however, they had counter-flow heat exchangers without moisture recovery. In addition, the outer parts of the well-insulated building envelopes consisted of moisture-resistant EPS insulation.

During the severe winter of 2009/2010, personnel at SP Technical Research Institute of Sweden became aware of several cases where there were problems with high humidity levels indoors. In all cases, it was single-family houses or apartment buildings with individual apartment units. Common to all were very airtight building envelope, closely balanced supply and extract air flows and rotary wheel heat exchangers.

In a presentation at the “Wood house days” 2017, experiences from several newer single-family houses with bi-directional air handling units and rotary wheel heat recovery were reported. They all had moisture

* Corresponding author: svein.ruud@ri.se

damages in the attic that was suspected to be due to the ventilation system [5]. The presentation also reported driving forces for moisture convection and how these are affected by the ventilation system.

However, theoretical studies [6, 7, 8, 9, 10, 11] have shown that it is possible to control airflows, and rotor speed, in such a way that the risk of moisture damage is minimized. In some cases, it may even be an advantage to use the rotary exchanger to provide a slightly increased indoor moisture content.

Since 2010, Swedish and Nordic manufacturers of ventilation units have observed the problem that excessively high moisture levels can occasionally occur in modern well-insulated and highly airtight detached houses. They have therefore developed different control strategies to deal with this. However, it is difficult to evaluate how it works as testing usually takes place in existing houses. It may then seem to work in most cases, but how well it works when it is really needed can be a bit difficult to evaluate. From experience, it is only in a smaller percentage of the households that the problems arise and only during certain, mainly very cold, periods. It is therefore a need for a methodology to test and develop the control strategies in a more structured way and independent of the season.

In collaboration with the Swedish ventilation industry, RISE has developed a dynamic method to test in a controlled laboratory environment how the control and regulation system of a bi-directional air handling unit with heat recovery can handle realistic variations of internal moisture generation in a moisture-safe manner. The methodology means that an air handling unit with its control system is connected to a test facility that can simulate in real time an equivalent installation in a real single-family house with different outside temperatures and internal moisture generation. This requires:
- a physical part that can create the desired air flows, air temperatures, air humidities, and external pressures around the tested unit.
- a virtual part with a mathematical model of a single-family house that from a given internal moisture generation profile can calculate in real time internal and external air flows and resulting moisture levels in different rooms as well as in the extract air.

2 Construction of test facility

2.1 Physical part to create air temperatures, air flows, relative humidity, and external pressures

The physical test facility that was built in the project consists of two parts, one to create desired outdoor air conditions and external pressures on the supply air side, and one to create desired extract air conditions and external pressures on the extract air side (see Figure 1).

Both parts are partially designed in the same way with a pre-cooling battery to lower the temperature to close to 0 °C and thereby lower the dew point as much as possible without the need for defrosting. Both parts are partially designed in the same way with a pre-cooling battery to lower the temperature to close to 0 °C and thereby lower the dew point as much as possible without the need for defrosting. This is followed by two parallel-connected cooling batteries that can lower both air temperature and dew point down to a minimum of approximately -20 °C. The parallel-connected cooling batteries are switched on alternately every hour to defrost the inactive cooling battery. Both parts have a filter cassette in the inlets to protect the cooling batteries from dust and then a duct fan to overcome the pressure drops in the cooling batteries, and to control the desired external pressure in the inlet to the air handling unit. On the outdoor air side, there is a smaller electric duct heater to fine-tune the outdoor temperature to the desired level. On the extract air side, there is a larger electric heater to raise the extract air temperature to approximately +21 °C, a steam humidifier to be able to quickly set the desired moisture content, and finally a balancing battery that stabilizes the extract air temperature by circulating water via a smaller tank.

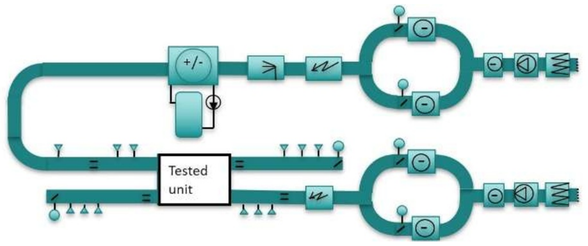

Fig. 1. Outline of the physical test facility.

The test facility is also equipped with measuring equipment for external pressures, air temperatures, relative humidity and air flows in all inlets and outlets of the air handling unit. This is partly as output values from the test, but partly also in several cases as input values for controlling the desired external pressures, air temperatures and relative humidity.

2.2 Mathematical model for pressures and air flows in the house model

The house model used was a two stories high single-family house that had a floor area of 150 m^2 and an internal air volume of 360 m^3. The floor plan of the house model used is shown in the Figure 2a and 2b.

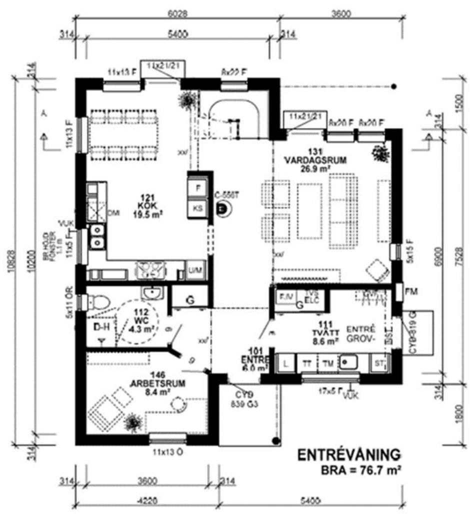

Fig. 2a. First floor of the modelled house.

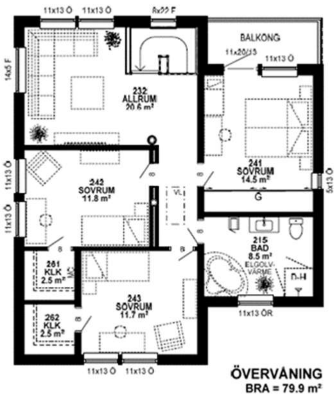

Fig. 2b. Second floor of the modelled house.

A mathematical model for how supply and extract air flows, outside temperature and the air density of the model house affect external pressures over the building envelope, in- and exfiltration air flows in individual rooms, as well as air flows between different rooms was first created in an Excel sheet according to Figure 3. In the test facility, this model description was then transferred to a MATLAB script.

		Constants			Calculated air flows (l/s)			
Floor	Room	Area (m²)	Volume (m³)	"Length" (m)	Extract	Supply	Infiltration	Range hood
1	Kitchen	19,5	46,8	9,3	-10,12		1,73	0,00
1	Living room	27,0	64,8	11,3		15,26	2,11	
1	WC	4,5	10,8	2,0	-10,12		0,37	
1	Entrance	6,0	14,4	1,8			0,34	
1	Working room	8,5	20,4	7,9		5,09	1,47	
1	Laundry	8,5	20,4	6,1	-10,12		1,14	
2	Common room	20,5	49,2	10,6		10,17	-0,65	
2	Hallway	4,5	10,8	0,0				
2	Bedroom 1	11,5	27,6	3,3		5,09	-0,20	
2	Wardrobe 1	2,5	6,0	1,6	-5,06		-0,10	
2	Bedroom 2	11,5	27,6	5,6		5,09	-0,34	
2	Wardrobe 2	2,5	6,0	3,2	-5,06		-0,20	
2	Bedroom 3	14,5	34,8	8,0		10,17	-0,49	
2	Bathroom	8,5	20,4	6,1	-15,18		-0,38	
	Sum	150,0	360,0	76,8	-55,66	50,86	4,80	0,00
	Comment:	"Length" is a measure of the length of the outward floor and ceiling angle for each room on the lower and upper levels, respectively, and is used to allocate infiltration and exfiltration in the different room volumes.						

Fig. 3. Calculation of air flows in different room volumes.

2.3 Creation of moisture generation profiles

A moisture load profile for two days with different load profiles per day has been developed. According to previous studies of moisture load in Swedish homes, the spread in moisture load between different single-family houses can be very large, with a spread of approximately 4 – 16 kg of water per day that is added to the room air. In this study, we have used a profile where we first start with a day with a high moisture generation of 12.3 kg/day, corresponding to a Sunday (se Figure 4). Then follows a day with a lower moisture load of 8.1 kg/day corresponding to a Monday where no one is present, and the moisture generation is very low for about 6 hours during the day (see Figure 5).

When creating the moisture generation, we have partially used results from a Norwegian SINTEF project financed by one of the participating air handling unit manufacturers.

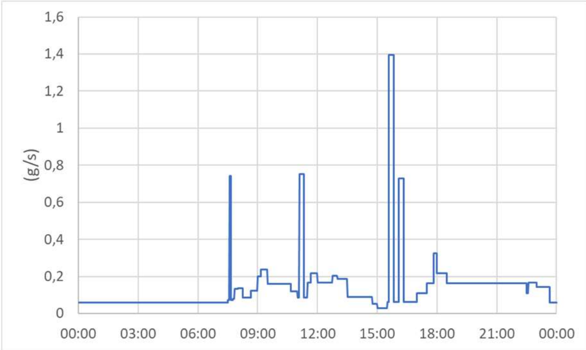

Fig. 4. Day (Sunday) with high moisture load (12.3 kg/day).

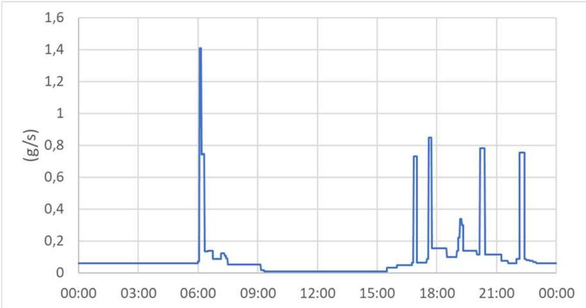

Fig. 5. Day (Monday) with low moisture load (8.1 kg/day).

Tests with showering have also been done in RISE research villa where the response in the extract air into the unit is slightly slower than in the model calculations (see Figure 6). This is probably because all humidification of the bathroom's air volume does not take place as directly as in the theoretical model. It is also a bit difficult to compare the measurements with the model calculations as the measurements took place at an outside temperature of about +15°C, while the model calculations took place at an outside temperature of -5°C and -15°C respectively.

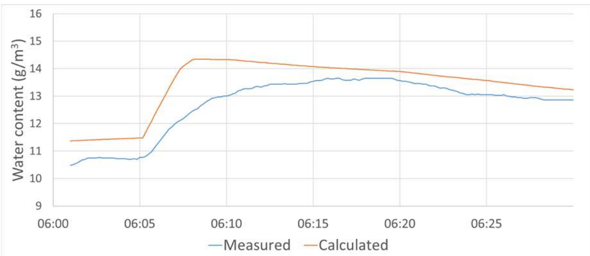

Fig. 6. Humidity increase in the extract air into the air handling unit in connection with showering.

When creating the moisture load profiles, a varying presence of people and different moisture-creating activities in the different room volumes are assumed. Figure 7 shows an example of part of a moisture load profile. Changes (marked in yellow) do not occur more often than every 5 minutes. Only times when changes occur need to be entered as input to the MATLAB script. There is also an underlying layer of input data that describes the various activities that give a summed moisture load per room volume.

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	Kitchen	Living room	WC	Entrance	Working room	Laundry
Time	Volume 1	Volume 2	Volume 3	Volume 4	Volume 5	Volume 6
(h)	0000	0001	0002	0003	0004	0005
17:00:00	0,0012	0,0018	0,0000	0,0000	0,0006	0,0000
17:05:00	0,0012	0,0198	0,0000	0,0000	0,0006	0,0000
17:15:00	0,0012	0,0198	0,0000	0,0000	0,0006	0,0000
17:30:00	0,0012	0,0018	0,0150	0,0000	0,0006	0,0180
17:35:00	0,0012	0,0018	0,0150	0,0000	0,0006	0,1120
17:40:00	0,0192	0,0018	0,0000	0,0000	0,0006	0,0940
17:45:00	0,0742	0,0018	0,0000	0,0000	0,0006	0,0140
17:50:00	0,0742	0,0018	0,0000	0,0000	0,0216	0,0140
18:00:00	0,0952	0,0018	0,0000	0,0000	0,0006	0,0140
18:25:00	0,0952	0,0018	0,0240	0,0000	0,0006	0,0140
18:30:00	0,0792	0,0018	0,0000	0,0000	0,0006	0,0140

Fig. 7. Example of aggregated moisture load profile (g/s) for the different room volumes on the 1st floor.

In a measuring and control computer, both airflow calculations and moisture generation are then linked together in a MATLAB script (see Figure 9) that calculates the moisture content in each room and how the moisture in the room air is transported between different rooms to finally end up in the extract air.

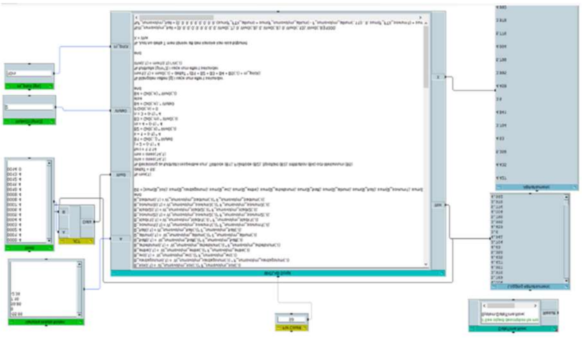

Fig. 8. Part of the MATLAB script used for the calculations.

The calculated humidity content in the extract air is then made in the physical part of the test facility and supplied to the real air handling unit under test.

2.4 Functional testing of the test facility

In the test facility, an external pressure is created that depends on measured air flows. The pressure increases quadratically with increasing flow much as if the unit were installed in a house with real ductwork. The calculation also includes the impact of the air tightness of the building envelope and how thermal buoyancy forces affect infiltration and exfiltration on both floors. Figure 9 shows how the external pressures change when a unit lowers its air flow from roughly 50 L/s to roughly 25 L/s. Once per hour, in connection with switching the cooling batteries, there is a short-term disturbance that lasts less than 30 seconds.

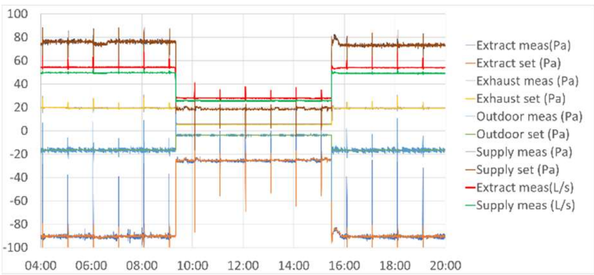

Fig. 9. External pressures as a function of air flow rates.

The major challenge in the project has been to control the humidity in the extract air in a stable manner within a wide control range and with the relatively rapid changes that are occasionally calculated based on the moisture load profile and the mathematical model of air and moisture movement in the modelled house. Figure 10 shows the set value, actual value and 5-minute moving average formation of the actual value for the relative humidity in the extract air during a test sequence are reported.

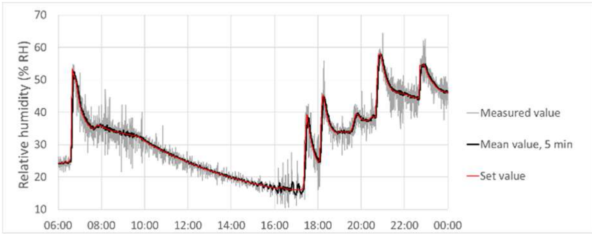

Fig. 10. Set value, actual value and 5 min average of the actual value for the relative humidity in the extract air.

As can be seen from Figure 11, the 10-second measured actual values fluctuate quite a bit compared to the desired setpoint. If, on the other hand, one look at 5-minute floating averaging of the actual values, there is a good agreement with the setpoint, but then of course with a certain delay. In the following, when we report measured relative moisture contents in extract air and supply air, as well as calculated moisture recovery rates, during the dynamic tests, this will be in the form of 5-minute average values.

It can also be noted that at actual values below 20 percent relative humidity even 5-minute average values are not completely stable and lower relative humidity levels than about 18 percent relative humidity cannot be created in the test facility in question. The latter, however, is not considered to have any major significance for the project as the focus is mainly on avoiding very high moisture levels, and partly as moisture recirculation in rotating heat exchangers is very low at low moisture levels in the extract air. The moisture content of the supply air will therefore be approximately as low as if it had been possible to create a moisture content as low as the setpoint in the extract air.

Figure 11 shows an example of the temperature control of the extract air temperature at a set value of +21°C. Fluctuations of up to ± 0.4°C can occur, but most of the time they stay within the range of ± 0.2°C. The temperature stability is judged to be good enough for the purpose of the project.

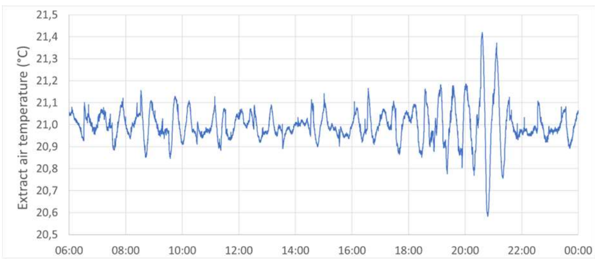

Fig. 11. Stability of the regulated extract air temperature.

Figure 12 shows an example of the temperature control of the outdoor air temperature at a set value of -15°C. Periodically when cooling batteries are switched, fluctuations of up to +1.5°C can occur, but most of the time they stay within the range of ± 0.5°C. The reason for the larger spread in air temperature on the outdoor air side compared to the extract air side is because there is no stabilizing equalization battery on this side. The temperature stability is still considered to be good enough for the purpose of the project.

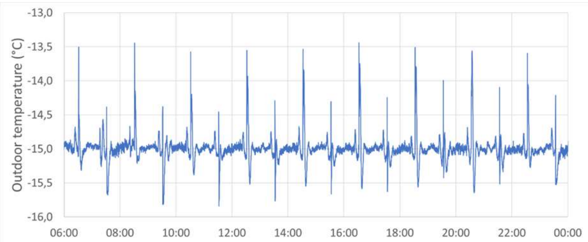

Fig. 12. Stability of the regulated outdoor air temperature.

3 Testing of air handling units in the test facility

3.1 Stationary tests of moisture transfer with different rotor materials

Since we had access to an air handling unit where we could test three rotors with different moisture transfer properties, many stationary tests were made with different temperatures, moisture contents and rotor speed, and in some cases also with other air flows. In this way, one could better understand how rotors with different characteristics can be controlled in the best way and we could also verify previous theoretical calculations. The tested rotors were as follows:
- ordinary condensing rotor (no surface treatment)
- hygroscopic coating for medium moisture recovery
- hygroscopic coating for maximum moisture recovery

In a condensing rotor the humidity transfer is made through condensation on cold surfaces and evaporation from warm surfaces. For hygroscopic coated rotors the humidity transfer is also made through adsorption and desorption driven by difference in humidity content in the air and in the coating of the rotor.

During the tests, the mass flow has been almost balanced, but in most cases with a 1–3 percent higher extract air flow. In most cases, supply and extract air flows have been around 50 L/s.

3.2 Dynamic tests with different air handling units, rotors, and control strategies

Several dynamic tests have been carried out with the developed methodology. The outside temperature has been kept constant at -15°C or -5°C. For two of three units their humidity control should have been tested. Due to delivery problems for one of these two units, we did not have time to test that unit's moisture control, which is based on increased flows. For both tested units we have studied temperature and humidity efficiency without humidity regulation and with and without reduced air flow during the day during day 2. In the tests of unit no. 1, we have also tested the influence of different air tightness of the building envelope and the influence of humidity control with reduced rotor speed at elevated humidity levels in the extract air. For unit no. 2, the tests have instead been carried out for the three different rotor types as above.

In some cases, we have tested day 1 and day 2 separately, but in most cases, we have tested them directly in connection with each other as a single test of two days. The latter means that the test time can be reduced significantly. During an evaluation, one can still choose to report only one day or both at the same time.

Sometimes we received negative moisture return values or values above 100 percent, which is of course unreasonable. This can partly be explained by the fact that the measurement uncertainty is relatively high, and partly by the fact that there is a certain time delay between when the moisture content changes in the extract air duct and when this change affects the measured value of the supply air. The calculation of moisture efficiency, on the other hand, takes place with values that are measured exactly at the same time. We have therefore used 5-minute floating average values when reporting relative moisture levels in extract air into the unit and supply air out of the unit, as well as when reporting humidity efficiency. Reported humidity and temperature effectiveness rates have been corrected for any mass imbalance in accordance with formulas given in the standard SS-EN 13141-7:2021.

During the dynamic tests, the units did not have balanced mass flows as prescribed in the test standard SS-EN 13141-7:2021, but instead with an imbalance of 5–10 percent, which is usually the case in a real installation to create a desired negative pressure. The external pressure drops have also been more realistic, higher and with a different distribution between inlet and outlet, than in a standard test according to standard SS-EN 13141-7:2021. Both units have been tested as they arrived from the factory/manufacturer and assembled in a way that corresponds to a normal installation but with the difference that, despite being intended for attic assembly, they have been placed in a warm space (such as the most units are located today).

If we had had more time and budget, it would have been desirable to also test external tightness and, above all, internal transfer of extract air to supply air. It had not affected the results but could have given some increased understanding of certain results. However, based on experience, one can assume an internal transfer of 5-10 percent.

4 Results

4.1 Results from stationary tests with different types of rotors

Selected results from stationary tests with different types of rotors can be found in the project report [12]. One conclusion from the stationary tests is that it seems more difficult to control the moisture recovery in a desired way by changing the rotor speed on a hygroscopic coated rotor, and more difficult the colder it is outside and the more hygroscopic it is. But even with a non-hygroscopic rotor, it becomes more difficult to control the moisture recovery when it gets very cold outside. It also becomes more difficult to control the moisture content, the higher the moisture content in the extract air. One should therefore preferably control the humidity control so that very high humidity levels never occur in the extract air into the unit, i.e. you should slow down the rotor speed and/or raise the air flow somewhat already at relatively low increases in the moisture content of the extract air. According to the stationary measurements, a reduction in the rotor speed results in a more effective reduction of moisture recirculation than a mere increase in the air flow. A combination of reduced rotor speed and increased flow gives an even more effective reduction, but it also means greater complexity to control two parameters. Even if many of the static tests are extreme cases that rarely occur, they are still of interest to understand how a rotor works when they do occur and how best to control to keep the moisture levels down. The dynamic "real" process that is sought in this project can also look different on the time axis, as time is always of great importance when it comes to moisture loading.

4.2 Results from dynamic tests

4.2.1 The repeatability of the methodology

Test day 2 was repeated approximately one week apart with the same unit and rotor, and with as similar external conditions as possible. The rotor was of type B with hygroscopic coating for medium moisture recovery. At the first test occasion, slightly lower moisture contents are generally obtained than at the second test occasion, especially at the lower moisture contents (see Figure 13). Because the external conditions given in the table above were so similar, we have not been able to find any explanation for the deviation. However, the appearance of the curves is very similar and the differences between the two tests are still so small that the repeatability of the methodology is deemed acceptable.

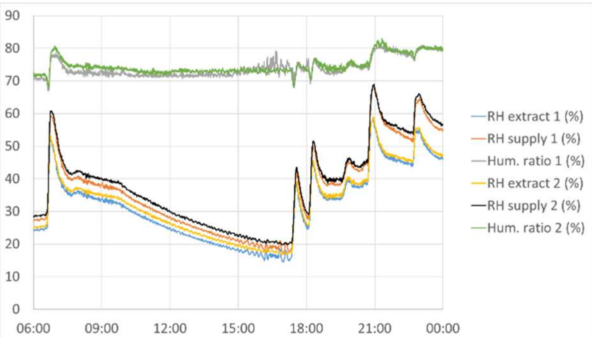

Fig. 13. Results from repeating the same test with the same unit and rotor.

4.2.2 The influence of the air tightness of the building envelope

As part of each test, calculations of infiltration and, where applicable, exfiltration through the building envelope, as well as pressure drop across the building envelope, where the calculated pressure between the inner ceiling and insulated wind is deemed to be the most critical, are included. The input data for this calculation is the building envelope's specified air tightness, the building envelope's specified enclosing inner surface, the outside temperature, and measured supply and extract air flows where, in the calculation, the supply air is assumed to be heated to the same temperature as the extract air. In addition, several assumptions about the distribution of the air leaks in the building envelope had to be made. The pressures and flows calculated in the program and reported in the diagrams below therefore give an indication of which pressures and flows that can occur over the building envelope. Tests were made at an outdoor temperature of -15 °C, an extract air flow of approximately 53–54 L/s and approximately 7–8 percent higher mass flow on the extract side. The air tightness of the building envelope was in the first test 0.30 l/(s·m^2) and in the second test 0.15 L/(s·m^2). The results from the tests (see Figures 14 and 15) show that at -15 °C outside temperature, an air density of 0.30 L/(s·m^2) is not enough to ensure a negative pressure between the inside of the ceiling at the second floor and the attic. This despite a relatively high mass imbalance. This will lead to some exfiltration through the building envelope and condensation and moisture damage may occur in the attic space. The overpressure on second floor is because the thermal driving force at -15°C outdoor temperature becomes greater than the negative pressure created by the ventilation unit. When we change the air tightness to 0.15 L/(s·m2), we manage to maintain a negative pressure at ceiling level on the second floor.

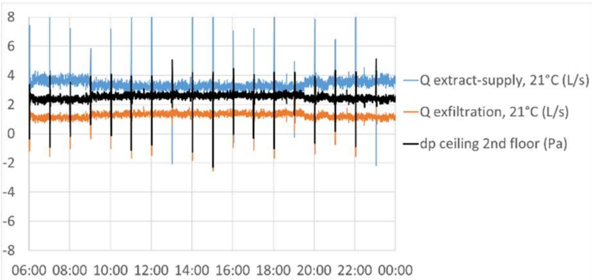

Fig. 14. Flow imbalance, exfiltration and pressure difference at outdoor temperature -15 °C and air tightness 0.30 L/(s·m^2).

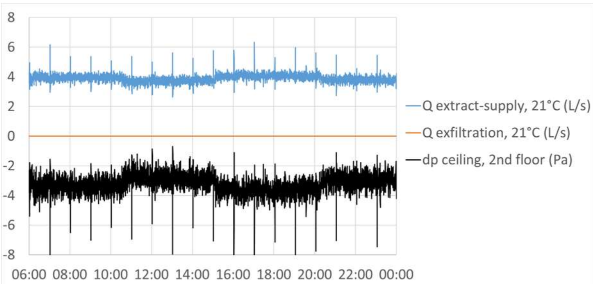

Fig. 15. Flow imbalance, exfiltration and pressure difference at outdoor temperature -15 °C and air tightness 0.15 L/(s·m^2).

Another way to create the desired negative pressure would have been to further increase the flow imbalance, but this would lead to an increased infiltration flow and poorer overall energy efficiency of the ventilation system. For a one-story house, you could have had a less airtight building envelope and/or a smaller imbalance in air flows and still maintained a desired negative pressure. With a gradual increase in the outdoor temperature, the excess pressure would eventually change to a negative pressure. The most energy efficient way to handle this in a moisture-proof way, apart from a very airtight building envelope, is then to vary the flow imbalance as a function of the outdoor temperature and to determine the necessary flow imbalance depending on the building envelope's airtightness and the number of floors. In practice, this can be done by adjusting the flow imbalance with the windows closed on a cold and windless day so that a certain negative pressure is achieved at ceiling level. In the following presentations we have consistently used an air tightness of 0.15 L/(s·m^2).

4.2.3 Influence of rotors with different hygroscopic properties

For unit no. 2, three rotors with different hygroscopic properties according to section 3.2 have been tested to see how they function during day 1 with a high moisture load, and during day 2 with a lower moisture load and absence for just over 6 hours during the day. For reference, we have also manipulated the MATLAB script so that we could do tests corresponding to a plate heat exchanger. Tests have been made both at -5°C and at -15°C. The rotors have only been tested at a maximum speed of 12 rpm. For rotor type C with hygroscopic coating for maximum moisture recovery, the tested moisture levels already at -5°C outdoor temperature were too high in several rooms (close to 100 %RH).

4.2.4 Dynamic test of a unit with humidity control

Moisture regulation in unit no. 1 is achieved by reducing the rotor speed. The rotor was a condensation rotor type A. The result of the test is presented in Figure 16. During the test, which lasted for almost two days, we also had a period of lowering the air flows during day 2. The outside temperature was kept constant at -15 °C.

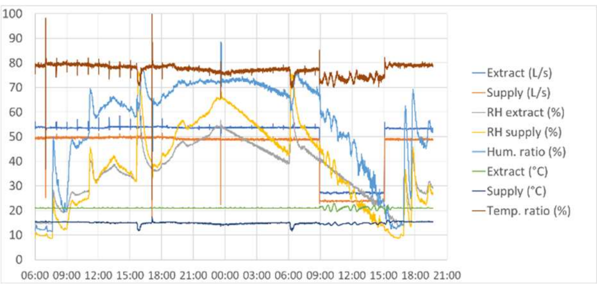

Fig. 16. Measured values around a unit with humidity-controlled rotor speed at -15°C outside temperature.

One can clearly see in Figure 16 that the increase of the measured moisture efficiency is attenuated, and the temperature efficiency is decreased when the moisture content of the supply and extract air exceeds a certain level. But when compared with a test for another rotor type A, only a marginal reduction in the highest moisture contents is obtained. It can be suspected that during the development of the control function, the developer did not know how far down in rpm one could go with relatively maintained temperature efficiency. Since it is a type A condensation rotor, the moisture control would also have been more effective according to the stationary measurements if the moisture return had been controlled before it became so high. The moisture-reducing function has only been tested at -15°C and, according to previous results, would probably have worked better at -5°C. Measured oscillations at low flows are judged to be due to some instability in the test facility.

More dynamic test results can be found in the project report [12].

5 Conclusions

The testing methodology developed in this project gives manufacturers of air handling units and their developers of control systems the opportunity to relatively quickly and in a repeatable way test and further develop their moisture control. Above all, this applies when they use rotary heat exchangers, but in certain aspects such as pressure control and reduced flow during absence, the methodology can also be of interest for non-regenerative heat exchangers.

By controlling the speed of a rotating heat exchanger, and partly by changing the air flows, you can largely avoid excessive moisture levels occurring indoors in winter. Rotors with hygroscopic coating are more difficult to control and are not recommended for use in single-family dwelling. The project results also show that reduction of high moisture levels by reducing the rotational speed of the rotor can be done without any significant deterioration of the energy performance. This is because the moisture efficiency drops faster than the temperature efficiency when the rotor speed is lowered. Moisture control can also be achieved by increasing air flow rates and/or increasing the air flow imbalance, but this is a less energy efficient control strategy.

However, there is a limit to how much you can reduce the moisture levels by controlling the rotor speed, and in the case of very high internal moisture loads, even with a plate heat exchanger you cannot avoid that high moisture levels can occasionally occur in certain rooms with high moisture loads. It is therefore important, regardless of the type of heat exchanger, to maintain a negative pressure over the building envelope.

The main prerequisite for being able to maintain a negative pressure over the building envelope is that it is sufficiently airtight. How airtight it needs to be is dependent on the surface area of the building envelope, the number of floors, the outside air temperature, and the airflow imbalance. The most energy efficient way to handle this in a moisture-proof way is to vary the flow imbalance as a function of the outdoor air temperature.

The necessary air flow imbalance at a certain outdoor temperature can be found by adjusting the flow imbalance with the windows closed on a cold and windless day so that a certain negative pressure is achieved at ceiling level.

By decreasing air flow rates during periods of no occupancy you can also reduce the number of hours with very low moisture levels, especially in combination with a regenerative heat exchanger. During longer periods without presence and with low internal moisture release, however, even with a rotating moisture-recovery heat exchanger and low air flow rates, there will be very low relative moisture levels in the indoor air when it's very cold outside. From a health point of view, it does not matter that much when no one is present in the house and the moisture levels can relatively quickly increase again when residents come back into the house again.

To reduce the number of hours with very low moisture levels, moisture recovery with a rotary heat exchanger is a much more cost- and energy-efficient solution than active humidification. Reducing the air flow during absence to further reduce the drying out of the room air also means energy savings.

In the air flow model used, it is assumed that the kitchen has a range hood with carbon filter and a recirculating air flow. This is an increasingly common solution in very airtight houses, partly to save energy but above all to avoid extremely high negative pressures. Compared to an extracting range hood, this means an increased addition of moisture, and that the supply of dry replacement air via leaks in the building envelope is reduced. Some of the results from the dynamic tests made in the project are therefore partly only relevant for the assumed range hood solution.

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