Ventilation Strategies in Greenland

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Abstract

Arctic winters are long and cold. When temperatures drop deep below freezing point, the occupants of Arctic dwellings become hesitant to opening windows to avoid cold draught. Natural vents are typically sealed. Mechanical ventilation is either not existing or comprises of bathroom fan and range hood. Air tightening of the building envelope to prevent draught results is a lack of makeup air for the extraction fans. This leads to reduction of air change in the majority of dwellings. One consequence of this reduction is poor indoor air quality (IAQ); another may be an increase in moisture levels sufficient to damage the construction. Current Greenlandic building code does not require use of complex ventilation systems. Lack of experience and requirements together with the high costs of construction in Greenland typically cause ventilation systems to either be excluded from construction projects, or to be included as bare minimum systems. This project mapped three ventilation solutions, two renovations and one new home. Measurements taken after the solutions had been installed showed that the IAQ improved significantly, and occupants reported increased comfort. The systems were capable of continuous operation throughout the Arctic winter. Installation of the mechanical ventilation proved itself to be an efficient solution to the IAQ problem in Greenland.

1. introduction

The design, construction, and operation of homes in Arctic regions presents many challenges. The lack of resources (both human and material), geographic remoteness, and extremely harsh climate are among the most significant ones. In all Greenland, with its population of 56,000 inhabitants living in 15 towns and 56 settlements [1,2], there are no exceptions to this phenomenon. The only local construction material is rock. All the other materials and technologies needed in construction industry must be imported. Skilled labor is frequently unavailable and must be brought from out of the country (mostly from Denmark). There are no roads between towns so all transportation is by air or sea conveyance, which substantial affects the prices of goods, including construction materials.

Climate

The Greenlandic climate varies along the coast. In general it can be described as cold and dry. Summers are short and cool with long lasting daylight and large solar gains. Winters are long and extremely cold with temperatures dropping below -30 °C in many places. The cold air has a limited ability to carry moisture so even though the relative humidity may be high, the actual moisture content is frequently lower than 1 $g_{water}/kg_{dry,air}$. In addition to low temperatures and humidity, Greenlandic coast often experiences strong winds. The famous katabatic wind from the icecap that regularly hits the east coast of Greenland reaches speeds of up to 80 m/s.

Current situation

In our studies in Sisimiut [3,4], we found that ventilation equipment (when present) is typically limited to an exhaust fan in the bathroom, range hood, and wall mounted fresh air valves in bedrooms and living rooms. Fresh air valves are source of cold draft and often will be sealed by the occupants to avoid discomfort from cold draught. Additionally the developing construction techniques, use of plastic vapor barriers and the intention to reduce heat loss through the building envelopes, lead to increased air tightness of buildings. As a result the air change inside homes is limited. As found in previous study [4], the air change is lower in newer buildings since ventilation strategies typically remain unchanged.

Reduced air change combined with the traditional lifestyle that includes slow cooking, drying laundry inside, and bringing wet outdoor clothing inside often leads to elevated concentrations of moisture and other pollutants such as CO_2, volatile organic compounds (VOCs), or tobacco smoke. High humidity increases the risk of dust mite growth and may lead to mold growth in the traditional wooden structures [5-7]. Dansk Standard DS/EN 15251 [8] specifies that the indoor RH should be kept between 30% and 50% to minimize its negative effects on human and structures. The effects of increased CO_2 and VOC concentrations on human have been described in the past for example [9-12]. Due to ease and reliability of CO_2 measurements carbon dioxide is commonly used as an indoor air quality indicator. Although different national recommendations and standards exist that suggest indoor CO_2 levels [8,13] a commonly used CO_2 limit for indoor space is 1000 ppm. In our previous study [3], a 34% of questionnaire respondents confirmed that they smoke inside their dwellings. Assuming low ventilation rates, the concentration of environmental tobacco smoke in those dwellings is likely elevated. Considering the amount of time people spend inside their homes during the long harsh Arctic winters, the effect of poor IAQ on their health is considerable.

Code requirements

The current building code in Greenland, which is from 2006 [14], sets the following requirements on ventilation of dwellings:

The minimum air change of a dwelling shall be 0.5 h^{-1}. Kitchens should have an exhaust that operates at a rate of 20 l/s either via a range hood or other mechanical exhaust, or by natural extraction with an area at least 200 cm^2. Bathrooms should have an exhaust that operates at a rate of 15 l/s via either mechanical exhaust or natural extraction with an area at least 200 cm^2. Separate toilets and other wet rooms (such as laundry) should have an exhaust that operates at a rate of 10 l/s via either mechanical exhaust or natural extraction with an area at least 200 cm^2. The supply of fresh air can be mechanical or via openable windows or fresh air valves providing a free opening of an area of 30 cm^2 per each 25 m^2 of living area for buildings with mechanical exhaust and 60 cm^2 per each 25 m^2 of living area for buildings with natural exhaust. Buildings with more than four apartments must be equipped with mechanical ventilation. That can however consist of mechanical exhaust and natural intakes.

New solutions

As described in the previous section, the current building code in Greenland does not even require the use of mechanical exhaust (never mind more complex ventilation systems) in homes with fewer than four dwellings. From our experience based on discussions with local contractors, complex ventilation systems are often suggested to investors even though they are not required. However, investors usually reject them because of the systems' higher costs, investors' lack of knowledge, and investors' bad past experience with such systems. Nevertheless, there are a few cases of new or renovated dwellings that were equipped with more complex ventilation systems. Efficiency, IAQ as well as satisfaction of the users varies among those systems. Heat exchangers that allow for certain level of moisture recovery are being tested with the intention to increase the otherwise very low relative humidity (RH) that occurs once the dwellings are ventilated properly with the extremely dry outside air.

This paper presents our experience with ventilation systems in three different homes. Two of the homes are existing row houses that were renovated for better IAQ. The third building is a newly built single family home. These systems represent what could be called the state of the art solutions currently used in small to medium Greenlandic dwellings (buildings with less than four apartments).

2. Cases

Building 1 – Row house renovation – Rotary heat exchanger

This building is a type row house in Tuapannguanut – Sisimiut built in the 1980s (Figure 1). It consists of two floors. In a ground floor there is an entrance, laundry, living room, and kitchen. In the second floor there are two bedrooms and a bathroom (see the floor plans in Figure 2). The floor area of the home is approximately 70 m^2. The house is occupied by a family of seven (two adults and five children). The original ventilation system consisted of fresh air valves (FA) in bedrooms and living room, range hood, and two vertical ventilation shafts from bathroom and laundry room (EA) (see Figure 2).

Figure 1. Building 1 – view

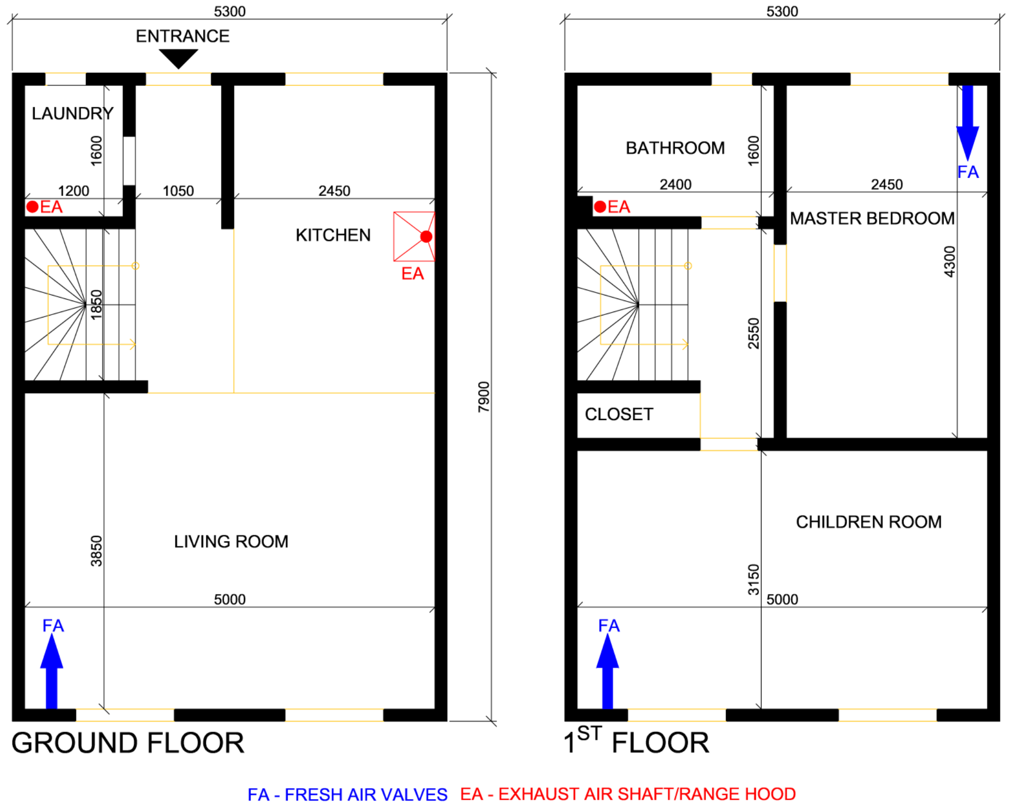

Figure 2. Building 1 - Floor plans

It was decided to renovate the building's ventilation system and install a state of the art balanced ventilation system using a ventilation unit with a rotary heat exchanger that allows a continuous operation down to -30 °C. Although the heat recovery wheel is not regenerative (coated with desiccant to accommodate moisture recovery), some degree of moisture recovery can be expected given the nature of the heat recovery principle. The condensed moisture from the exhaust air can remain stuck in the wheel channels and evaporate to the supply air afterwards. According to the manufacturer, heat recovery efficiency reaches up to 86%. The unit is equipped with an electric after heater. The heater ensures that the supply air is always at a comfortable temperature (above 18 °C) even during the coldest periods. The character of the renovation and space solutions of the house did not allow for use of large metal ductwork. Instead, semi-flexible small diameter air channels with smooth inner surface were chosen. The installation and maintenance (cleaning) of such system is easier than the conventional system with large diameter spiro ducts. In particular in renovation projects. The schematic layout of the ductwork can be seen in Figure 3. Fresh air is supplied into the two bedrooms and to the living room. Exhausts are placed in the kitchen, bathroom, and laundry. The range hood remained connected directly to the outside and was not part of the installation. The existing fresh air valves on the façade were sealed with a PUR foam.

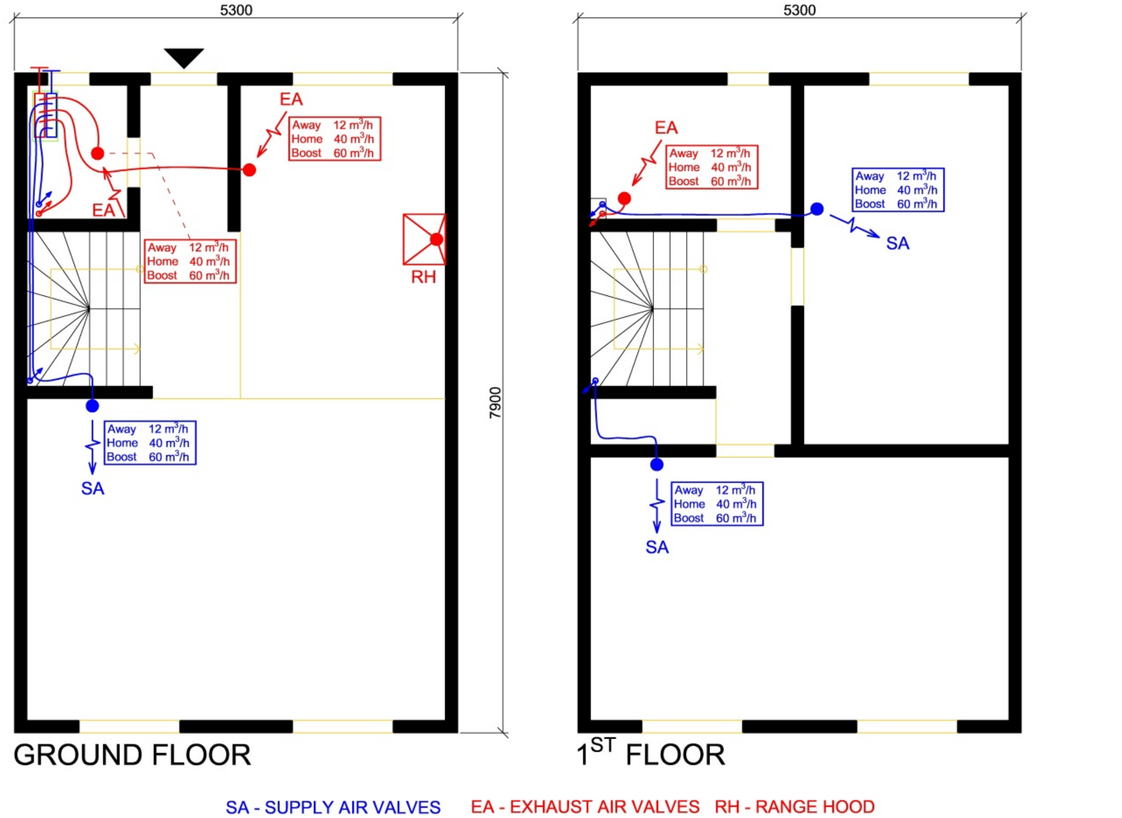

Figure 3. Building 1 - Ventilation schematics

The ventilation unit is equipped with a simple controller that allows the users to choose from three operation modes (Table 1). The occupants do not have the option of turning the ventilation system completely off. In addition to the controller there is a hygrostat placed in the bathroom that activates the "Boost" mode when RH exceeds 60%.

Table 1. Ventilation unit modes.

Mode	Speed [%]	Air flow [m^3/h]	Air change [h^{-1}]
Away	25	36	0.19
Home	55	120	0.63
Boost	80	180	0.95

The measurements of IAQ (T, RH, and CO_2) and interviews with the occupants took place before and after installation of the ventilation unit during winter period. The ventilation unit was set to mode "Home" during the entire measurement period.

Building 2 – Newly build single family home – Rotary heat exchanger

The second building in our study is a newly built (2018) single family home. It is a 120 m^2 wooden structure on concrete foundations. Its single story consists of three bedrooms, two bathrooms, an entrance and a kitchen/dining/living room. The building was designed by a Greenlandic consulting company with energy efficiency and sustainability in mind. Therefore, the U-value of the envelope is significantly lower than the building code requirements and there is a complex ventilation system. The building is ventilated by balanced mechanical ventilation system with ventilation unit with rotary heat exchanger (the unit is identical to the one used in Building 1). Similarly to Building 1, the ventilation channels are made of semi-flexible plastic ducts of small diameter (d_{in}= 63 mm). Figures 4 and 5 show ventilation schematics, and Figure 6 shows the connected ventilation unit.

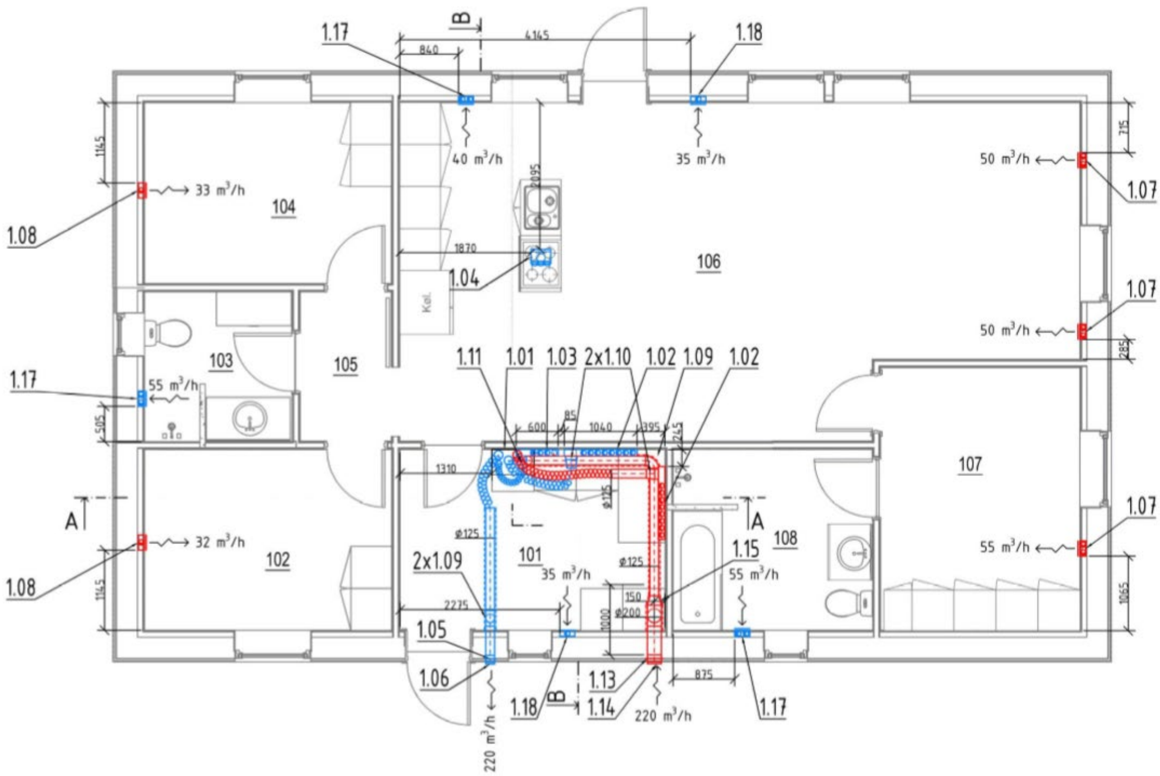

Figure 4. Building 2 - Ventilation schematics - Floor plan

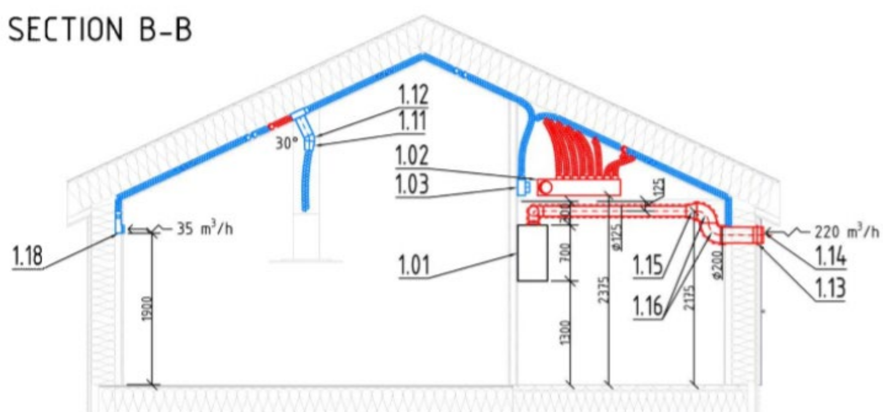

Figure 5. Building 2 - Ventilation schematics - Section

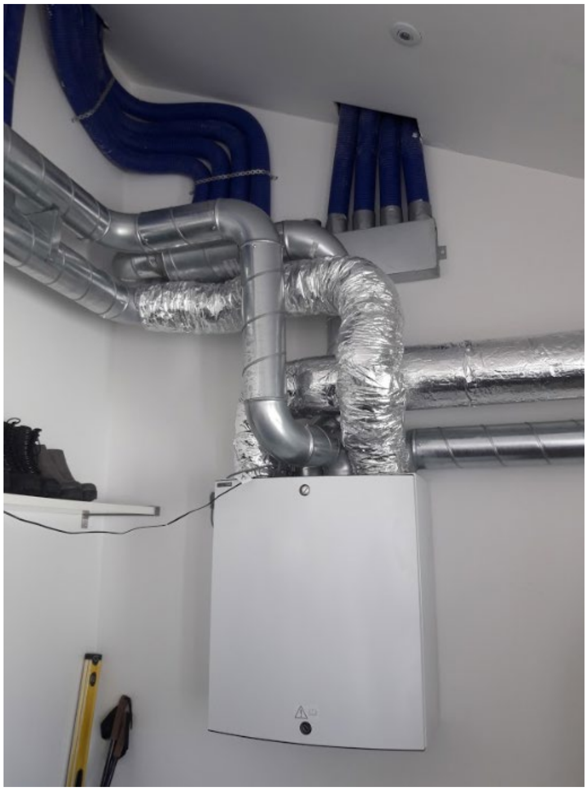

Figure 6. Building 2 - Ventilation unit

In this building, the range hood is connected to a dedicated fifth port in the central ventilation unit. The extract air from the range hood is moved by the extract fan in the ventilation unit. However, it bypasses the heat exchanger to avoid spread of odors and moisture from cooking and to protect the rotary heat exchanger from grease. Also this unit is equipped with a simple controller that offers the users to choose from three regimes (Table 2).

Table 2. Ventilation unit modes

Mode	Speed [%]	Air flow [m^3/h]	Air change [h^{-1}]
Away	30	30	0.11
Home	85	220	0.80
Boost	100	305	1.10

The occupants were interviewed about their user experience with the ventilation system and perceived IAQ. Additionally, temperature, RH, and CO_2 concentration were monitored in the master bedroom for a period of 1 week during the winter period. The ventilation unit was set to mode "Home" during the entire measurement period.

Building 3 – Row house renovation – Decentralized ventilation

Building 3 is a two story row house built in 1980s. The total floor area is 60 m^2. In the ground floor there is an entrance, bathroom, kitchen, and living room. The second floor is comprised of two bedrooms and two storage rooms (see Figure 7). The building is occupied by a family of two adults and two children. The original ventilation principle was identical to the one in Building 1. Fresh air valves (FA) operate in combination with mechanical range hood and natural exhaust from bathroom via ventilation shaft (EA).

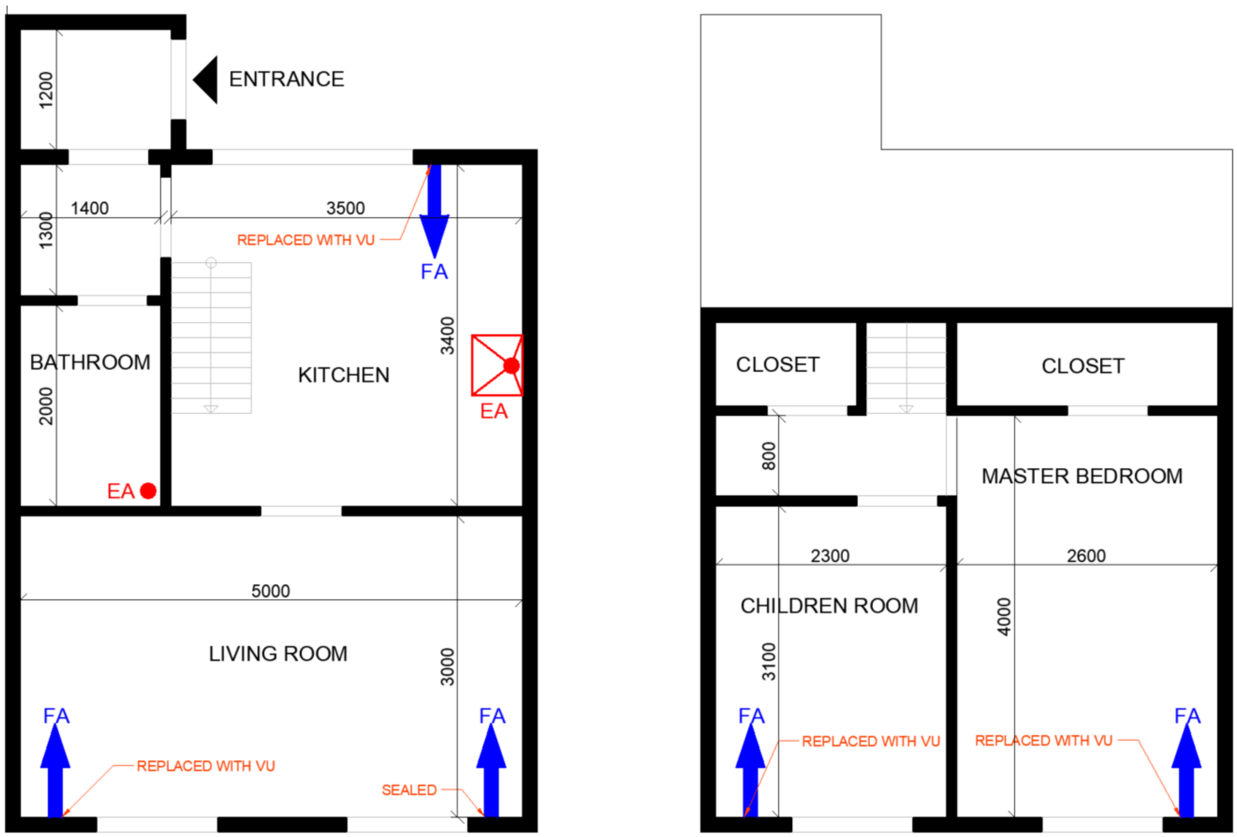

Figure 7. Building 3 - Floor plans

In this case, the renovation consisted of installation of four decentralized (one-room) ventilation units (VU) in the façade (Figure 8). Existing fresh air inlets were used to accommodate the new ventilation aggregates (Figure 7). The existing range hood and natural ventilation shaft in the bathroom remained unchanged.

Figure 8. Schematics of the decentralized ventilation unit

The ventilation units run in two cycles. Cycle 1 – the built-in ventilator blows the fresh air into the building. Cycle 2 – The direction of the fan changes and air is extracted out of the building. The cycles switch at the interval of 70 s. Inside the device, there is a ceramic-based element that acts as a heat and moisture recovery. It accumulates heat and moisture of the extract air (during cycle 2) and reintroduces it to the fresh air (during cycle 1). To maintain pressure balance inside the house, the four units are synchronized in a way that when two of them run in cycle 1, the other two run in cycle 2.

The speed of the ventilators can be adjusted in three steps as shown in Table 3. The provided air change was calculated assuming two of the ventilation units in cycle 1 and two units in cycle 2.

Table 3. Ventilation speeds

Speed	Air flow of one unit [m^3/h]	Air change [h^{-1}]
1	10	0.14
2	20	0.28
3	30	0.42

The IAQ in the master bedroom was monitored before and after the installation. The temperature of the air supplied via the unit was measured in 2-second intervals to evaluate the efficiency of the heat recovery and identify risks of cold draught. Additionally the occupants were interviewed to get an overview of the user satisfaction with this solution. During the measurement period, all units were set to the maximum speed.

3. Results

CO_2 concentrations in bedrooms

Figure 9 shows the CO_2 concentrations measured in the master bedrooms of the three case homes alongside the measurements from our previous study. Note that each curve from our past study represents multiple dwellings whereas the new curves each represents one particular case. For all cases, only night measurements (21:00 – 07:00) were included.

Substantial improvement can be seen in case of renovation in Building 1 where the average nighttime concentration dropped from 3312 ppm down to 1471 ppm. The CO_2 concentration remains higher than recommended for the entire night due to high occupancy (this bedroom sleeps two adults and one child). However, the extreme concentrations above 2000 ppm were mitigated by the ventilation system. Also in Building 3 the improvement is significant as the CO_2 concentration dropped from 1141 ppm in average to 743 ppm. However, note that this bedroom was only occupied by one adult during the entire test period. Therefore, the CO_2 concentration was generally low. The ventilation unit however, ran on a 100% of its maximum speed. Building 3 as a new building performs very well with a CO_2 concentration below 1000 ppm for over 70% of the nighttime in a two-person bedroom. None of the case buildings experiences CO_2 concentrations higher than 2000 ppm during the nighttime. In contrast, our previous study shows that existing buildings have nighttime concentrations above 2000 ppm for at least 10% of the time. Moreover, the newest buildings exceed this level for over 20% of the nighttime.

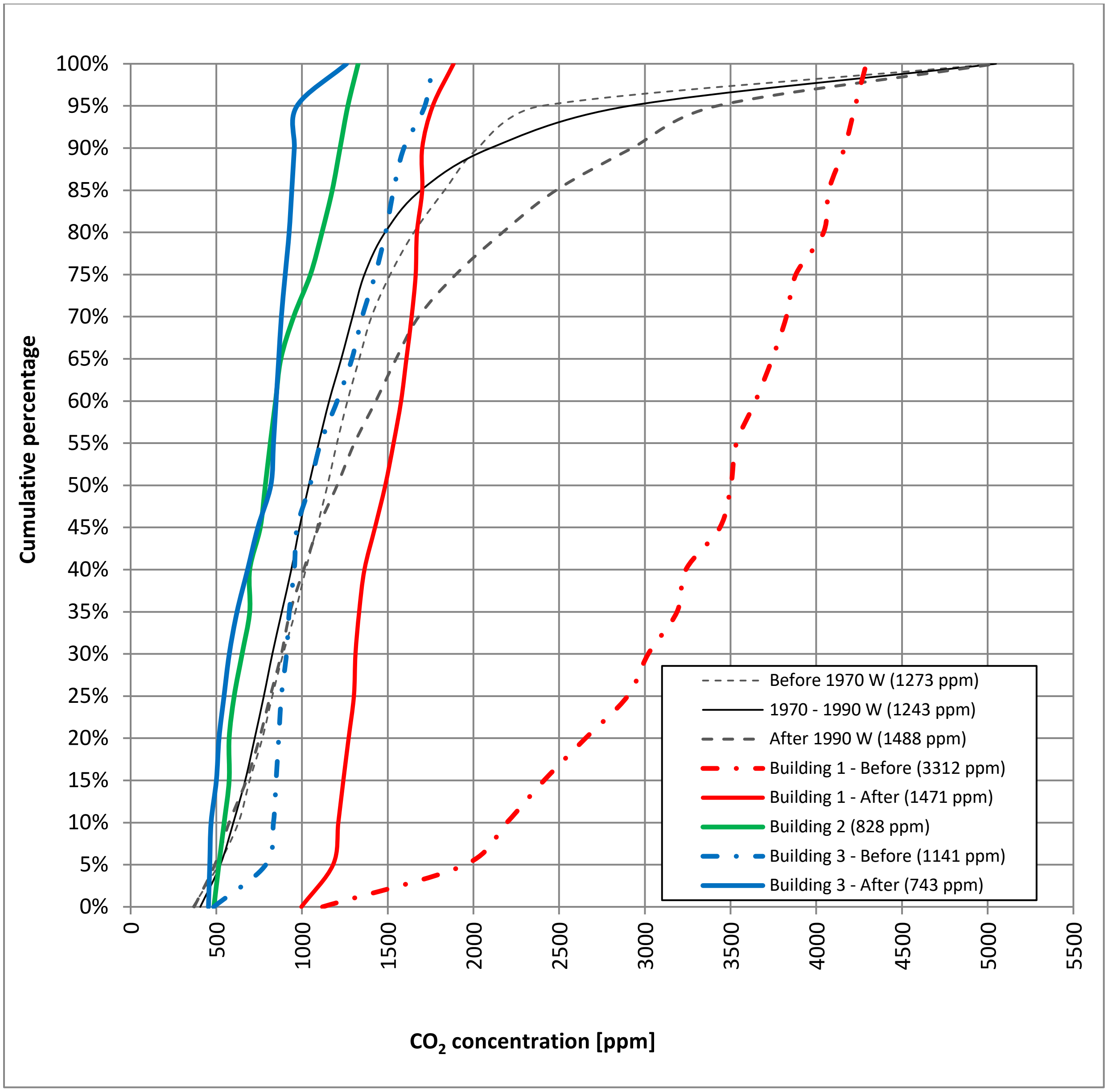

Figure 9. Cumulative percentage distribution of CO_2 concentrations in the bedrooms during nighttime compared with results of our previous study [4]

Humidity in the bathrooms

The highest RH peak levels in the home are typically reached in bathrooms as the room volume is relatively small and the generation of moisture is large during bathing. Figure 10 shows two shower events that were captured in Building 1 before and after renovation. From the graph one can see that although the RH peaks at higher level in situation after the ventilation unit was installed (80% versus 73%), it only takes 27 minutes before the RH falls to the recommended range. Before renovation, the RH remained above 50% for nearly 2 hours.

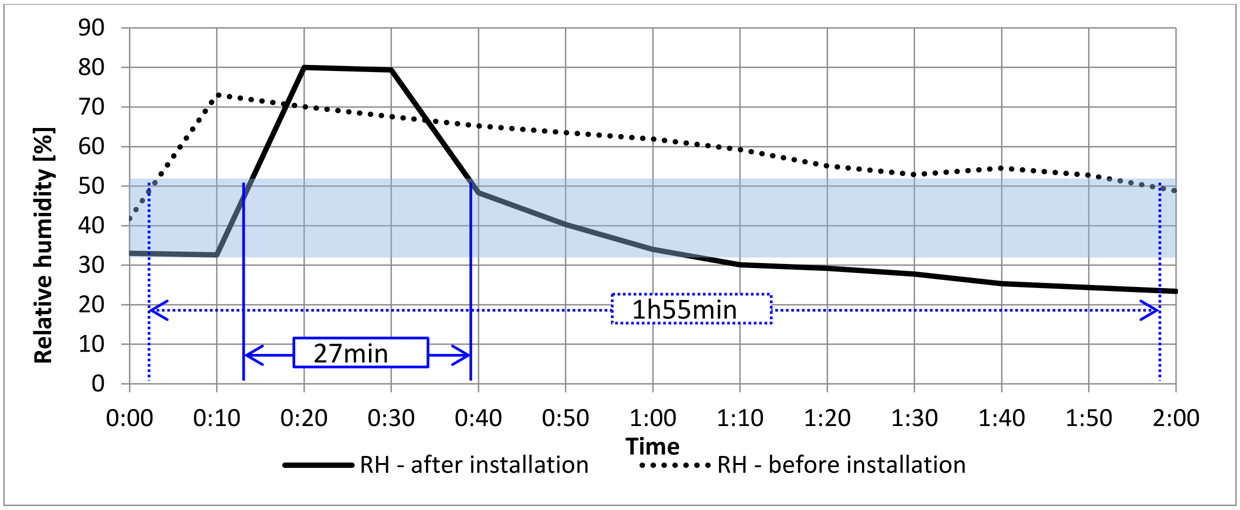

Figure 10. Building 1 - RH at shower events before and after installation

Figure 11 shows the Figure 9 relative humidity measurements in the bathrooms as cumulative percentages over the entire monitoring periods. It can be seen that the RH only exceeds 50% less than 5% of the time in both mechanically ventilated bathrooms. In the two bathrooms before renovation (Building 1 and 3) the 95 percentile reaches 48% and 53% relative humidity. It is also obvious that the introduction of ventilation to Building 1 further reduces the RH.

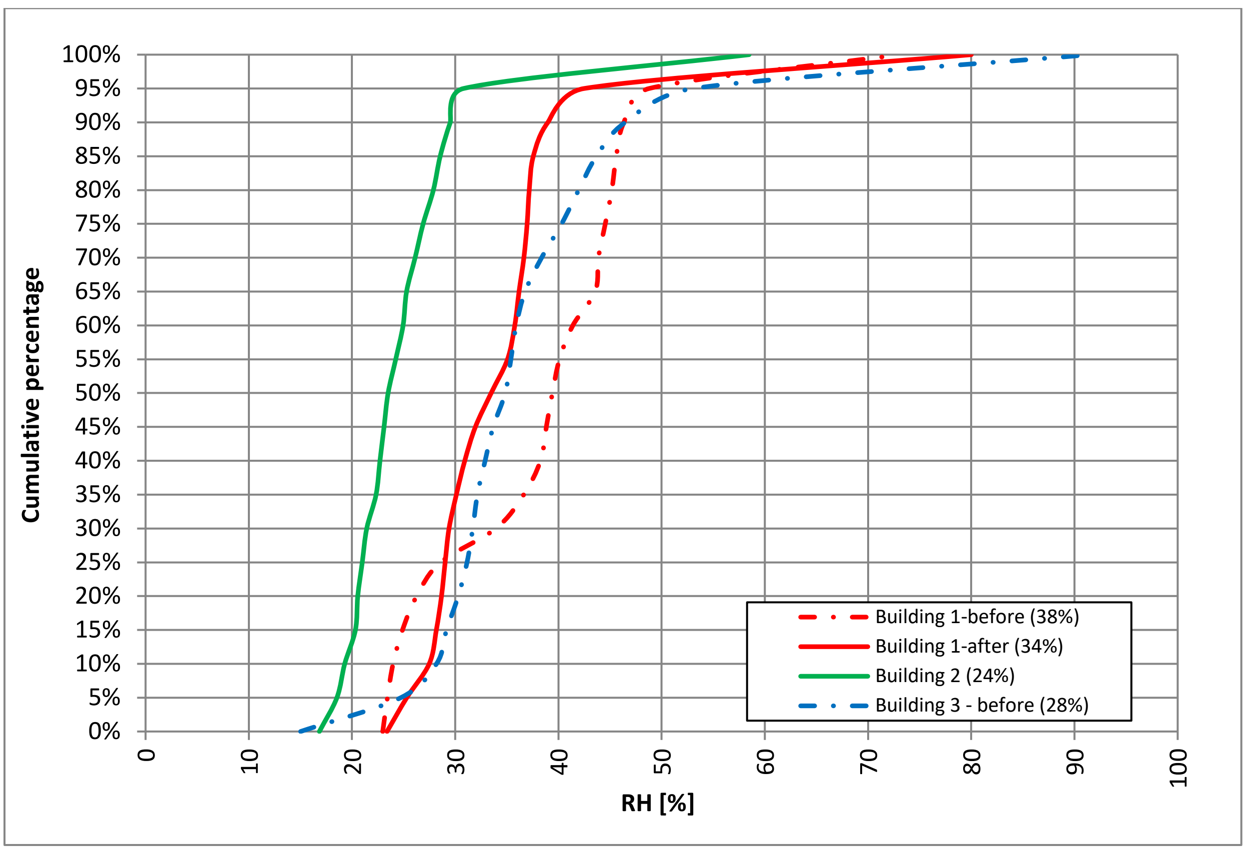

Figure 11. Relative humidity as a cumulative percentage of the monitored periods.

Comfort – Supply air temperature

The ventilation units used in Building 1 and 2 are equipped with a rotary heat exchanger and electric reheater (500 W) to ensure that the supply air is at comfortable temperature. Figure 12 shows the supply air temperature over the period with a cold spell where outside temperatures dropped to -25°C.

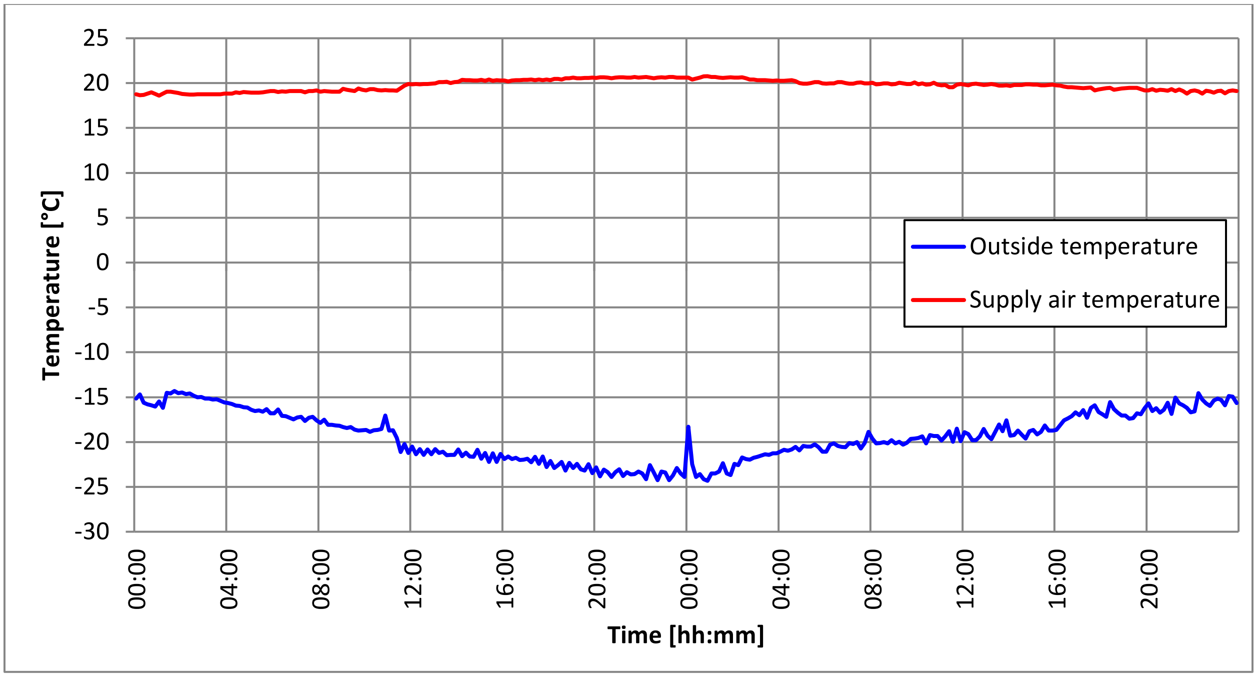

Figure 12. Building 1 - Supply air temperature

Figure 13 shows the temperature of the supply air provided by the decentralized ventilation unit used in Building 3. Notice that each unit only provides supply air for 50% of its operation time. The other 50% is used for Cycle 2 – air extraction.

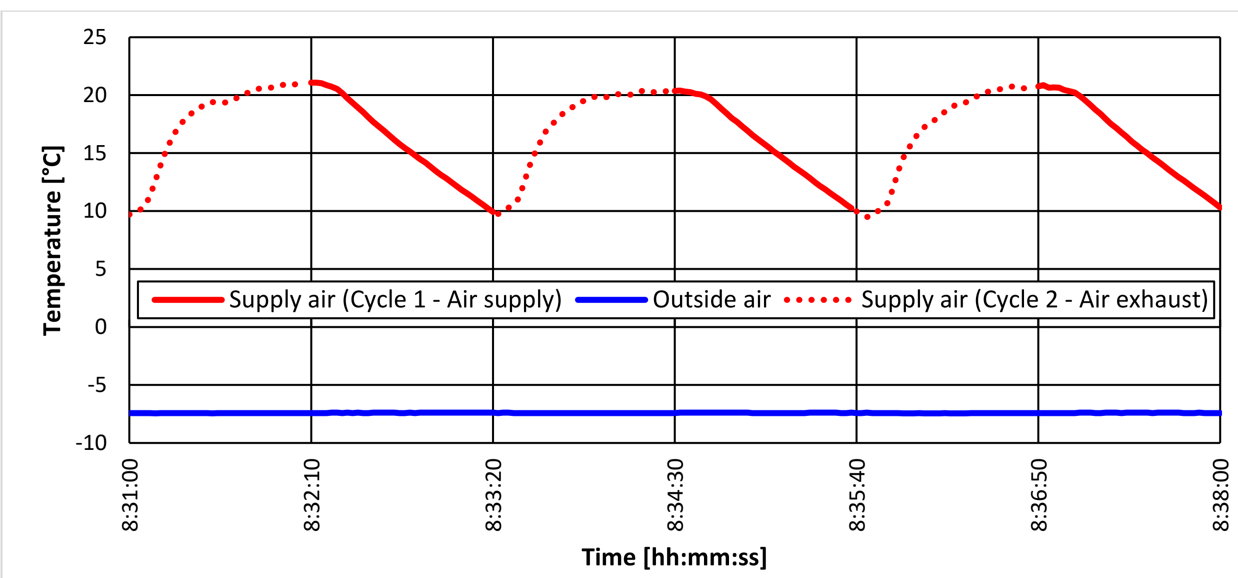

Figure 13. Decentralized ventilation unit - supply air temperatures

User feedback

When interviewed, occupants expressed satisfaction with the quality of the air in all three cases. In Building 1, both adults and children noticed the improvement. The occupants sensed a significantly reduction of stale air and odors from cooking, clothes drying, and other everyday activities. Also the tiredness that the adults experienced when waking up was improved. There was one minor complaint regarding the sound levels of the system at highest speed. However, the unit runs on the medium "Home" speed most of the time in which case the sound is barely noticeable according to the users. The users also appreciated the ease of changing the filters as they frequently did to accommodate the needs of an allergic child. Another criticism noted the space the installation takes in the rather small home.

The occupants of Building 2 did not have a chance to experience the before/after situation like the others. However, they notice a lessening of their morning tiredness levels. They did complain about the absence of a "bathroom switch" that would switch the unit into "Boost" mode either manually or automatically. The biggest complaint however, was regarding the unit's high noise levels. After closer investigation it was discovered that the unit was connected with insufficient sound attenuators between the unit and distribution manifolds. Once this was fixed the sound levels fell to non-disturbing levels.

The largest complaint of the occupants in Building 3 was toward the noise. The continuous switching of the fan directions and getting back to speed was found disturbing such that they eventually switched the system off for the nights. They also expressed concerns about the supply air temperature. The occupants found the supply air temperature too low, especially during windy periods. However, the users did appreciate the space solutions and ease of installation.

4. Discussion

This study confirms the findings of previous studies, that the common ventilation strategies based on natural ventilation (Buildings 1 and 3 before renovation) do not provide sufficient air change in Greenlandic dwellings. The interviewed users confirmed that the discomfort caused by cold draught is substantial and prevents them from keeping the fresh air vents open. Introducing forced preheated supply air into bedrooms improves the IAQ substantially. One could argue that the CO_2 concentration in the bedroom of Building 1 remains high. This is most likely caused by the larger number of occupants in rather small room. Adjusting the ventilation unit to provide even higher air change should help resolve the problem. As mentioned, the bedroom in Building 3 was only occupied with one person during the experiment. The ventilation units however were running on 100% of maximum speed. It is therefore questionable whether the decentralized unit will be able to maintain good IAQ in case of two occupants in the room. An obvious solution would be to increase the number of units although this would require a larger investment, which could soon reach the price of centralized system. (price was one of the major advantages over centralized systems.) Moreover, the user satisfaction with the decentralized solution was rather poor as the noise from the unit was found disturbing. The unit was able to maintain supply air temperature above 15 °C with outside temperatures of -7 °C. Unfortunately, our test did not take data during any colder periods. However, it is only logical to expect that with decreasing outside temperature, the temperature of the supply air will continue to drop. Occupants later confirmed this. After experiencing a cold spell with windy weather, the device had to be turned off and covered up to prevent cold air from entering the room. The efficiency of the heat recovery in very low temperatures is therefore questionable and needs to be further evaluated.

The recorded moisture levels were generally low. That can be explained by very low moisture content in the outside air that replaces the moist indoor air continuously in the properly ventilated buildings. We could see that the bathrooms without mechanical ventilation can experience extended periods of elevated moisture levels during and long after showers or baths were taken. As a result, there may be an increased risk for mold grow. However, once the mechanical ventilation was introduced, the moisture levels quickly fell. Here the use of hygrostat proved useful as the ventilation unit could stay in "Boost" until the RH drops back to normal. In contrast, there is a risk of RH being too low (the RH in Building 2 was below 30% for 95% of the monitoring period). To address this issue, the use of proper moisture recovery via regenerative heat exchangers offers a large potential and should be tested.

During the entire monitored test period, none of the mechanical devices experienced mechanical failure. The units in Buildings 1 and 2 remained running without breakdowns regardless of the outside conditions. The upcoming study will take a closer look at the efficiency of these units. The decentralized ventilation had to be decommissioned at the users' request, primarily because of the system's noise and cold draught. It's further use in the Arctic would require some adjustments such as reheating of the supply air.

When inspecting the buildings, some errors were found that required attention such as insufficient sound attenuators in Building 2 or need for proper balancing in Building 1. All of those were caused by lack of knowledge and experience of the installation crews. More examples and their proper presentation is needed to address this issue.

5. Conclusion

Despite the fact that the current building code in Greenland allows homes with fewer than four dwellings to be built without mechanical ventilation, such construction typically provides occupants with poor IAQ.

On the other hand, new and renovated homes equipped with state-of-the-art ventilation systems designed for Arctic conditions can work flawlessly and provide good IAQ with low CO_2 concentrations, low noise levels, and absence of cold draught.

It remains unknown whether the ventilation systems with heat recovery will become a requirement in Greenland. Meanwhile, the good examples and user experience must be disseminated to convince both contractors and homeowners/users about the benefits of this solution.

The overall energy performance of these systems, especially their performance in new homes, remains to be studied in Greenland.

6. Acknowledgements

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