COLD CLIMATE HOUSING RESEARCH CENTER

CCHRC

Survey of Indoor Air Quality

University of Alaska Fairbanks Sustainable Village

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Acronyms

AHFC.................................... Alaska Housing Finance Corporation

ASHRAE .... American Society of Heating, Refrigerating and Air Conditioning Engineers

ASTM.................................. American Society for Testing and Materials

BEES ....Building Energy Efficiency Standards

CCHRC .... Cold Climate Housing Research Center

CFM .... Cubic Feet per Minute

EN....................................... European Norm

ERV .... Energy Recovery Ventilator

HRV .... Heat Recovery Ventilator

HVAC .... Heating Ventilation and Air Conditioning

IAQ .... Indoor Air Quality

ppm .... parts per million

REMOTE .... Residential Exterior Membrane Outside Insulation Technique

RH....................................... Relative Humidity

UAF..................................... University of Alaska Fairbanks

°F .... Degrees Fahrenheit

°C.. Degrees Celsius

Introduction

In a harsh arctic climate with long, cold winters, living inside a heated space requires a great amount of energy. With the goal of decreasing the amount of energy being used for heating, residents in cold climates are adding more insulation to their homes to make them more airtight (Kalamees, 2007; Pan, 2010). With natural air infiltration being brought close to zero, a new problem has arisen—poor indoor air quality (Yu and Kim, 2012; Van Straaten et al., 2005). Insufficient air exchange with ambient outside air causes the concentration of various pollutants generated indoors to increase, with negative impacts to the health and comfort of occupants (Breysse et al., 2011). Introducing ventilation systems to provide building occupants with sufficient fresh air is essential to keep well-insulated, airtight buildings healthy and comfortable (Yu and Kim, 2012). These systems would ideally be equipped with heat recovery to decrease the heating demand of buildings.

In Summer 2012 four student houses were built in Fairbanks, Alaska as a part of the University of Alaska Fairbanks (UAF) Sustainable Village. The project was funded by UAF and contracted with the Cold Climate Housing Research Center (CCHRC). The aim of this project is to promote sustainable ways of living in the arctic and to study new technologies and their performance in the cold north. Different building and energy technologies were applied to produce energy efficient but affordable homes. The homes have similar layouts and each accommodates four students, however each has a unique combination of foundation type, envelope materials, heating and ventilation systems, and domestic hot water systems. The overall energy performance of each house is being continuously monitored by the CCHRC and UAF.

In addition to CCHRC and UAF monitoring, a survey of Indoor Air Quality (IAQ) was performed in the homes for two weeks in December 2012. During this survey the air temperature, relative humidity (RH), and CO_2 concentration were measured in all occupied bedrooms, along with temperature and RH in corridors and temperature in all four connections to the ventilation units. The goal of this survey was to identify any possible issues with IAQ and to evaluate the sensible energy recovery performance of the ventilation units.

Description of the buildings

The UAF Sustainable Village is situated on Fairbanks Street as shown in Figure 1.

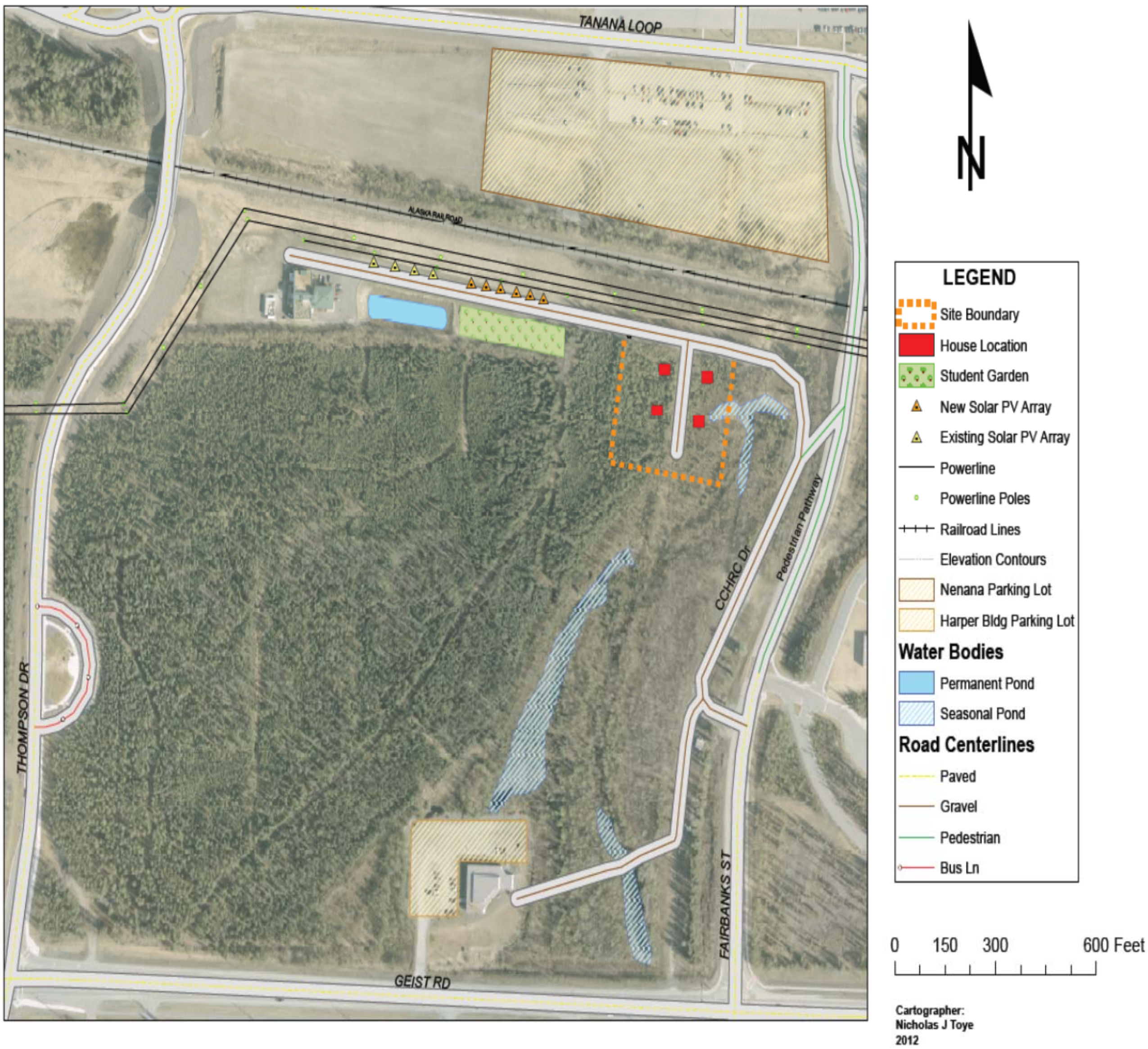


Figure 1. Site plan of the Sustainable Village. This site is located at 440 Fairbanks St. in Fairbanks, Alaska, 64° 50' North, 147° 43' West. Fairbanks has approximately 14000 °F heating degree days (7778°C).

Northeast house (Tamarack, Unit 2, 441 Fairbanks Street)

Figure 2. Tamarack house. This house has 5.5 inches (14 cm) of fiberglass batt in the stud space and 8 inches (20cm) of rigid polystyrene foam on the outside of the sheathing.

Space heating:

Space heating is provided by in-floor hydronic heating. The heat sources are a solar thermal system with three solar collectors charging a 120-gallon tank and an OM 180 Toyotomi oil heater.

Ventilation:

The ventilation unit is a Venmar EKO 1.5 ERV. The unit has a cross-flow heat exchanger made of water vapor permeable material that allows heat exchange as well as moisture transfer between fresh and stale air flows. The ventilation layout is shown in Figure 3.

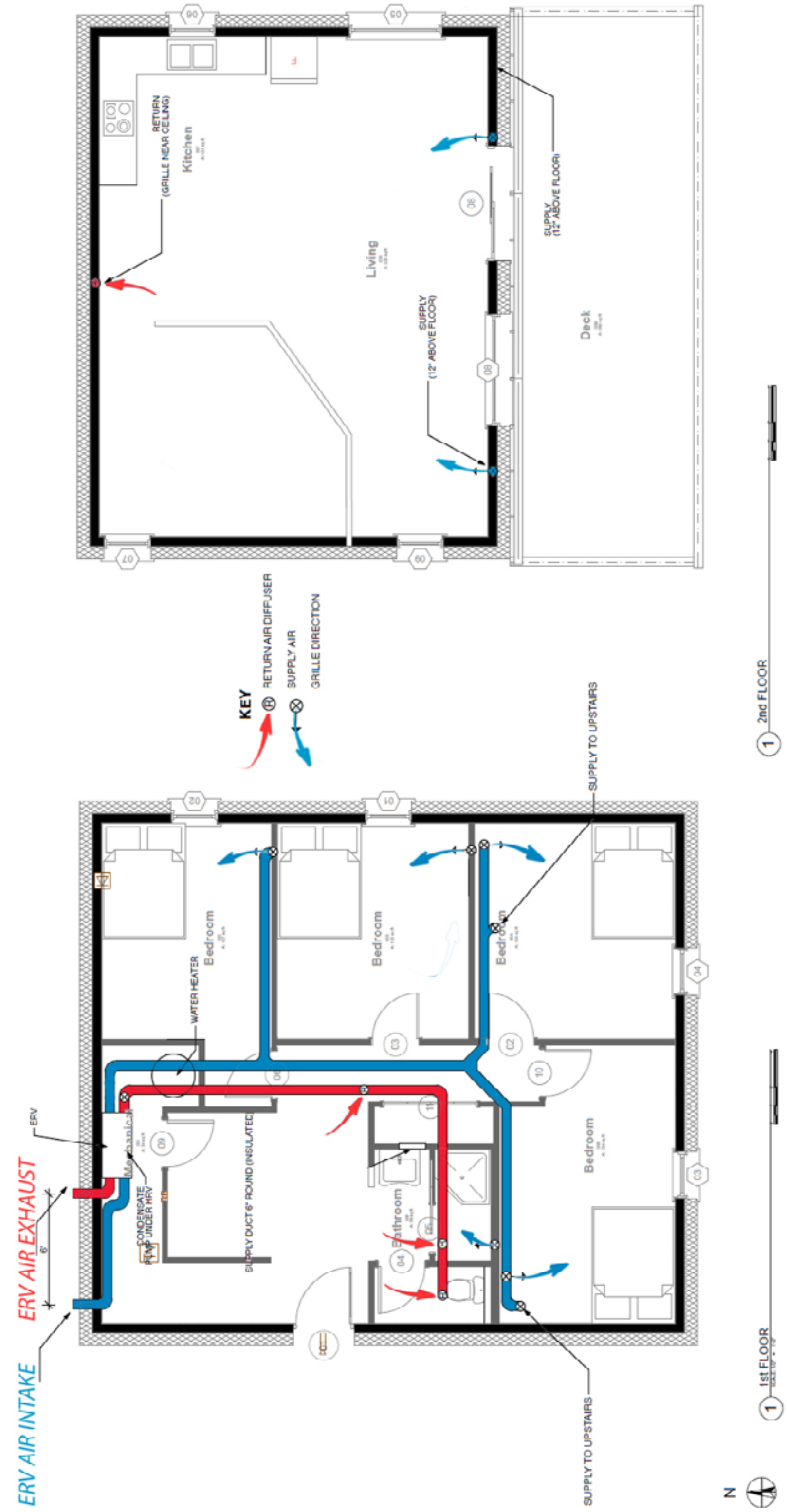


Figure 3. Northeast house ventilation layout. Air is supplied to the bedrooms and main living air (blue arrows). The return vents pull air from the bathroom, hall, and kitchen air (red arrows).

Occupants can choose from the following modes of operation:

- MAX HIGH speed fans and 100% fresh air supply
- MIN LOW speed fans and 100% fresh air supply
- 20min/h 20 minutes fresh air on LOW speed and then 40 minutes recirculation on HIGH speed or OFF
- RECIRC HIGH speed and recirculation (0% fresh air supply)
- OFF Stand-by mode, the fans are off

Additionally, the HRV has a frost protecting function which, when activated, will put the unit into recirculation mode. The activation happens automatically based on the outside temperature according to the following table. When the outside temperature drops below the threshold, the frost protection function activates.

Table 1. Frost protection of the ERV core

Outside Temperature		Recirculation	Normal Operation
-10 °C	14 °F	7 min	25 min
-27 °C	-17 °F	10 min	22 min

Northwest house (Birch, Unit 1, 440 Fairbanks Street)

Figure 4. Birch house. This house has 5.5 inches (14 cm) of fiberglass batt in the stud space and 8 inches (20cm) of rigid polystyrene foam on the outside of the sheathing.

Space heating:

Primary space heating is provided by the BrHEAThe system developed by CCHRC. It is an integrated heating and ventilation system, consisting of a 5 kilowatt (kW) Webasto sealed combustion diesel heater that injects hot air into the supply air stream from the ventilation unit to the house (see Figure 5). The current connection of the Webasto heater does not allow the power output to be modulated so it is only on/off (0/100%) controlled. The secondary heat source is a stand-alone pellet stove.

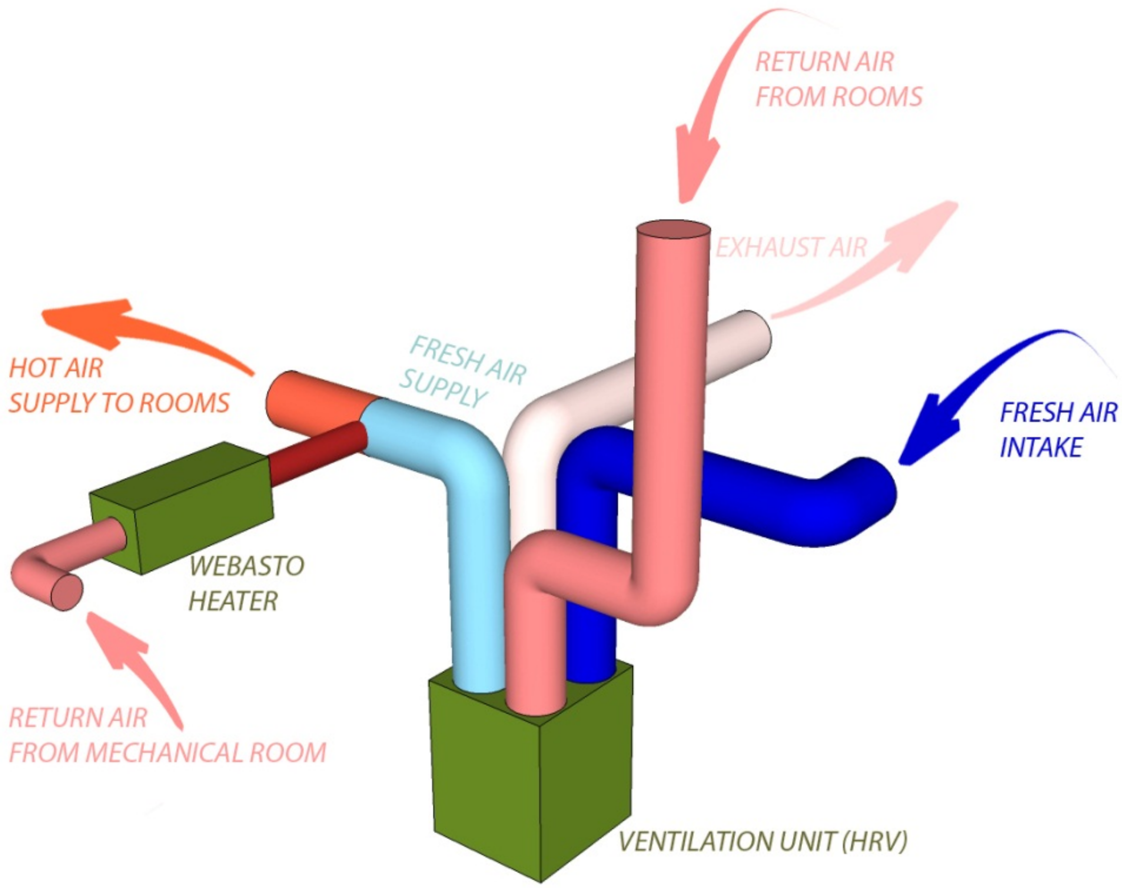


Figure 5. BrHEAThe system schematic. The Webasto heater is an oil heater designed to heat commercial-sized truck cabins so the trucks wouldn't have to idle overnight to keep the cab warm.

Ventilation:

The ventilation unit is a Zehnder ComfoAir 350 EXP L Luxe. The unit has a counter flow heat exchanger and is the only unit in the Sustainable Village that does not have a recirculation mode, which means it provides constant air exchange with outside air. The occupants can choose from four fan speeds ("Absent", 1, 2, and 3) or automatic regime. There is also a booster switch in the bathroom. The ventilation layout is shown in Figure 6.

As a protection against freezing, the unit is equipped with an 800 Watt (W) electrical preheater for the cold air,, which activates when the outside temperature drops below 15°F (-9.5°C). In the event that the preheater cannot sufficiently protect the core against freezing, the controller can start reducing the supply air flow while maintaining the exhaust air flow, which will help to reduce the risk of freezing.

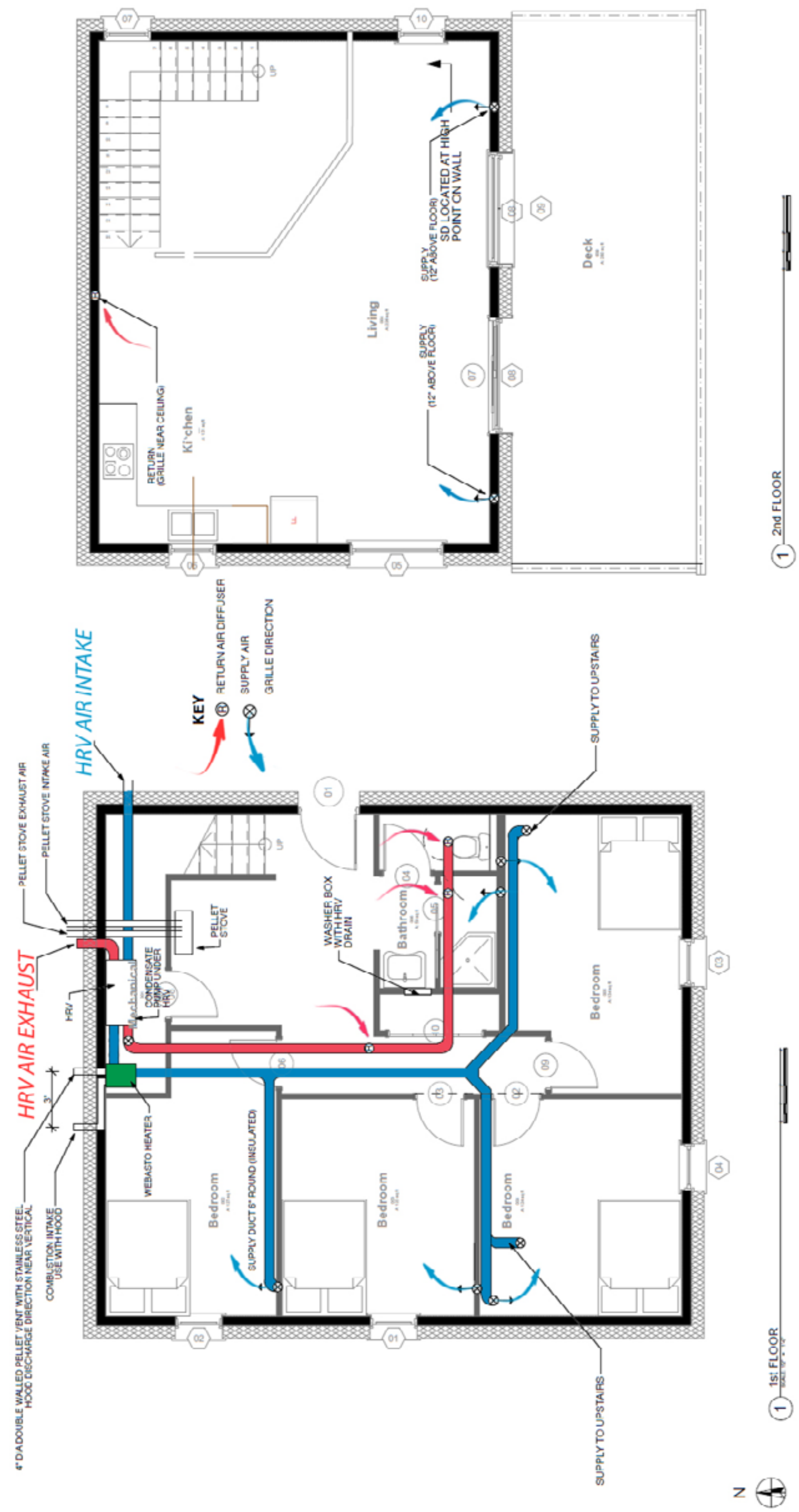


Figure 6. Northwest house ventilation layout. Air is supplied to the bedrooms and main living air (blue arrows). The return vents pull air from the bathroom, hall, and kitchen air (red arrows).

Southeast house (Willow, Unit 3, 442 Fairbanks Street)

Figure 7. Willow house. This house has 5.5 inches (14 cm) of fiberglass batt in the stud space and 8 inches (20cm) of rigid polystyrene foam on the outside of the sheathing.

Space heating:

Space heating is provided by in-floor hydronic heating. The heat sources are a solar thermal system with three solar collectors and an Evolution propane boiler

Ventilation:

The ventilation unit is Venmar EKO 1.5 HRV. Ventilation layout can be seen in Figure 8.

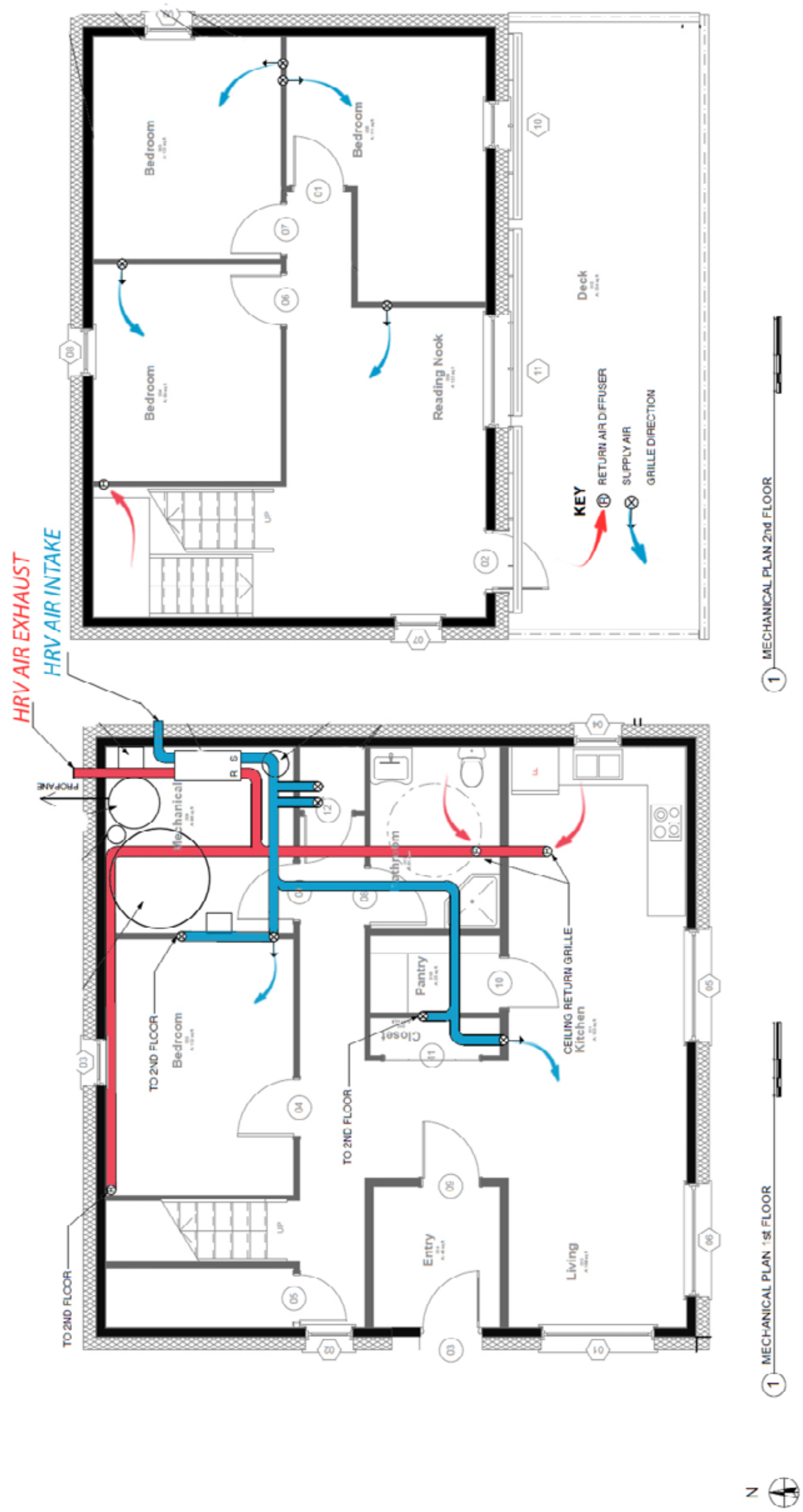


Figure 8. Southeast house ventilation layout. . Air is supplied to the bedrooms and main living air (blue arrows). The return vents pull air from the bathroom, hall, and kitchen air (red arrows).

The unit has a cross flow heat exchanger. The occupants can choose from the following modes of operation:

- MAX HIGH speed fans and 100% fresh air supply
- MIN LOW speed fans and 100% fresh air supply
- 20min/h 20 minutes fresh air on LOW speed and then 40 minutes recirculation on HIGH or OFF
- RECIRC HIGH speed of the fans and recirculation (0% fresh air supply)
- OFF Stand-by mode, the fans are off

Additionally, the HRV has a frost protecting function which, when activated, will put the unit into recirculation mode according to the following table. When the outside temperature drops below the threshold the frost protection function activates.

Table 2. Frost protection of the HRV core

Outside Temperature		Recirculation	Normal Operation
-5°C	23°F	7 min	25 min
-27°C	-17°F	10 min	22 min

Southwest house (Spruce, Unit 4, 443 Fairbanks Street)

Figure 9. Spruce house. This house has 5.5 inches (14 cm) of fiberglass batt in the stud space and 12 inches (30.5 cm) of dense pack cellulose on the outside of the sheathing.

Space heating:

Primary space heating is provided by the same BrHEAThe system described in the Northwest house summary. The secondary source of heat is a Steffes electric thermal storage unit. The Steffes was not in operation during the measurement period.

Ventilation:

The ventilation unit is same Venmar EKO 1.5 HRV described in the Southeast house summary. Ventilation layout is shown in Figure 10.

Figure 10. Southwest house ventilation layout. Air is supplied to the bedrooms and main living air (blue arrows). The return vents pull air from the bathroom, hall, and kitchen air (red arrows).

Methods

The survey was performed over the course of three weeks in December 2012. Due to the malfunction of the ventilation unit in the Tamarack house during the final week of measurements, only the data obtained during the first two weeks were used for indoor air quality (IAQ) analysis. During this period the Tamarack, Birch, and Willow houses were fully occupied by four people whereas the Spruce house was only occupied by three people. Therefore only three bedrooms were monitored in the Spruce house. The variables monitored and the equipment used are described below.

Air flow

The fresh air intake into the houses was measured with the Energy Conservatory Exhaust Fan Flow Meter (TECEFM) at the beginning of the survey. Before the measurements the ventilation units were balanced, so it can be assumed that supply and exhaust air flows are equal. The measured values were compared with the requirements given by ASHRAE (ANSI/ASHRAE, 2004) and the AHFC Building Energy Efficiency Standard (BEES) (AHFC, 2011).

Temperature, RH and CO_2

Onset HOBO U12 loggers were used to measure air temperature and relative humidity inside the houses. The logging frequency was set to 2.5 minutes. The HOBO loggers used in bedrooms were combined with Vaisala CO_2 sensors with a range of 0 – 5000 parts per million (ppm). In bedrooms the sensors were placed far from the bed, so the measurements were not affected by proximity to the breathing zone of a sleeping person, and away from the air supply vents.

HRVs

The temperatures of all four air streams connected to the ventilation units were measured by TMC6-HD temperature sensors from Onset connected to HOBO U12 loggers. In houses with the BrHEAThe system, the air temperature from the Webasto heater was also measured to identify when the heater was on. The sensible heat efficiency of the heat exchangers for the periods with fresh air supply (no recirculation) was calculated according to the following formula:

$$\varepsilon = \frac{T_{sa} - T_{fa}}{T_{ra} - T_{fa}} \cdot 100\ [\%]$$

Where:

T_{sa}	is temperature of the supply air to the house
T_{fa}	is temperature of the cold fresh air
T_{ra}	is temperature of the return air from the house

Results for Indoor Air Quality Results

Air flows

The measurements in Table 3 show that none of the ventilation systems meet the BEES requirement for ventilation with outdoor air in residential buildings. However, the requirement for ventilation given by ASHRAE Standard 62.2 is met by the Tamarack house and almost met (within 5%) by the Birch house. In MIN mode, the Venmar units meet the stricter BEES requirements; however since they automatically switch to recirculation mode to protect the core from freezing, the air exchange is reduced significantly in winter. ASHRAE 62.2 calls for the supply of outside air to meet the target air flow rate, whereas recirculation mode only redistributes air within the house. The occupants of the Willow house set the ventilation unit to 20 min/hour mode, which reduced the air exchange by as much as 67% resulting in an hourly average fresh air supply rate of 25 cubic feet per minute (CFM), less than half of the air supply rate recommended by ASHRAE 62.2 and BEES. The Zehnder unit in the Birch House exchanges air continuously, but since the unit is running on speed 1 (by the occupants' choice) the flow rate does not meet the requirement either. These findings demonstrate that home occupant behavior and the frost protection mechanisms of residential ventilation systems are important factors influencing indoor air quality.

Table 3. Actual ventilation rates

	Tamarack (Northeast)	Birch (Northwest)	Willow (Southeast)	Spruce (Southwest)
HRV	Venmar ERV	Zehnder	Venmar HRV	Venmar HRV
Heating	Floor Hydronic	Webasto + Pellet Stove	Floor Hydronic	Webasto
Frost protection	Recirculation	Electric preheating	Recirculation	Recirculation
Ventilation settings	MIN	1	20 min/h	MIN
Supply Air Flow 1)	80	52	76	78
Total portion of time the unit was in recirculation mode during the monitoring period	27%	0%	67%	41%
Hourly average fresh air supply to the house	58 CFM	52 CFM	25 CFM	46 CFM
ASHRAE 62.2 - Recommended ventilation rate	55 CFM	55 CFM	53 CFM	53 CFM
BEES - Recommended ventilation rate	67 CFM	67 CFM	65 CFM	65 CFM

1) Measured on the envelope level when the unit was on exchange with the outdoors mode.

While ASHRAE 62.2 and BEES provide prescriptive ventilation standards, IAQ outcomes in specific buildings depend on many factors including contaminant emissions within the building enclosure, ambient air quality, and building occupant health sensitivities, among other factors. In Turner et al. (2013) the researchers found that providing homes with minimum air flow rates according to ASHRAE Standard 62.2 may not be sufficient for good indoor air quality. In low-contaminant houses, 85% of the ASHRAE 62.2 requirement was considered optimal, whereas in medium- or even high-contaminant houses 200% or 310%, respectively, of the ASHRAE 62.2 required minimum was needed to obtain the ideal combination of IAQ and energy benefits. According to the Healthvent project (Healthvent, 2013) 4 liters/(second·person) (8 CFM/person) is the "health-based minimum ventilation rate" in places where occupants are the only source of pollutants. However the same study concludes that to reduce the risk of asthma and allergic symptoms 7 liters/(second·person) (14 CFM/person) is recommended in homes. With this given, the health-based minimum for a house with four occupants is 32 CFM (15 liters/(second·person).

This minimum is not met by the Willow house due to the ventilation unit mode (20 min/hour) selected. The recommended minimum for asthma and allergy symptoms reduction is 56 CFM/house, which corresponds to the ASHRAE requirement. This is only met by the Tamarack house.

In order to meet the ASHRAE requirements for minimal air exchange, the Venmar units control settings could be adjusted to supply more fresh air so even if the unit goes into recirculation mode, the average fresh air supply would still meet the requirement. Similarly, the Zehnder unit could be set to a higher speed to provide the required air exchange. Because these adjustments would increase the heating demand of the buildings, it is worth considering whether programmable controllers should be used to provide increased ventilation rates only during occupied hours.

Room air temperatures

Figure 11 shows that houses with floor heating (Tamarack and Willow) experience smaller deviations from the mean temperature in bedrooms than houses with forced air heating (Birch and Spruce). In the Spruce house the temperatures even exceeded 80°F for short periods of time. Even though the temperature fluctuations were large in the Birch house, the rooms were less overheated than the Spruce house. The possible reasons are:

a. differences in the ventilation layout;
b. distribution of the air/heat flows;
c. presence of occasionally fired pellet stove in the Birch house; and
d. lack of recirculation mode in the ventilation unit in Birch house which, when activated, significantly decreased the actual heat demand of the Spruce house.

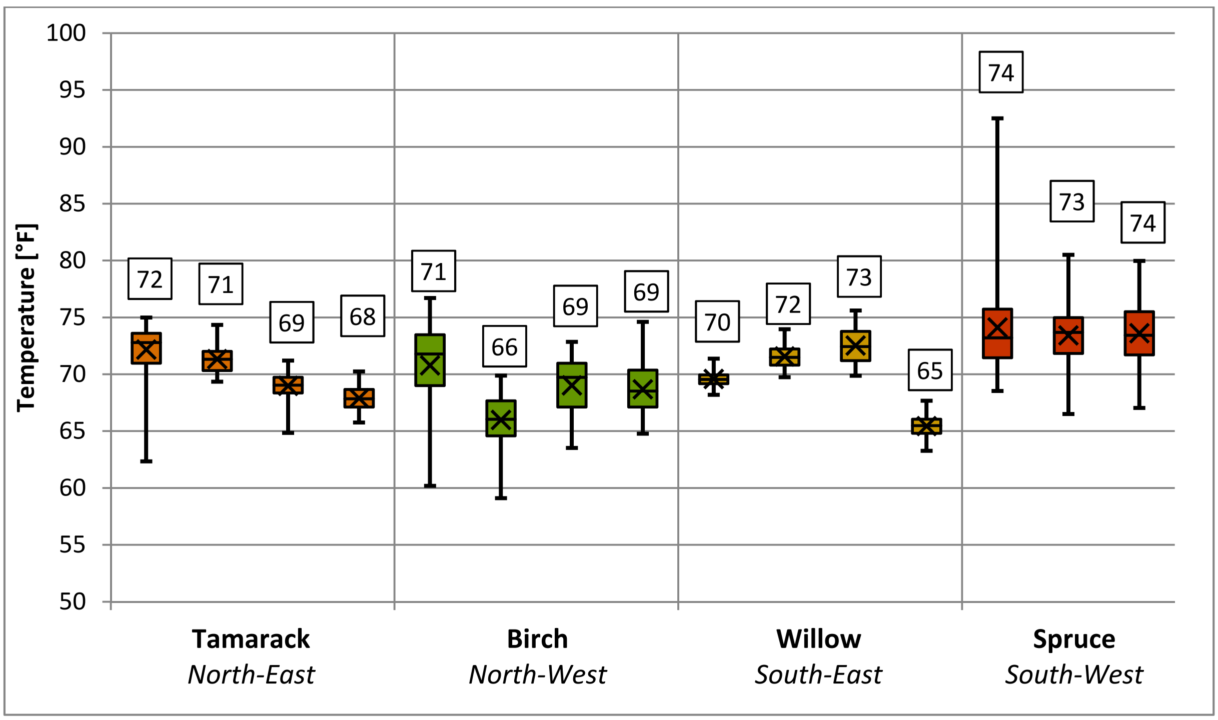


Figure 11. Temperature distribution in bedrooms. The colored boxes describe the lower and upper quartiles, the bands inside the boxes are medians, crosses are mean values and the ends of the whiskers represent 1st and 99th percentiles.

Thermal comfort depends on many factors, but the findings from some recent studies can help to provide benchmarks by which to compare these data. The recent study on thermal environment in residences in cold climates (Yang et al., 2013) performed in Lhasa, China concludes that the neutral temperature during winter is 66 °F (19°C). An earlier study in Harbin, China (Wang et al., 2003) found that the thermal neutrality (optimal temperature at which the majority of occupants will not feel hot or cold) occurred at 70.7 °F (21.5°C) and that 80% of occupants were satisfied when the interior temperature was within the range 64.4 – 77.9 °F (18-25.5°C). The author indicates a link between quality of sleep and bedroom temperature with a significant drop in sleep quality at temperatures above 75.2 °F (24°C) (Humphreys, 1979).

The average temperature in all bedrooms was within the 64.4 – 77.9°F (18-25.5°C) range suggested by the Harbin study (Wang et al., 2003) to satisfy 80% of occupants. However, according to interviews with the occupants, the large temperature swings leading to occasional overheating in Spruce house have caused some discomfort (more details can be found in the section on the Spruce House HRV). In order to compensate for the high temperatures, the occupants started closing the air terminals and even opening windows as shown on Figure 12.

Figure 12. Frost formation above the window was created by the vapor escaping from the open window in the Spruce house.

Analysis of the night-time temperatures (10 p.m. – 8 a.m.) showed that the Spruce house bedrooms exceeded 75.2°F (24°C) for significant periods of time (see Figure 13).

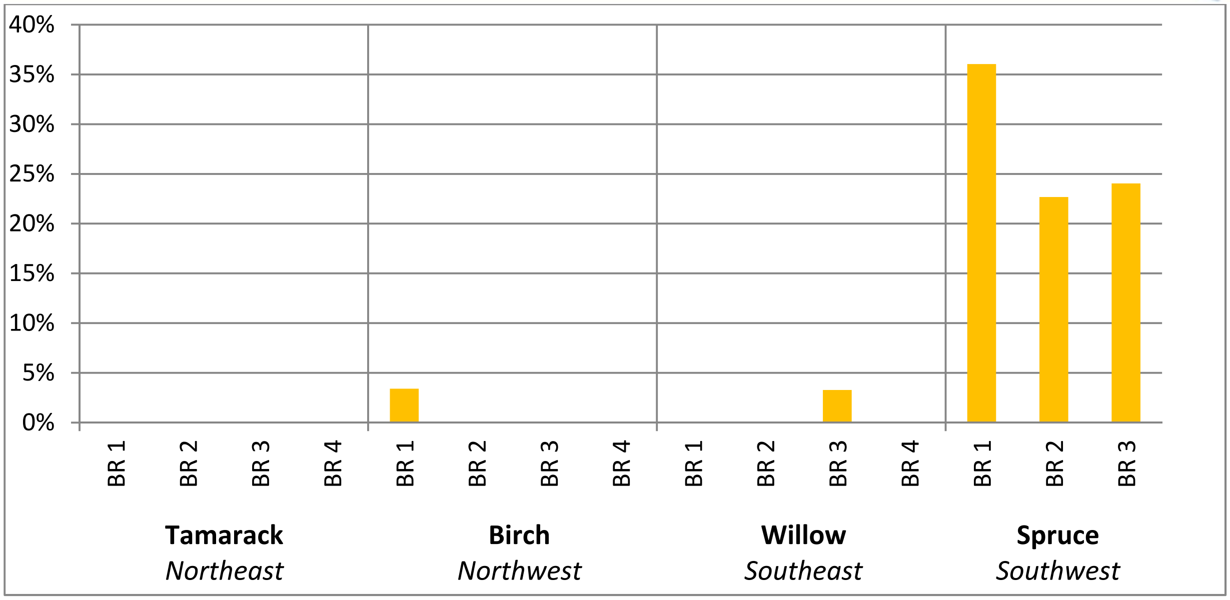


Figure 13. Percentage of night time (10 p.m. – 8 a.m.) the temperatures were above 75.2 °F. The three bedrooms are on the second floor of the house.

Relative humidity

Since all the houses have four occupants (except for the Spruce house with three occupants) and thus potentially similar moisture loads, it is likely that the differences in moisture conditions inside the houses are caused mainly by different ventilation strategies. It can be seen in Figure 14 that the house with lowest air exchange (Willow house) has the highest relative humidity. However the house with the highest air exchange (Tamarack) does not have the lowest relative humidity as a result of the moisture recovery potential of the heat exchanger.

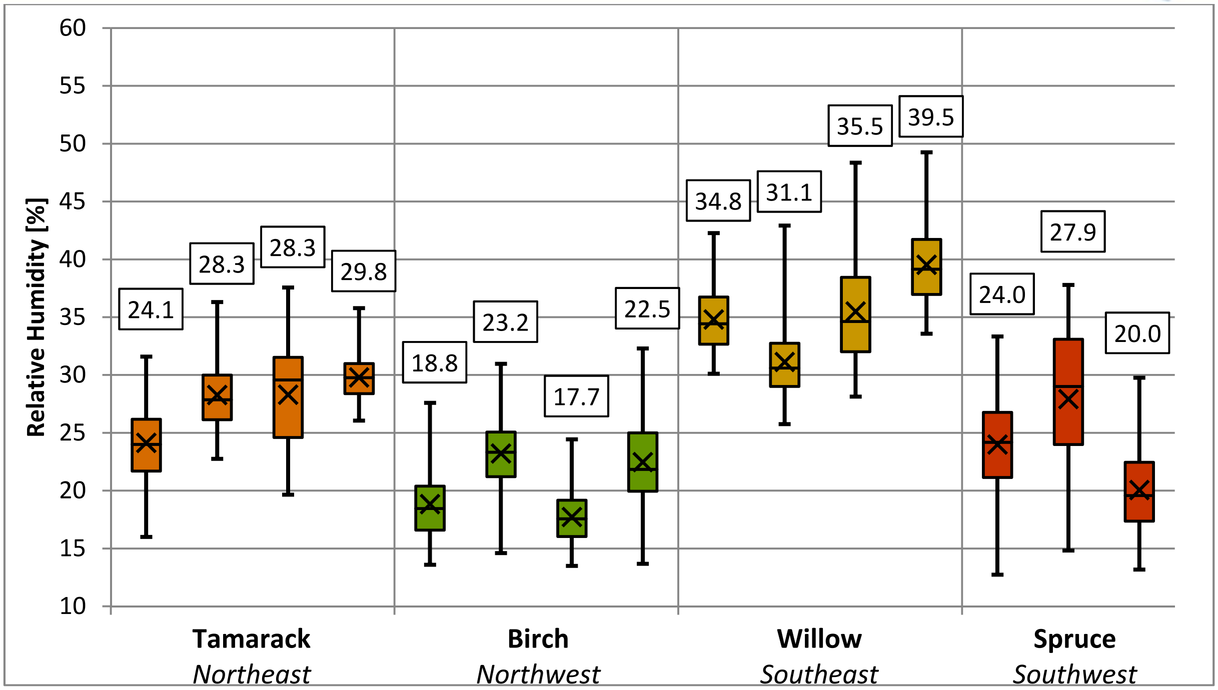


Figure 14. Relative humidity in monitored bedrooms. The colored boxes describe the lower and upper quartiles, the bands inside the boxes are medians, crosses are mean values and the ends of the whiskers represent 1st and 99th percentiles.

A Finnish study (Reinikainen et al., 1992) on the effects of humidification in offices has shown that office workers have reported fewer symptoms (skin irritation, mucous membrane irritation, dryness sensation) when exposed to an environment with humidified air at 30–40% relative humidity (RH) than when exposed to an environment with 20–30% RH. The occupants of the Birch house have been complaining about the low humidity which, according to the measurements, is the lowest of all four houses—less than 25% RH most of the time. This house has the second largest air exchange and does not have moisture recovery, which combined with forced air heating can cause low humidity. Increasing the air flows up to required levels would most likely decrease the humidity even more.

Moisture recovery, as provided by the ERV in the Tamarack house, seems to have great potential for maintaining higher RH while providing greater potential for efficiency attributable to recovery of energy contained in the water vapor of the return air. . Active humidification or indoor plants may also help boost humidity levels.

CO_2 concentration

It has been found that exposure to moderately elevated concentrations of CO_2 can negatively impact human performance, the perception of poor IAQ and the prevalence of certain health symptoms (such as irritation of mucous membranes, headaches or tiredness) (Wargocki et al., 2000; Erdmann and Apte, 2004; Seppanen et al., 1999). However, these symptoms can be caused by various other pollutants whose concentrations rise along with the CO_2 as a result of insufficient ventilation. CO_2 is therefore conveniently used as an indicator of IAQ. Nevertheless a recent study on effects of CO_2 on human performance (Satish et al., 2012) found clear link between elevated CO_2 concentration (above **1000 ppm**) and decreased decision-making performance in a controlled environment free of other pollutants.

According to EN 15251 (Unsure how to cite, the EN # might be sufficient), new buildings should have a CO_2 concentration lower than 500 ppm above outdoors for most of the time. ASTM Standard D6245 (based on past studies) suggests indoor CO_2 concentrations lower than 650 ppm above outdoors so at least 80% of the unadapted persons will find the level of body odor acceptable. ASHRAE 62.1 (ANSI/ASHRAE, 2004) recommends 700 ppm above outdoors as an upper limit.

Assuming that the outdoor CO_2 concentration in Fairbanks is 400 ppm, the recommended indoor concentration according to ASTM Standard D6245 is **1050 ppm**, according to ASHRAE Standard 62.1 **1100 ppm** and according to EN 15251 **900 ppm**. Because the occupied period is of main concern, only night (10 p.m.–8 a.m.) concentrations were taken into account when evaluating the CO_2.

The lowest CO_2 concentrations were in the Tamarack house, which has the highest air exchange. However, the air exchange is lower than recommended (due to defrosting), which could explain why the CO_2 concentration is above the 1100 ppm recommended by ASHRAE for 25% of the night-time (see Table 4 for a complete overview). The charts for separate bedrooms are shown in Figure 15. The plots representing each house after the bedroom data were put together are in Figure 17.

Table 4. Average percentage of time the CO_2 concentration was above the limit recommended by various standards during the night-time (10 p.m.–8 a.m.)

	Tamarack house	Birch house	Willow house	Spruce house
EN 15251 (>900 ppm)	53%	59%	92%	78%
Commonly referred value (>1000 ppm)[1]	38%	49%	86%	70%
ASTM (>1050 ppm)[2]	31%	46%	83%	64%
ASHRAE (>1100 ppm)	25%	40%	78%	60%

1) Based on ASTM D6245; 650 ppm above outdoors when 350 ppm as an ambient concentration considered.

2) Based on ASTM D6245; 650 ppm above outdoors when 400 ppm as an ambient concentration considered.

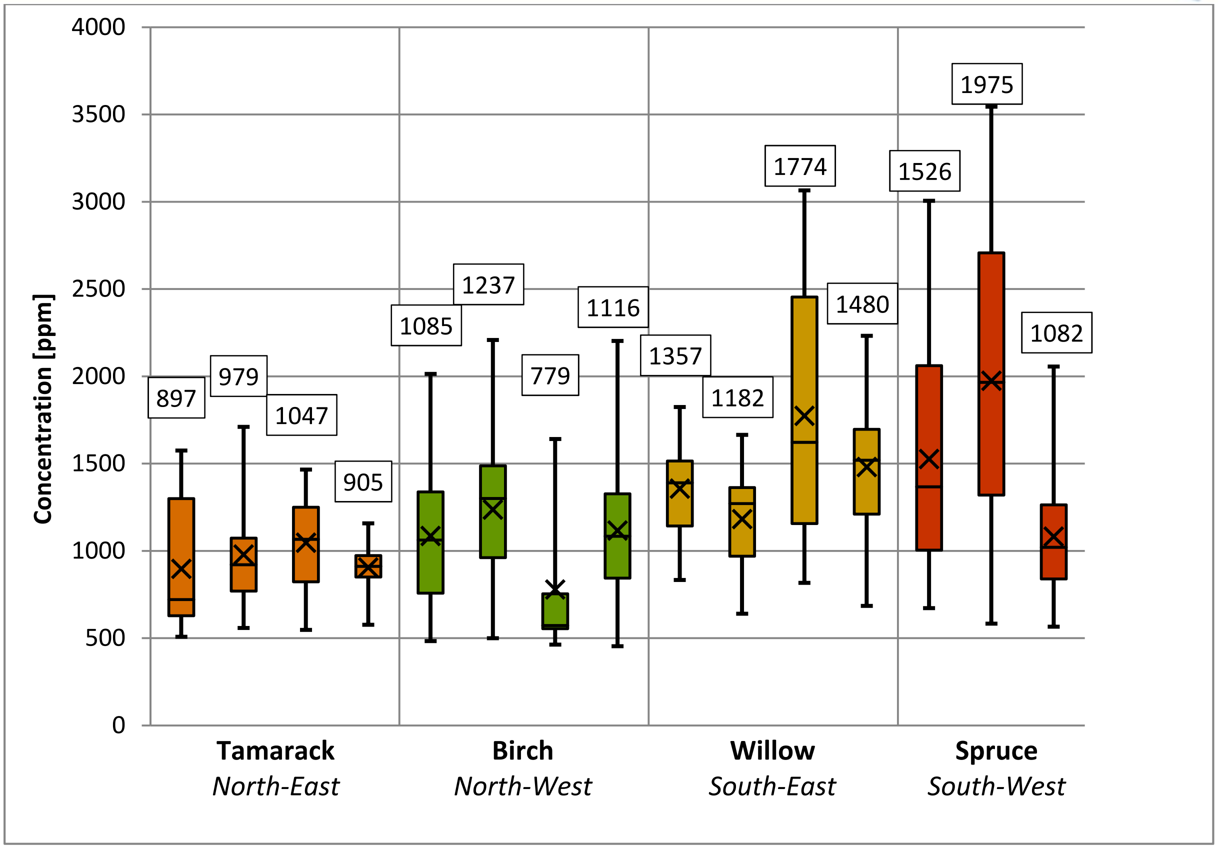


Figure 15. CO_2 concentrations in bedrooms during the night hours (10:00 p.m. - 8:00 a.m.). The colored boxes describe the lower and upper quartiles, the bands inside the boxes are medians, crosses are mean values and the ends of the whiskers represent 1st and 99th percentiles.

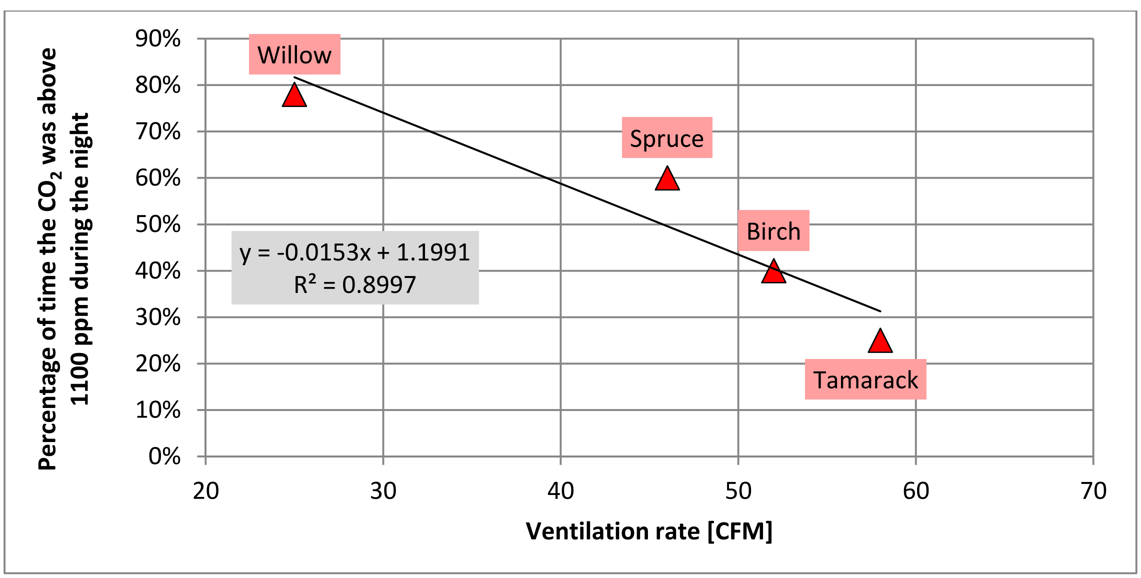
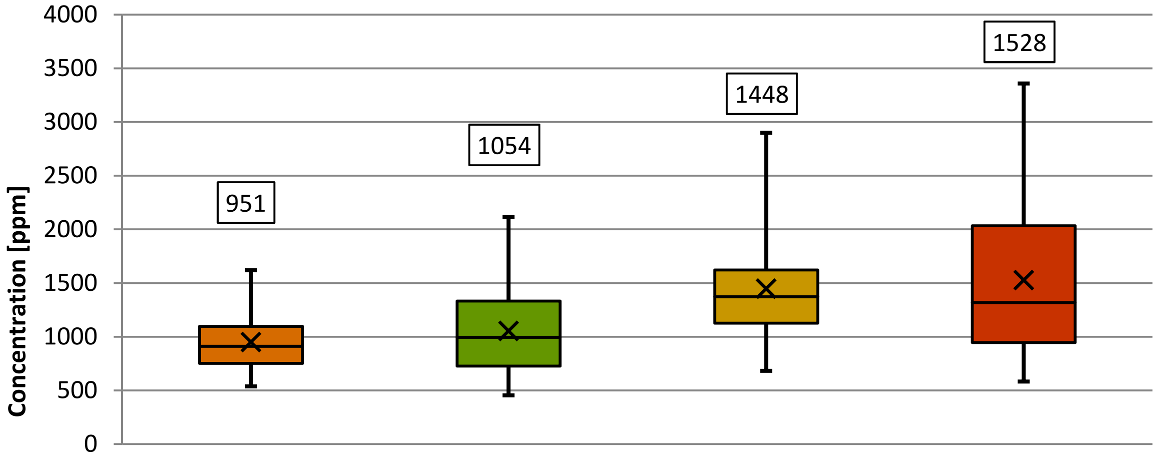


Figure 16. Ventilation rate vs. CO_2 concentration above the ASHRAE 1100 ppm limit

In Figure 16 it is clear that the higher the ventilation rate, the less time the CO_2 concentration is above the recommended level. However, the Spruce house has significantly higher CO_2 concentrations than the Birch house even though it only gets 11% less air exchange. The explanation is provided later in the text.



	Tamarack *North-East*	**Birch** *North-West*	**Willow** *South-East*	**Spruce** *South-West*
Fresh air supply	**58 CFM**	**52 CFM**	**25 CFM**	**46 CFM**
>1100 ppm	**25%**	**40%**	**78%**	**60%**

Figure 17. Night CO_2 concentrations for each house when all occupied bedrooms within the house are put together.

Adjusting the ventilation systems to provide the required ventilation rates could help to eliminate problems with elevated CO_2 concentrations. However, the occupants' interaction with the systems can significantly affect the final results. Increasing ventilation rates will increase the heating demand of the houses as well as lowering the RH more. Variable air flow systems could be considered for future projects to achieve good indoor air quality and low energy use.

Ventilation System Performance

ERV: Tamarack house

The average sensible heat efficiency of the heat exchanger when the unit was in air exchange mode was 76.5%. The moisture recovery rate was not measured.

As the measurements of indoor environment confirmed, the moisture recovery is functioning and effectively increases the humidity inside the house.

During the measurements, the unit suddenly turned off and did not start again automatically. When this was discovered about a week later, the unit had to be restarted. When analyzing the data (see Figure 18) it was discovered that the unit stopped when the intake temperature was close to 14°F, which is a set point for frost protection. It is believed that the unit froze and turned itself off as the frost protection deactivated. The period with the unit off was not part of the IAQ analysis.

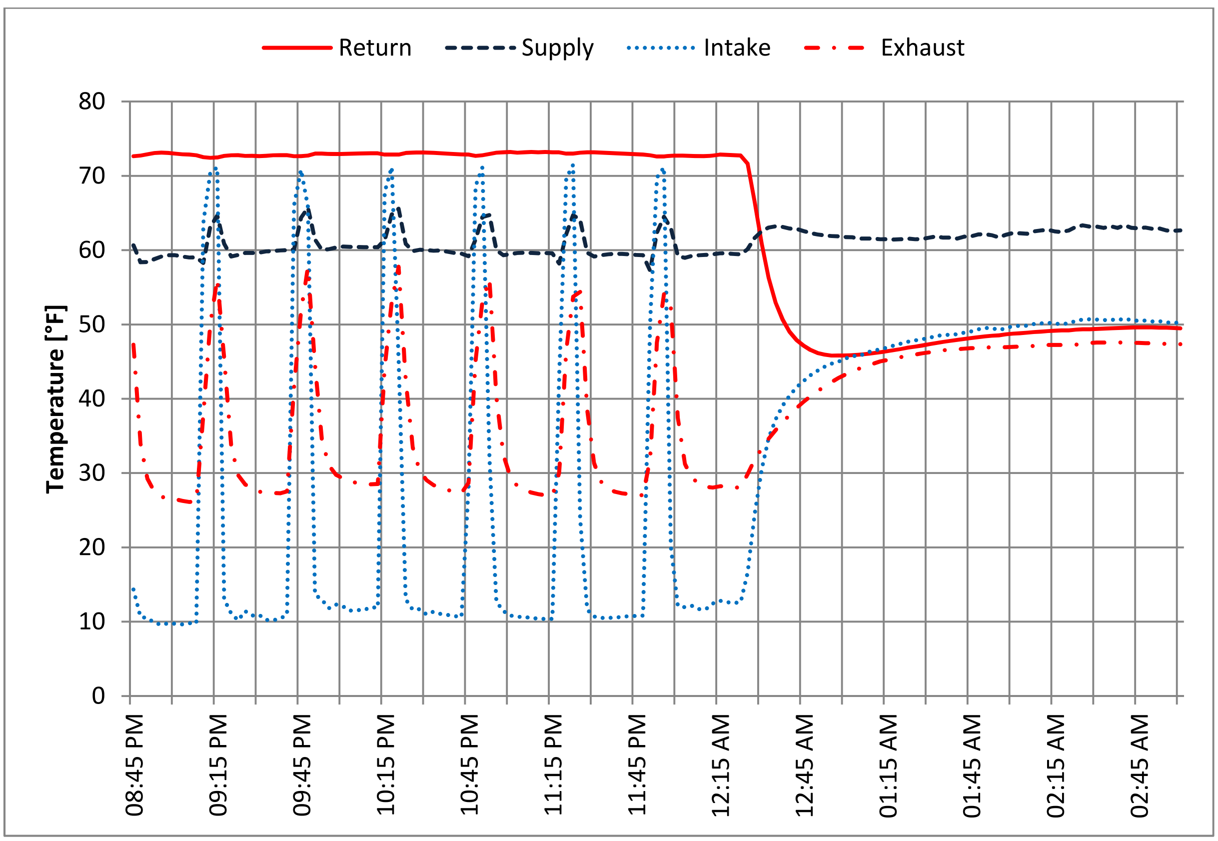


Figure 18. Freezing of the ERV core at temperature above 14 °F as a result of deactivated frost protection. Return is the return temperature from the living space, supply is the temperature supplied to the living space.

HRV: Birch house

When analyzing the results it was found that the electric preheater of the Zehnder HRV is activated when the outside temperature drops below 15 °F (-9.5°C). According to the producer the preheater modulates its power output from 0 to 800 W to provide sufficient protection against frost formation in the heat exchanger. The electricity use was however not monitored during the survey.

The average sensible heat efficiency of the heat exchanger was 71.7% when measured after the electric preheater. The combination of 100% air exchange with no recirculation, forced air heating and no moisture recovery or humidification can explain why the Spruce house had the lowest indoor humidity, but also a considerably lower CO_2 concentration.

The Webasto heater was on for 60% of the time and on average turned on and off 19 times every day. The effect of such frequent switching on the lifetime of the heater is considerable.

Better control (possibly demand-based) of the air flow could increase the efficiency of the ventilation system, the rooms would be ventilated more during the occupied hours and less when empty. Such control would bring energy savings and improve the air quality at the same time. Moisture recovery or moisture generation (by means of plants or humidifier) would help to keep the humidity at desired levels. Modulating the power output of the Webasto heater would have a positive effect on the temperature fluctuations inside the house as well as on the switching frequency. Another means of frost protection rather than electric resistance heating may also be considered (heating coil or ground loop) to decrease the primary energy use.

HRV: Willow house

The sensible heat efficiency of the heat exchanger was 70.7%

Due to the operation mode (20 min/hour) selected by occupants, the Willow house was the least ventilated which resulted in highest humidity and longest periods with CO_2 concentration above 1200 ppm.

The 20 min/hour mode is beneficial during unoccupied periods as it does not use much heat while it still provides some air exchange, but it should not be used when the building is occupied, as it does not provide nearly enough fresh air for the house. A programmable controller that switches the modes according to occupancy would help to solve the problem.

HRV: Spruce house

The average sensible heat efficiency of the heat exchanger when the unit was in air exchange mode was 76.6%. The Webasto heater used for heating the house does not have a modulating heat output, meaning that there is either 0 or 5 kW of heat being introduced to the air stream, causing large fluctuations in the temperature of the air delivered to the rooms and consequently fluctuations in room temperatures. On average the Webasto heater turned on and off 14 times a day and was on for 58% of the time.

When interviewing the occupants of the Spruce house, they mostly complained about overheating in their rooms, which forced them to manually close the air inlets. Subsequently this led to insufficient ventilation of their rooms, which can be seen in Figure 19. During the first two nights the air inlet was almost closed so there was just enough heat entering the room to keep the temperature at comfortable levels (around 70°F). The air exchange, however, was too low, which resulted in CO_2 concentrations above 2000 ppm for extended time periods. After the second night the air inlet was opened to provide more air, which decreased the CO_2 concentration but also overheated the room.

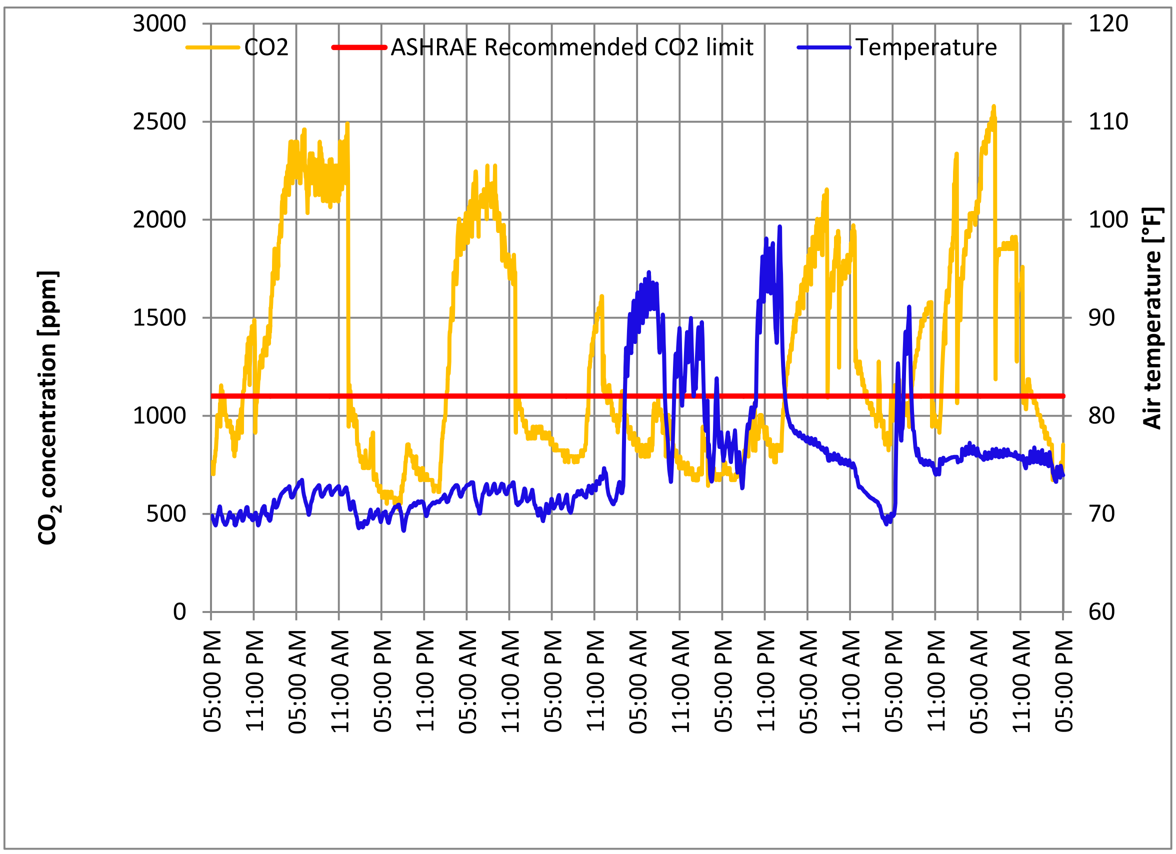


Figure 19. Temperature and CO_2 concentration in a Spruce house bedroom. The bedroom is above the ASHRAE recommended 1100 ppm most of the time the room is occupied.

Conclusions

The houses in the UAF Sustainable Village are a great representation of various state-of-the art residential ventilation systems that demonstrate the complexities in providing energy-efficient ventilation and achieving good IAQ in cold climates. The data presented showed significant differences in IAQ between the four houses. These differences are partially attributable to variations in HVAC systems and in occupant interactions with these systems.

The ventilation rate, even though it can fulfill the ASHRAE Standard 62.2 requirements under standard operation, gets reduced either by the occupants or by the frost-protecting strategy of the unit (i.e. recirculation). With the air exchange rate too low, the concentration of CO_2 along with other pollutants increases, which may have an effect on comfort and performance of the occupants. In order to meet the requirements during the winter, system refinements and occupant education are recommended. For example, it is likely that ASHRAE Standard 62.2 and BEES recommended ventilation rates could be achieved simply by changing the ventilation system control settings.

Higher ventilation rates introduced another issue—extremely low interior relative humidity. To deal with this, moisture recovery provided by the Venmar ERV in the Tamarack house showed promise in providing adequate ventilation while helping to keep humidity levels closer to the range considered optimal for occupants. This is despite water vapor permeable cores being considered by many to be unuseable in a very cold climate.

For the houses equipped with the BrHEATthe systems, zoning that allows occupants to set their own room temperature would increase the comfort and could also decrease the heat demand thanks to setbacks during unoccupied and night hours. Unfortunately zoning in forced air heating requires a great deal of research and development before it is introduced to highly energy efficient homes.

Suggestions for further research

Will it be possible to meet the ASHRAE requirements for ventilation rates in the four studied houses by simply introducing more advanced controls of the HVAC systems?

Will it be possible to eliminate overheating and reduce the frequency of the on/off switching of the Webasto heater in BrHEAThe systems by modulating the power output?

Will changing the frost protection set point on the Venmar ERV unit help to avoid freeze-ups of the core?

Would a hydronic heating coil or ground loop have a better cost/benefit ratio than the electric preheater in the Zehnder ventilation unit?

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