



COLD CLIMATE HOUSING RESEARCH CENTER

CCHRC

Improving Indoor Air Quality for Small Alaska Homes



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Prepared by the Cold Climate Housing Research Center

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Disclaimer: The products were tested using the methodologies described in this report. CCHRC cautions that different results might be obtained using different test methodologies. CCHRC suggests caution in drawing inferences regarding the products beyond the circumstances described in this report.



Abstract

Mechanical ventilation is the conventional way to maintain healthy indoor air in highly efficient, air-tight homes in cold climates. The amount of air exchange recommended for small homes is often much less than the amount supplied by typical ventilation systems. This over-ventilating of small homes costs money in energy loss and lowers air quality by over-drying the home. This study looked at alternative ventilation options for these smaller homes by evaluating six different small ventilation systems: three in private homes and three in the CCHRC Mobile Test Lab.

*Two small HRVs were evaluated in the Mobile Test Lab to see how they managed high relative humidity at low outside temperatures. Both units used recirculation defrost. One unit failed due to freezing in the core both times it ran. Three through-wall ventilators were also studied to determine whether they could maintain adequate indoor air quality and whether they would freeze in the cold. One through-wall ventilator was in the Mobile Test Lab and two were in private homes. All were exposed to different interior conditions and had variable performance. **All but one had the exterior hood freeze closed. Experiments with different exterior hoods are promising but more study is needed.** A passive ventilation system was also evaluated, but did not provide adequate air exchange for the space.*

While ventilation options are available for smaller homes, this study did not find any cost-effective options that perform well in a cold climate. Small HRVs use more electricity than larger ones (because they do not have variable speed motors) and some of the through-wall ventilator exterior hoods freeze in high interior humidity situations.

Keywords: ventilation, indoor air quality, ventilators, HRVs



Improving Indoor Air Quality for Small Alaska Homes

In order to maintain healthy indoor air quality (IAQ) in a home, fresh, clean air needs to be introduced while removing stale inside air. To date, the most effective method to maintain healthy IAQ is through ventilation—exchanging the inside air with outside air. While many options exist for Alaska homes, the most energy efficient ones recover heat from the exiting air to preheat incoming air. Heat recovery systems are usually ducted to all parts of the house and have a central Heat Recovery Ventilator (HRV) that moves air and has a heat exchanger at its core. These central distribution systems can be expensive and are sometimes too large for smaller homes. This study evaluated six small ventilation options for smaller homes, including two ducted systems, three through-wall distributed systems, and one homemade exhaust only system.

Summary of project and objectives

Indoor air quality is critical to the health of home occupants and durability of the structure. Current methods of providing fresh air to a space while exhausting stale air have highly variable results, which are often due to user interaction with ventilation systems and lack of education about the systems. Ventilation systems that deliver too much cold air, use excess energy, or over-dry a house tend to get shut off. CCHRC looked at alternative IAQ systems for smaller homes in an effort to address these issues. They were evaluated on the following metrics:

1. How do the operation and maintenance requirements differ from exhaust-only and HRV systems?
2. Do the systems work at cold temperatures with a high moisture load?
3. Can alternative IAQ systems maintain good indoor air quality?

Brief literature review

In general, indoor air has higher concentrations of pollutants than outside air. $PM_{2.5}$ is the greatest health concern (in the absence of second-hand smoke and radon) followed by formaldehyde and acrolein (Sherman, 2013). These pollutants are generated by activities such as cooking, cleaning with solvents, and off gassing furniture and building materials. In order to minimize the health effects of these pollutants, a home needs 0.3 air changes per hour (ACH) and a new home needs 0.5 ACH (Sherman and Hodgson, 2004).

Generally, the amount of air exchange required for a home is determined by *ASHRAE Standard 62.2, Ventilation and Acceptable Indoor Air Quality in Residential Buildings*. ASHRAE 62.2, developed in 2003 and regularly updated, requires a ventilation rate that will provide “minimally acceptable air quality for typical situations” (Sherman, 2004). Its aim is 0.35 ACH (Sherman, 2015). According to 62.2-2016 the whole house ventilation rate should be calculated using this formula:

$$Q_{tot} = 0.03A_{floor} + 7.5(N_{br} + 1)$$

Q_{tot} is the total required ventilation rate in cfm,
 A_{floor} is the floor area of residence in square feet, and
 N_{br} is the number of bedrooms (not to be less than 1)

This ventilation rate can be achieved using a balanced system, an exhaust-only system, or a supply-only



system (not recommended in cold climates (Alaska Housing Finance Corporation, 2012)). Part of the natural air leakage of the home can be used toward meeting this total house ventilation rate.

According to the *2018 Alaska Housing Assessment*, 55% of homes in Alaska are at an elevated risk of IAQ problems due to lack of adequate ventilation. Approximately half of the 8,330 new single-family homes built in the last 10 years have exhaust-only ventilation or no ventilation system. In other words, 3,966 new homes lack balanced ventilation. Only half of the newer homes have an HRV, according to the Alaska Retrofit Information System (ARIS).

HRVs that are typically installed in Alaska tend to be oversized for most homes, which makes them expensive to purchase and install and in some cases more energy-intensive. For example, a 1,500 ft² home with two bedrooms only needs 67 cubic feet per minute (CFM) of fresh air to meet ASHRAE 62.2 (2,800 of the homes built in the last 10 year are 1500 ft² or less (ARIS)). Typical whole-house HRVs usually deliver 60 CFM and higher (although higher end models can modulate to lower speeds). These larger HRVs tend to over-ventilate a space if operated continuously, thereby drying out the inside air and also costing money in extra electricity and make-up heat. While smaller HRVs are available from most manufacturers, it is hard to find models that defrost properly.

In addition to centralized, ducted ventilation systems, this study looked at decentralized ventilation systems with multiple through-wall ventilators. Small through-wall ventilators with heat recovery cores are available in Europe and have become more available in the U.S. recently (Holliday, 2011). Older versions of through-wall ventilation systems were designed for multifamily dwellings and were common in retrofits (Manz et. al, 2000). While many options are on the market, few are rated for cold climates.

There are also very few studies that look at through-wall ventilators in cold climates. Murgul et al. (2014) installed several units in a multifamily building in St. Petersburg, Russia, but no follow-up has been reported. Merzkirch et al. studied 42 decentralized systems and compared them to 20 centralized systems in Luxembourg (2016). The coldest outdoor temperature was 0°C, but the study resulted in some useful information for other environments as well. The decentralized units had unbalanced supply and exhaust flow, leading to loss in exchange efficiency and more infiltration/exfiltration losses. They were very sensitive to wind pressures, which exacerbated the imbalance between the supply and exhaust flows. They also studied whether the units “short-circuited” and found that decentralized systems did not have much recirculation internally, indicating they were not “throwing” the fresh air far enough into the room. The decentralized systems had fan power that was about 50% less than the centralized systems. The heat recovery efficiency for the through-wall ventilators averaged 70% (Merzkirch et al., 2016).

Market review summary

Due to lack of information on small ventilation systems, CCHRC started with a market review of available systems that met the following criteria:

1. Delivers 67 cfm and lower (the ASHRAE requirement for a 1500 ft² house with 2 bedrooms)
2. Has heat recovery
3. Works to -40°F

CCHRC reached out to Green Building Advisor (an online forum on energy efficient housing), building science experts, and industry leaders to develop a list of potential products. General consensus from interviews was that ventilation in small homes is difficult and many of the current options need testing. Table 1 provides a list of the potential systems; the greyed-out systems were not chosen for this study due to factors including cost, availability, perceived duplication, and lack of cold temperature operation.



Table 1. Potential small systems.




Unit	Fan Speeds (CFM)	Advertised Heat Recovery Efficiency	Low Temperature	Defrost Method	W/CFM
Lunos Ego	3/12	85% sensible 20% latent	Unspecified	Alternates supply and exhaust - Below -10°F operate on low and keep RH below 35%	3.45
Lunos E2	10/15/20	90.6% sensible 20-30% latent	Unspecified	Alternates supply and exhaust - Below -10°F operate on low and keep RH below 35%	7.14 to 9.09
TwinFresh Expert RA1-50-2	9/18/29	97%@low sensible 90%@medium sensible 82%@high sensible	-22°F	Alternates supply and exhaust	2.49 to 5.58
Lifebreath RNC4-TPD	58/67/70/7 5	70%@32°F sensible 65%@-13°F sensible	Unspecified - tested to -13°F	Recirculation	1.32 to 1.53
Broan HRV80T	37-86	68% @ 32°F sensible 60% @ -13°F sensible	Unspecified - tested to -13°F	Recirculation	1.0 to 1.21
Panasonic Intelli-Balance	50-100	64% @-13°F sensible 0.7 latent	-22°F	Recirculation	0.81
DUKA ONE S6	8-30	97% sensible	unknown	unknown	5.3 to 7.5
Lifebreath 30 ERV	42/61/67/7 2	70%@32°F sensible	Unspecified - tested to -13°F	Sensor shuts down supply motor periodically	0.95 to 1.26
Broan ERV70T/S	35-78	50%@32°F 56% @ -13°F sensible 0.59 @ 32°F 0.55@-13°F latent	Unspecified - tested to -13°F	Recirculation	1.03 to 1.28
Broan HRV K7	30/71	55%@32°F and -13°F sensible 0.03 @32°F and 0.06 @-13°F latent	Unspecified - tested to -13°F	Recirculation	0.9 to 1.13
Broan ERV K7	35/70	66%@32°F and 56%@-13°F sensible 0.03 @32°F and 0.55 @ -13°F latent	Unspecified- tested to -13°F	Recirculation	10.3 to 1.4
TwinFresh Comfo RA1-50-2	8/16/32	90%@32°F sensible	-4°F	Alternates supply and exhaust	2.11 to 5.7
TwinFresh Micra 60	17.7/26.5/ 35.3	79%@low sensible 74%@medium sensible 70%@high sensible	-4°F	Thermostat prevents condensation	2.31 to 4.43
TwinFresh Micra150	35/53/71	88%@low sensible 87%@medium sensible 85%@high sensible	-13°F	Exhaust only to warm the core	1.39 to 4.38
Zehnder ComfoAir 160	19-92	88% sensible	Unspecified	Optional geothermal or electric preheater	1.37 to 1.9



Testing methodology

CCHRC studied six different small ventilation installations described in Table 2. The three systems tested in three different private homes had limited data collection compared to the three systems tested in the CCHRC Mobile Test Lab (MTL). The final column describes the data collected from each installation. The complete data plan is available upon request. The Panasonic Intelli-Balance was evaluated in a previous study, and results are available [here http://www.cchrc.org/energy-recovery-ventilators-ervs-cold-climates](http://www.cchrc.org/energy-recovery-ventilators-ervs-cold-climates). All units were monitored for icing events, but the three units in the MTL were subjected to RH levels around 40% to create a worst-case scenario for freezing. Interviews with homeowners about performance and icing were also conducted.

Table 2. Systems tested.

Unit and Location	Unit	Data Collected
Lunos Ego Private Home 280 ft² 1.2 ACH₅₀ 3 occupants	 https://www.lunos.de/en/product/ego-mit-waermerueckgewinnung-e/	<i>Interior Conditions:</i> Temperature, Relative Humidity (RH), and Carbon Dioxide <i>Ventilator Conditions:</i> Supply Temperature and RH inside the house Exhaust Temperature and RH inside the house
Lunos E2 Private Home 1000 ft² 1.6 ACH₅₀ 1 occupant	 https://www.lunos.de/en/product/e_with_heat_recovery/	<i>Interior Conditions:</i> Temperature, RH, and Carbon Dioxide <i>Ventilator Conditions:</i> Supply Temperature and RH inside and outside the house Exhaust Temperature and RH inside the house
TwinFresh Expert RA1-50-2 Mobile Test Lab 200 ft² 3.76 ACH₅₀ 0 occupants Humidified to 40% Temperature set to 70°F	 https://vents-us.com/cat/724/	<i>Building Conditions:</i> Temperature, RH, Carbon Dioxide, and Pressure differential with the outside <i>Ventilator Conditions:</i> Supply and Exhaust temperature and RH inside and outside the MTL and electrical power consumed



Lifebreath RNC4-TPD

Mobile Test Lab
200 ft²
3.76 ACH₅₀
0 occupants
Humidified to 40%
Temperature set to 70°F



<https://www.lifebreath.com/us/product/lifebreath-rnc4-tpf-residential-heat-recovery-ventilator-hrv/>

Building Conditions:

Temperature, RH, Carbon Dioxide, and Pressure differential with the outside

Ventilator Conditions:

Incoming, Supply, Return, and Exhaust temperature and RH at the duct connection and Electrical power consumed

Broan HRV80T

Mobile Test Lab
200 ft²
3.76 ACH₅₀
0 occupants
Humidified to 40%
Temperature set to 70°F



<https://www.broan.com/Fresh-Air-Systems/Residential-Balanced-Ventilation/Flex-Series/HRV80T>

Building Conditions:

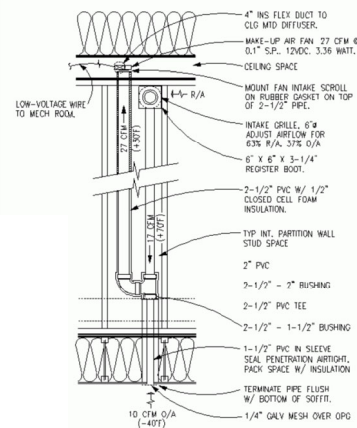
Temperature, RH, Carbon Dioxide, and pressure differential with the outside

Ventilator Conditions:

Incoming, Supply, Return, and Exhaust temperature and RH at the duct connection and Electrical power consumed

Exhaust system with tempered make-up air

Private Home
900 ft²
2 occupants



(Crosby, 2001)

Interior Conditions:

Temperature, RH, and Carbon Dioxide

Ventilator Conditions:

Supply Temperature and RH on the inside of the passive supply ducts

Results

There were two different protocols for collecting and evaluating data for the MTL and for private homes. The private homes allowed for minimal data collection in 2- to 4-week periods with no checking of equipment during those periods. Results for these three installations are included toward the end of this section.

All MTL units had the same controlled interior conditions, except for several power outages in January. They ran in the MTL at different times, as shown in Figure 1. Figure 1 also shows the daily outside temperature range during the study.

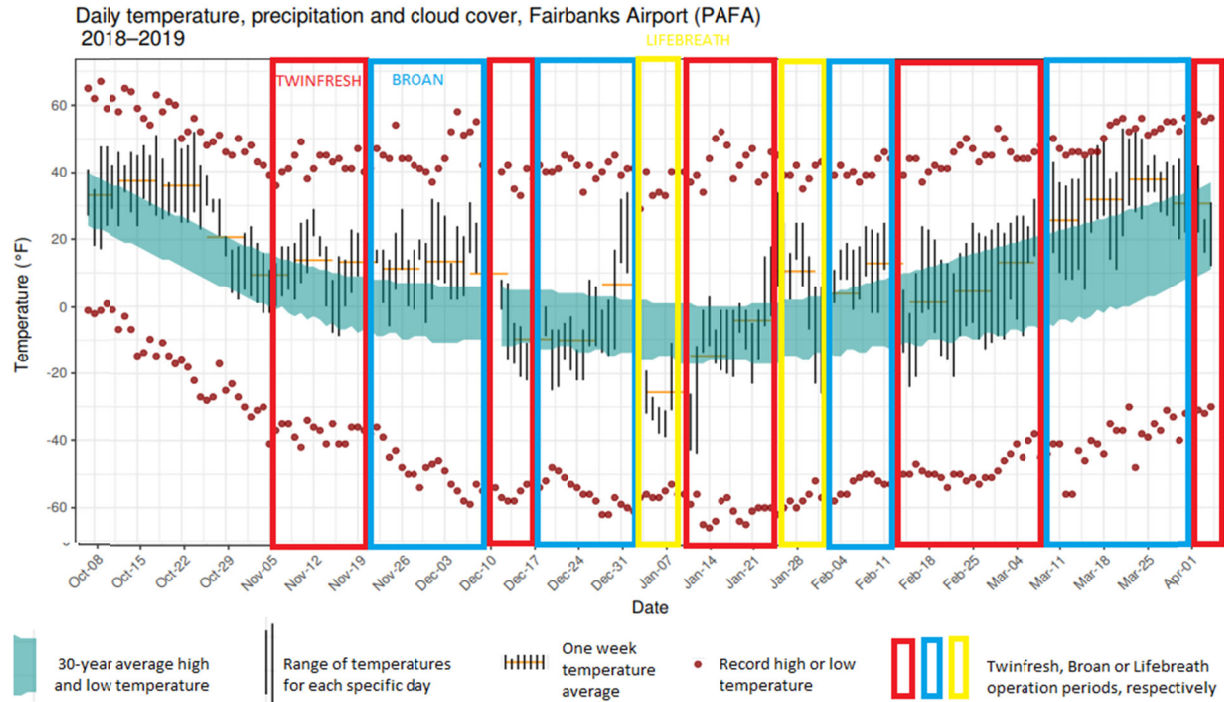


Figure 1. The MTL study period. The Lifebreath unit was running at the coldest outside temperatures and encountered power outages. Adapted with permission from C. S. Swingley. (2019).

The two HRVs in the MTL had the same sensor naming system. Figure 2 presents a diagram of an HRV with the location of sensors.

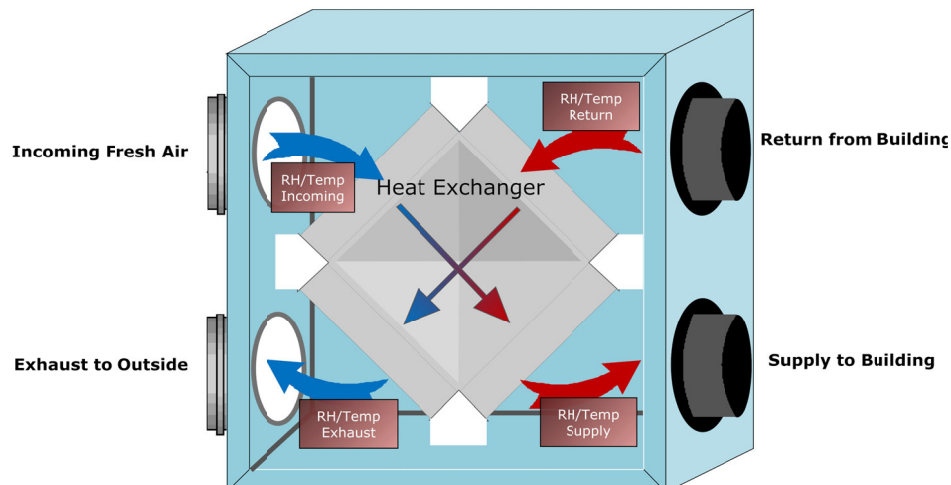


Figure 2. HRV schematic with sensor locations. This naming is repeated in the charts for the MTL HRVs.

MTL TwinFresh

The TwinFresh Expert RA1-50-2 was installed in CCHRC's MTL. As a system, it consists of two through-wall units installed at opposite ends of the 24-foot length of the 200 ft² lab. An air leakage test found the MTL is 3.76 ACH at 50 Pa (ACH₅₀) or about 5.2 CFM of natural air leakage.

The manufacturer's specifications state this unit will deliver from 9 to 29 CFM depending on its speed



setting. The specifications also claim 82-97% heat recovery depending on speed. The TwinFresh airflow on high speed was measured at 11.5 CFM at 21°F outside. Lower settings did not provide enough airflow to be accurately measured. The airflow was measured at 23.25 CFM on high speed and 15.25 CFM on medium speed at 43°F outside. The two units moved a volume of air within 1 CFM of each other in supply or exhaust.

An examination of the TwinFresh performance during two time periods (November 5, 2018 to November 14, 2018 and the day of April 2, 2019) illustrates its working characteristics. The core heat transfer efficiency was calculated using equation 1.

$$\text{heat transfer efficiency} = \frac{(T_{in} - T_{exh})}{(T_{in} - T_{out})} \quad (1)$$

Where,

T_{in} = interior temperature

T_{out} = exterior temperature

T_{exh} = the average exhaust temperature

Equation 1 is based on a 140-second cycle, which includes 70 seconds of supply and 70 seconds of exhaust. There are sensor errors that were accounted for when the average exhaust temperature was determined.

The period from November 5-14, 2018 illustrates the normal working conditions of the TwinFresh around the critical temperatures over a period of 10 days. Note that while the core of the unit did not freeze, moisture condensate accumulated in the hood, especially in conditions at or below the crucial zone of exterior temperatures (about 20°F) (Figure 3).



Figure 3. The TwinFresh outside hood. The hood was filled with ice, completely preventing airflow.

Figure 4 shows the calculated efficiency with the interior and exterior temperatures. When it was colder than 20°F, icing started to occur inside the exhaust hood. On November 7, the icing passed a critical threshold and began impeding system efficiency. A period where the temperature exceeded 25°F for approximately 24 hours on November 11-12 de-iced the exhaust hood and restored normal airflow. Following November 14, 2018, the temperature fell below 20°F for an extended period and the exhaust hood became fully frozen, blocking airflow; this can be seen in Figure 4 when the efficiency drops suddenly below zero.

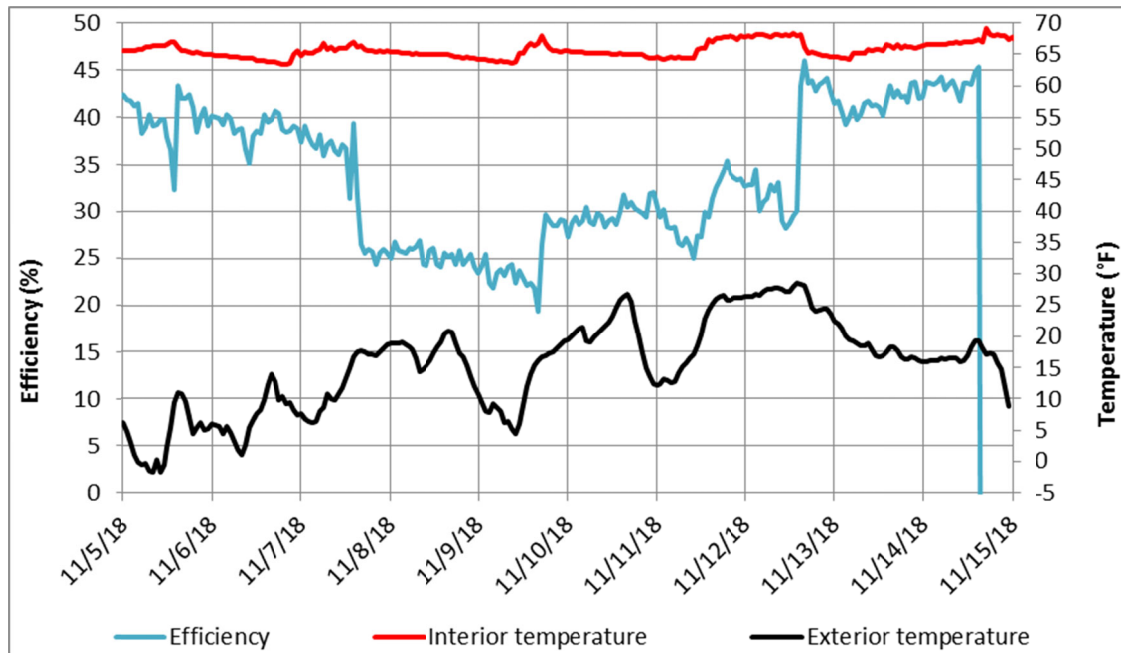


Figure 4. TwinFresh efficiency and surrounding conditions. The drop in efficiency at colder temperatures is an indication of ice blocking air movement.

Figure 5 provides a closer view of interior conditions over the same period.

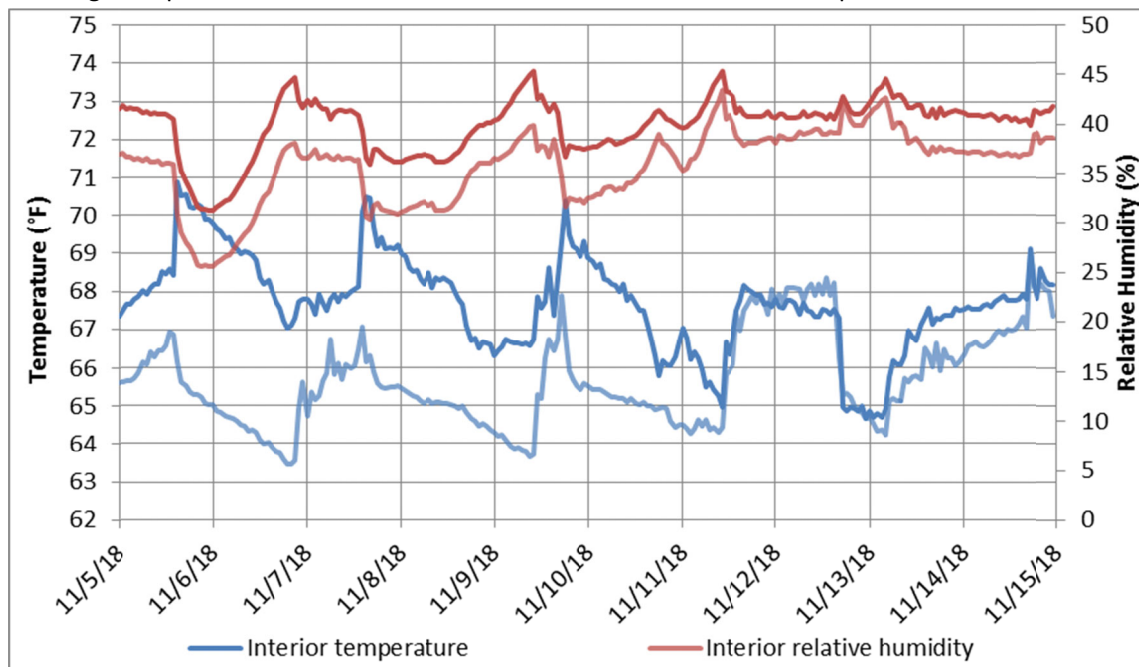


Figure 5. MTL interior conditions. Note the inside temperature stability on November 11 and 12 corresponding to the period when the outside temperature was above 25°F. The two shades of temperature and relative humidity show the variation between the interior sensors, mostly due to placement within the room.

Figure 6 illustrates data from the period in a different way. By plotting efficiency vs. temperature, two distinct clouds of data emerge. The points of lower efficiency correspond to the period where partial icing of the exhaust hood was identified.

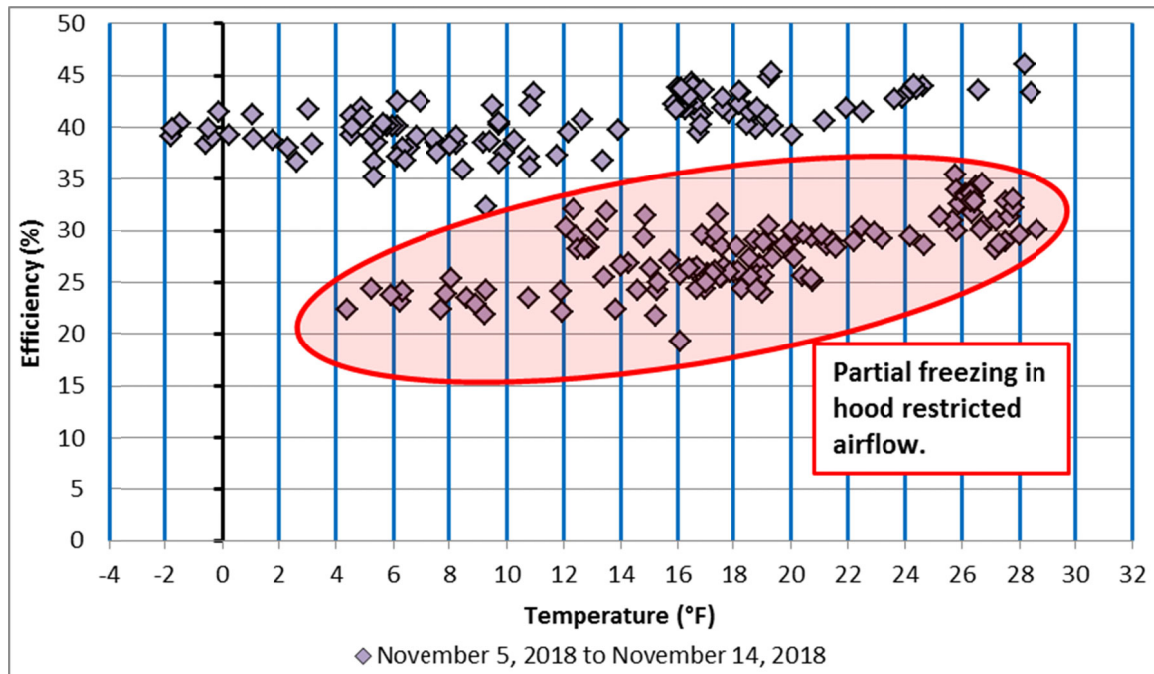


Figure 6. TwinFresh efficiency vs. outside temperature. When the TwinFresh was running as designed, it had a relatively stable efficiency around 40%, much lower than the 82-97% in the specifications.

Figure 7 identifies the periods where the temperature in the TwinFresh core was below the calculated dew point for the interior conditions. Based on the findings, the primary issue with the TwinFresh's performance is the hood design. The hood will ice up and impede airflow before the temperature in the core can reach both the dew point and freezing conditions.

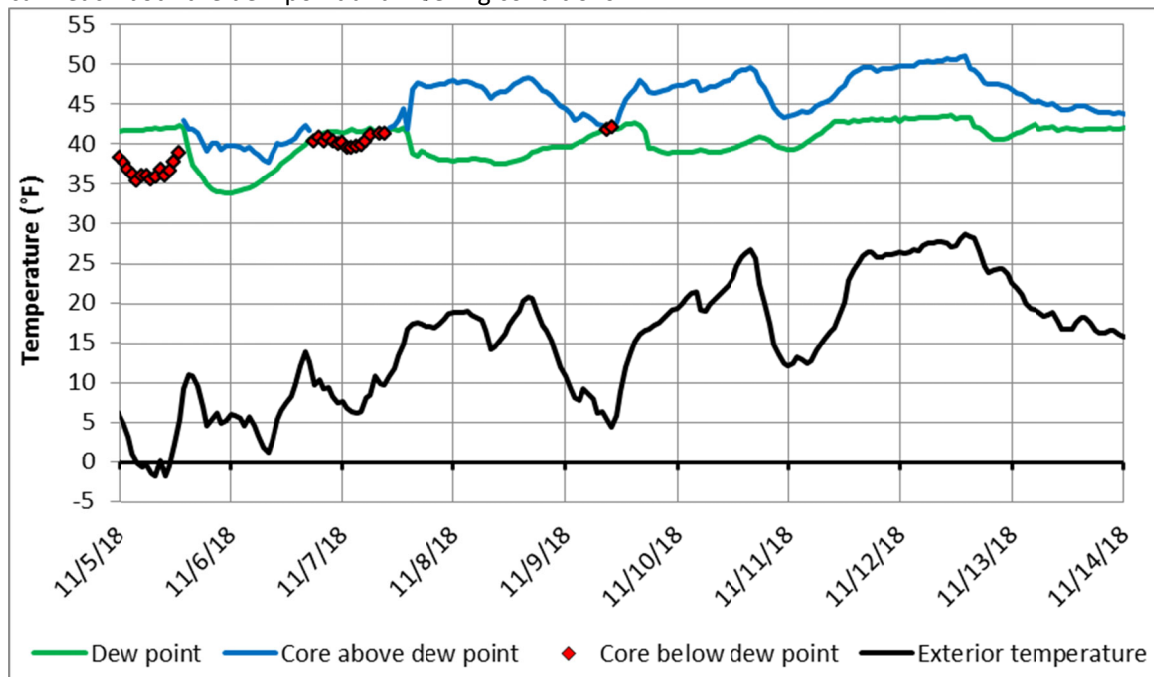


Figure 7. TwinFresh dew point in the core. The core temperature is an estimate based on the average of the inner and outer temperatures around the core.

The period on April 2, 2019 shown in Figure 8 illustrates the normal working conditions of the TwinFresh



in ideal temperature conditions. Figure 8 also shows the calculated efficiency with interior and exterior temperatures.

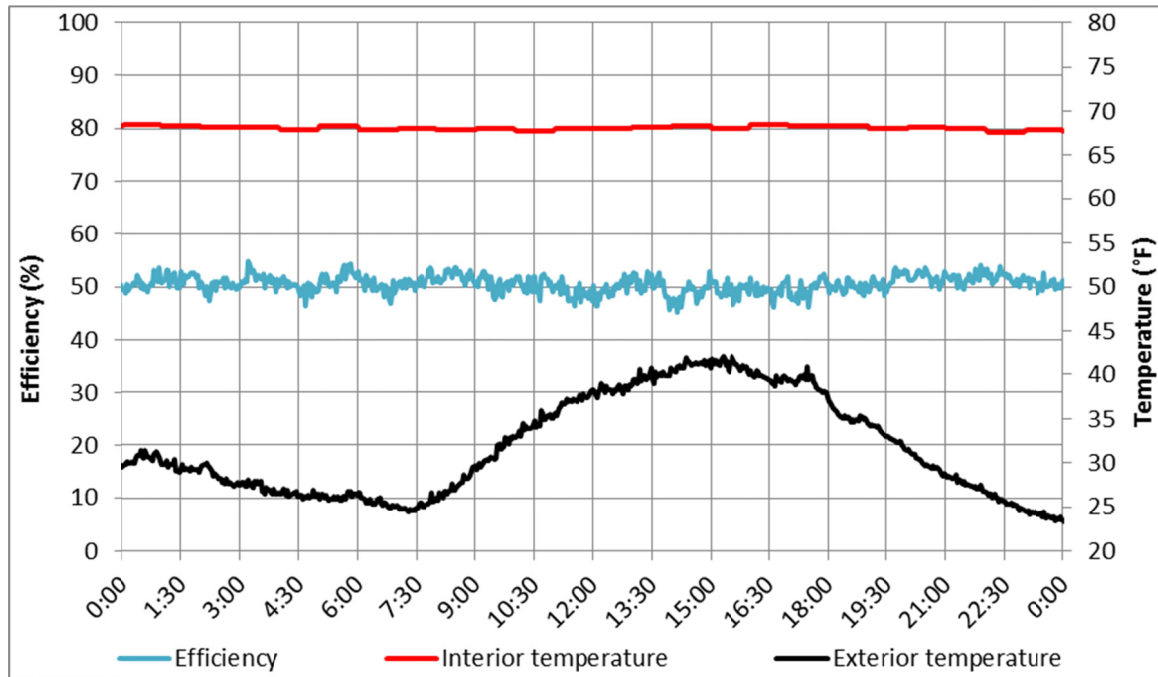


Figure 8. TwinFresh efficiency at warmer temperature. The heat transfer efficiency was constant at 50%, not near the expected 82-97%.

Figure 9 is a closer view of the interior conditions and shows much more stable temperature and RH profiles as compared to the November period in Figure 5.

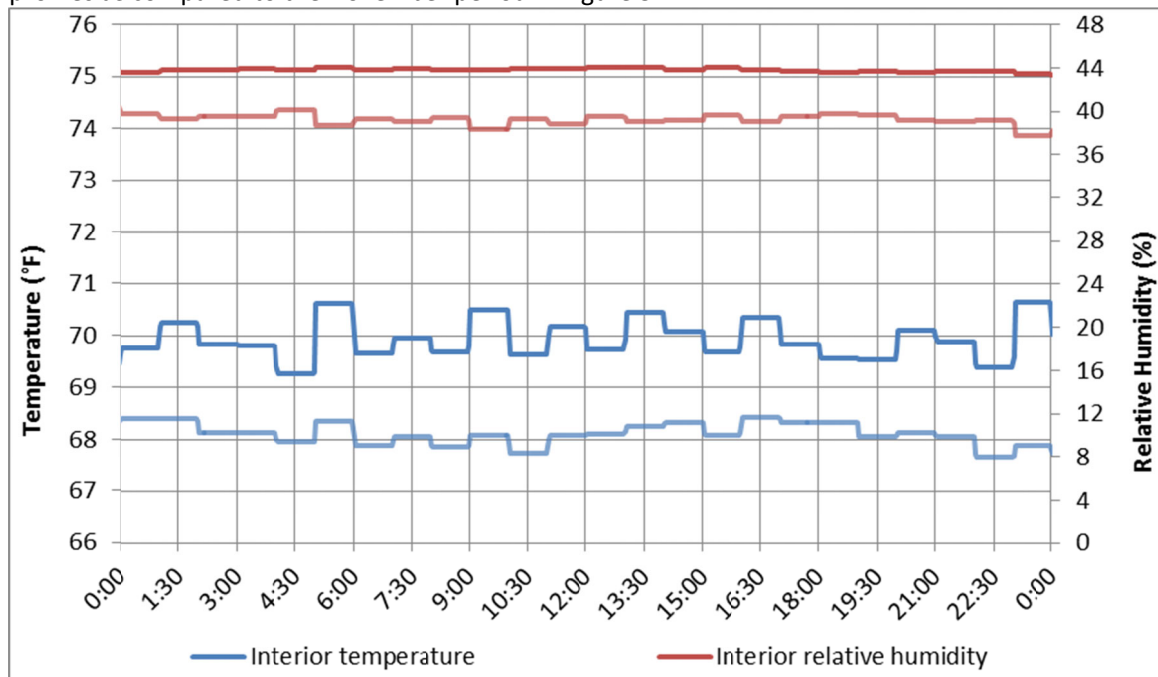


Figure 9. MTL interior conditions on April 2, 2019. The two lines come from different sensors, the variation in readings show less-than-perfect air mixing.



Figure 10 shows a single data cloud and a fairly consistent efficiency range. This indicates that abnormal conditions were not affecting the TwinFresh, such as the partial icing observed in the November period.

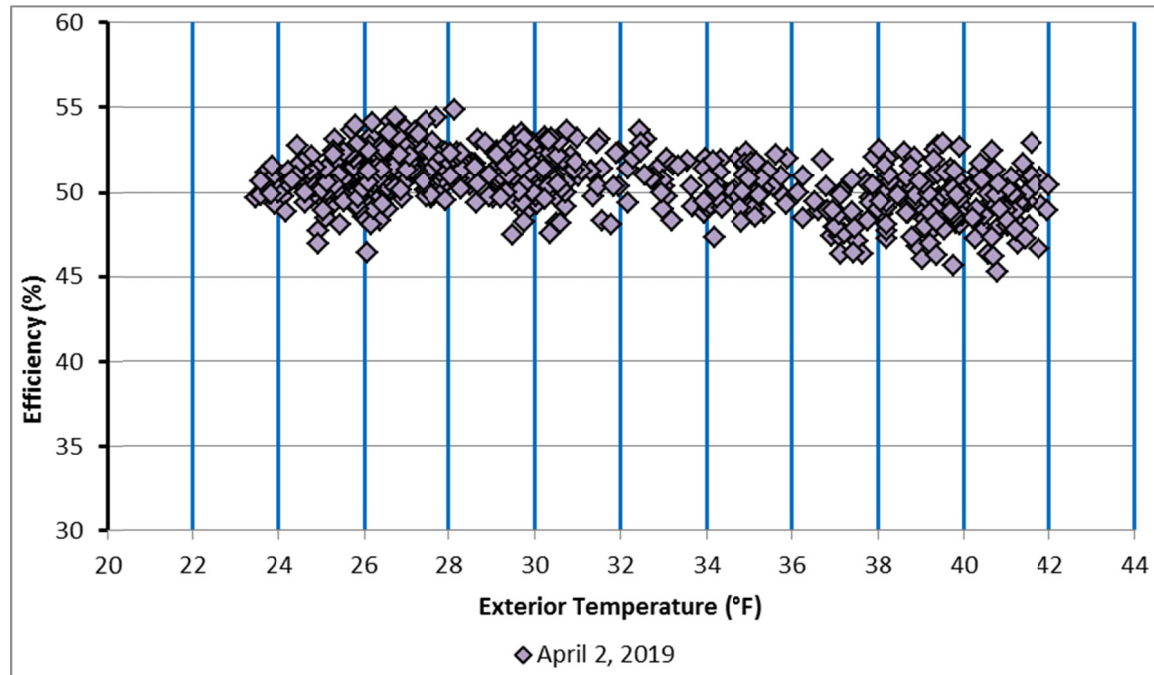


Figure 10. TwinFresh efficiency versus outdoor temperature. The efficiency is consistently around 50% from 24 to 42°F.

Figure 11 shows that the core temperature never fell below the calculated dew point, so no condensation occurred in the core. This is a difference from the colder November period.

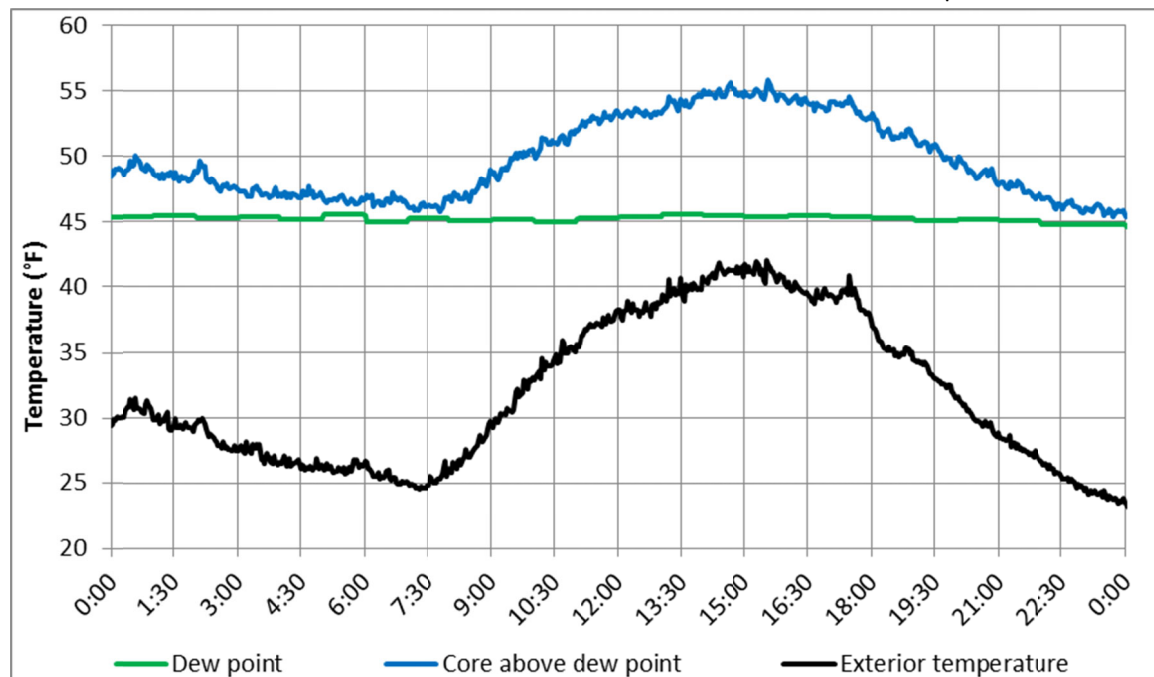


Figure 11. TwinFresh core temperature and dew point comparison for April. The core temperature is an estimate based on the average of the inner and outer temperatures around the core.



Since the manufacturer's exterior hoods froze closed but the cores remained ice-free, different outside hood configurations were implemented. The manufacturer's hood was removed from the north-side unit and left open. The fans and the core developed ice that rendered the unit inoperable within a week. The south side hood was replaced with a typical 6-inch exhaust hood with no damper. The hood did not freeze closed but ice developed around it (Figure 12).



Figure 12. Ice around modified TwinFresh hood. This ice developed over the course of 10 days in January, when the outside temperature averaged -7°F .

MTL Lifebreath

The Lifebreath RNC4-TPD was installed into the ducted system in the MTL. The unit ran on low speed throughout most of the testing portion of the study. The unit was tested from January 4-9, when it failed. A visual inspection determined there was ice build-up in the unit cabinet and core. CCHRC research staff confirmed with Lifebreath's technical support service that the unit was configured properly for defrost mode to occur automatically. The RNC4-TPD's condensate drain outlets were installed incorrectly, which inhibited the release of condensate before the condensate froze. This exacerbated the freezing problems of the unit. Unfortunately, this was not corrected prior to the second test run. The ice from the unit was melted and measured at 0.75 liters. Figure 13 shows the ice on the top of the HRV core.

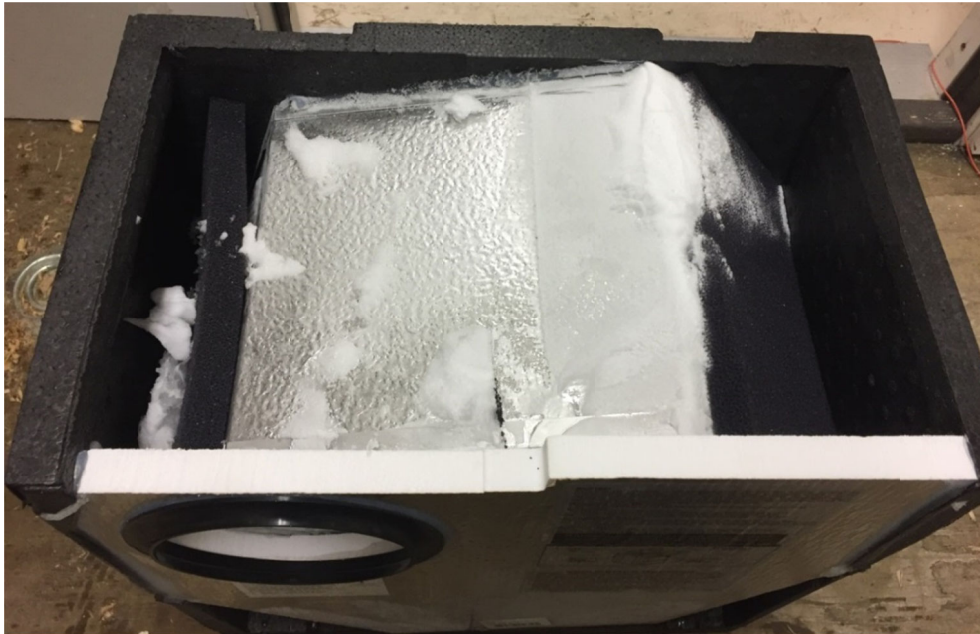


Figure 13. Ice on the top of the Lifebreath core. The black filter visible to the left is frozen to the core and blocks the view of the core.

Figure 14 and 15 show the temperatures and relative humidity entering the Lifebreath core from all four sides compared to the MTL inside and outside temperatures. The defrost cycles can be observed as spikes in the data for the supply air, exhaust air, and incoming air; they occur roughly every 15 minutes. Exterior temperatures averaged 21.1°F during this test period.

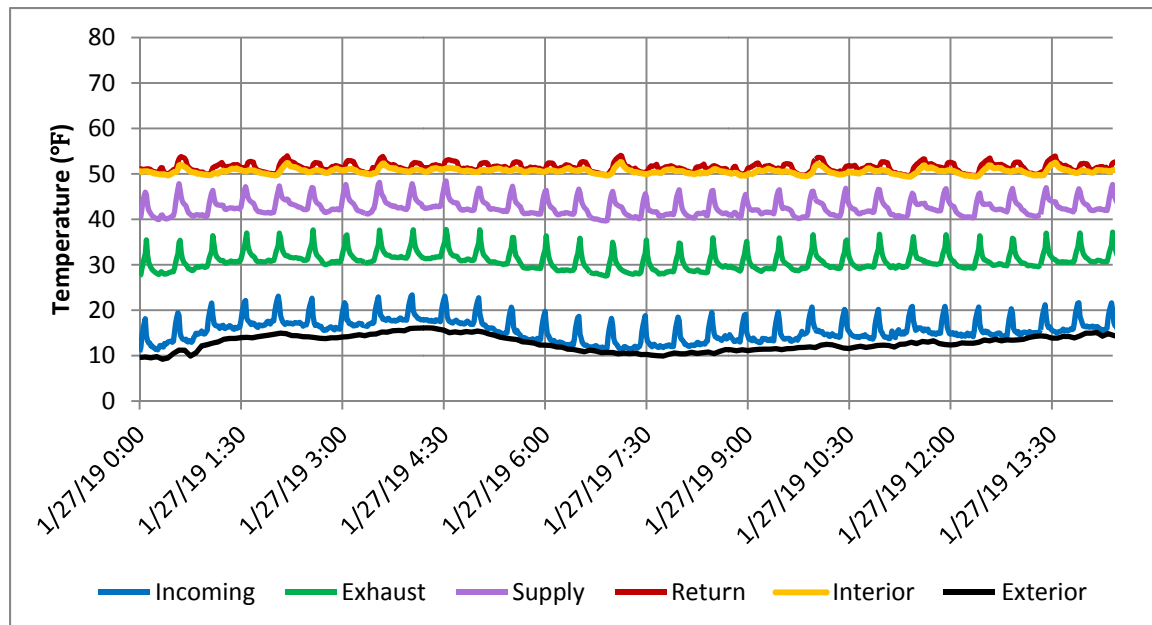


Figure 14. Temperatures in the Lifebreath air streams and MTL conditions. The location names correspond with Figure 2.

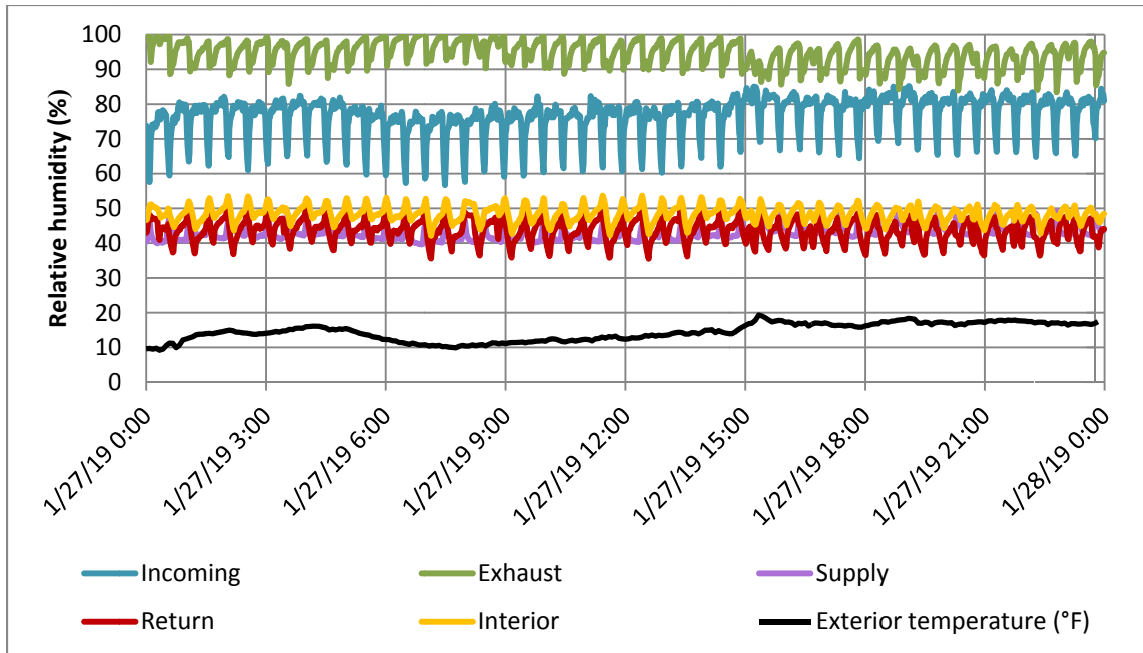


Figure 15. Relative humidity in the Lifebreath air streams and MTL conditions. The location names correspond with Figure 2.

Figure 16 shows when the temperature in the core was in danger of condensing and freezing. The 40% humidity inside the MTL created the worst-case scenario for condensation in the HRV. The dew point line is based on the interior conditions and is higher than typical because of the high humidity. Ice developed in the core where the red dots occurred below the freezing line. Toward the end of this period, the defrost cycles were not keeping up with the ice formation and the HRV failed.

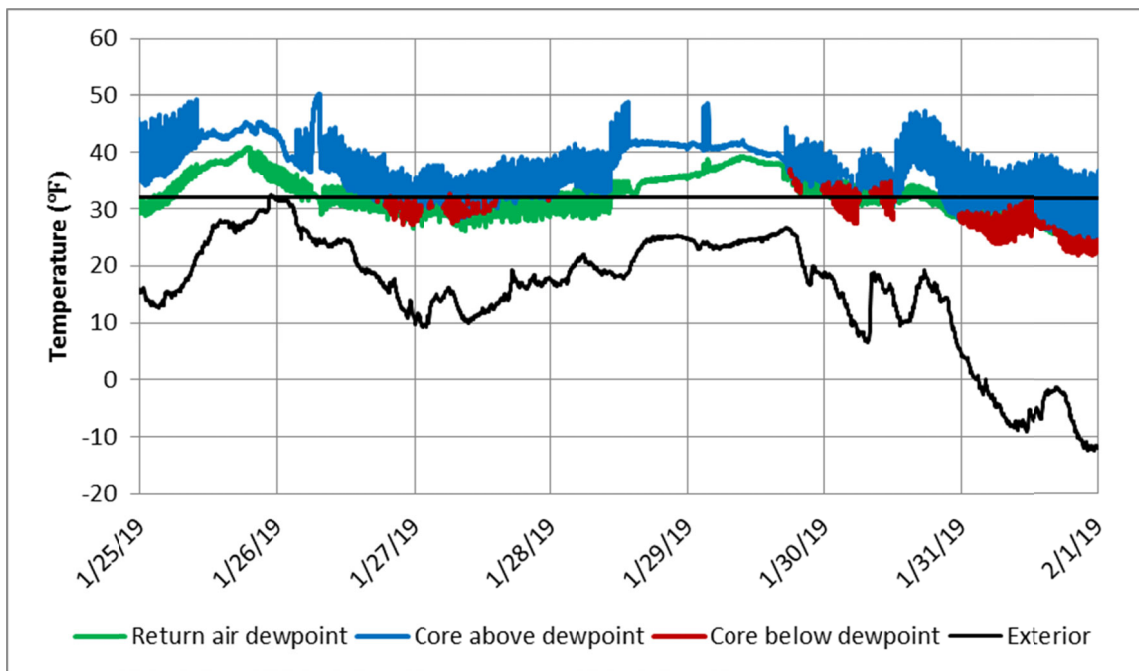


Figure 16. Lifebreath exhaust and return air temperatures. This demonstrates periods when the HRV core was above or below the dew point with respect to the exhaust air stream. The instances of condensate freezing potential increased from January 30 until the HRV ultimately ceased operation on February 1.



MTL Broan

The Broan HRV80T was installed into the ducted system in the MTL. The Broan ran on multiple speeds over the course of the study. This unit was set to “extended defrost” mode, as described in Table 3.

Table 3. Broan defrost cycle from the HRV80T manual.

Regular defrost cycle			Extended defrost cycle	
Outdoor temperature (°F)	Defrosting (minutes)	Operation between each defrost cycle (minutes)	Defrosting (minutes)	Operation between each defrost cycle (minutes)
23	5	30	6	20
5	5	20	6	15
-17	7	15	7	12

December 30, 2018 data for the Broan is shown in Figure 17. The figure shows the temperatures in the four air streams by the Broan unit together with the outside temperature and room temperature. The defrost cycles can be seen as spikes in the data until the outside temperature rose above 0°F. The data shows that the Broan successfully defrosts. The exhaust temperature is warm when compared to the exterior temperature showing that the heat exchange efficiency is not very high for this time period.

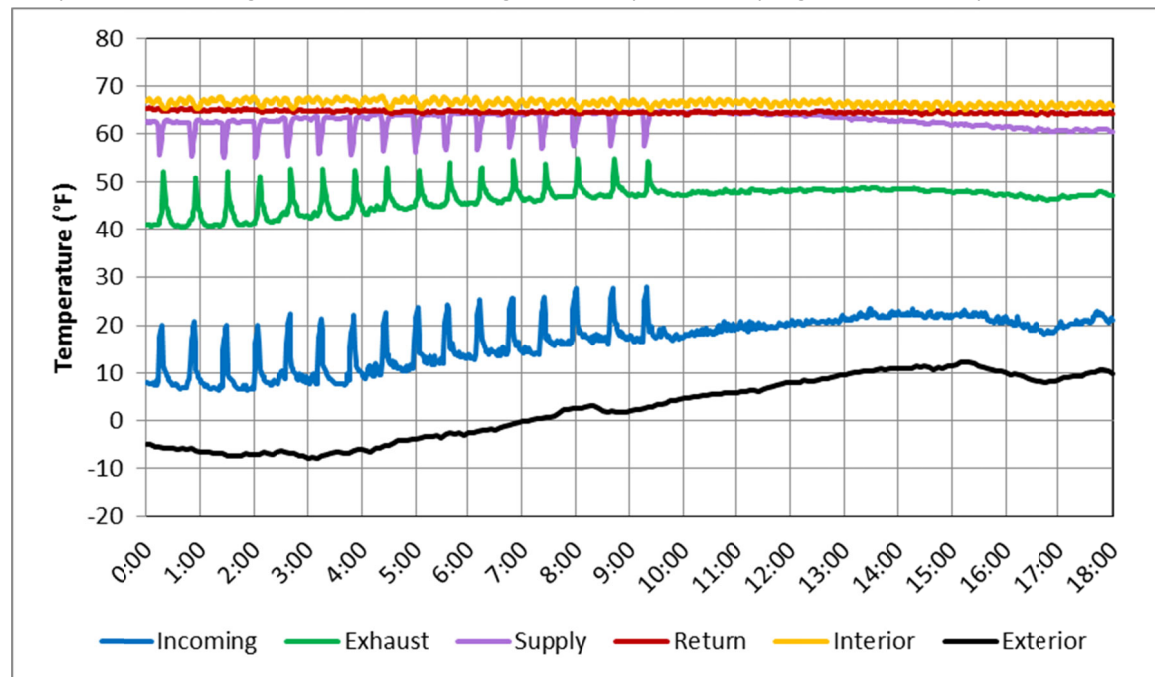


Figure 17. Temperatures in the Broan system on 12/30/2018. The incoming air from the outside (blue) is warmed in the duct slightly before reaching the Broan unit. There, the heat exchange from the return air warms that stream further, so the supply air into the room (purple line) is not too different from room temperature. The heat being removed from the room (return, in red) is room temperature; however it transfers some of its heat to the incoming air so that by the time it is exhausted outside (in green) it is cooler than room temperature. The location names correspond with Figure 2.

The relative humidity in the four air streams as well as the room is shown in Figure 18. The HRV does not recover moisture, which is apparent in the low humidity in the supply air to the building. Most of the moisture in the 30-40% humidity room air is exhausted outside in the exhaust air stream (70-80% humidity when not in defrost mode). An energy recovery ventilator (ERV), which can recover some moisture, would



alter this graph slightly.

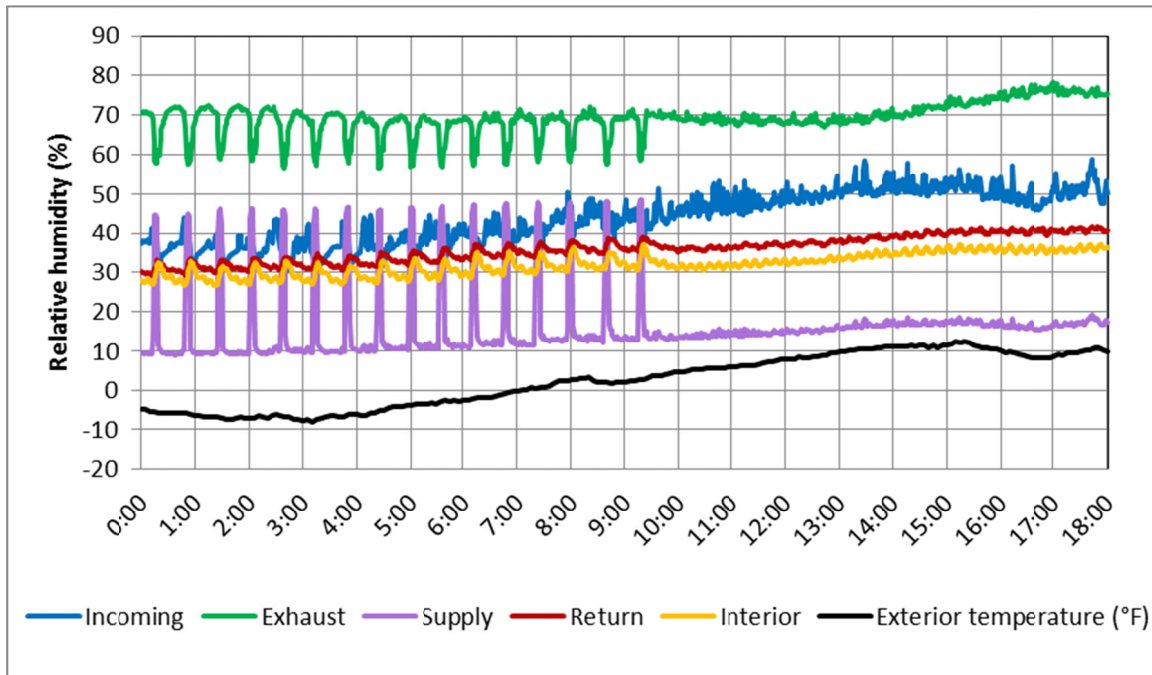


Figure 18. Broan system relative humidity on 12/30/2018. The location names correspond with Figure 2.

For the same time period, the dew point of the return air is shown in Figure 19, together with the core temperature (which is actually the exhaust temperature, the coldest part of the exhaust stream). During this period, the HRV core temperature remains well above the calculated dew point, indicating that the air in the core is not likely to condense.

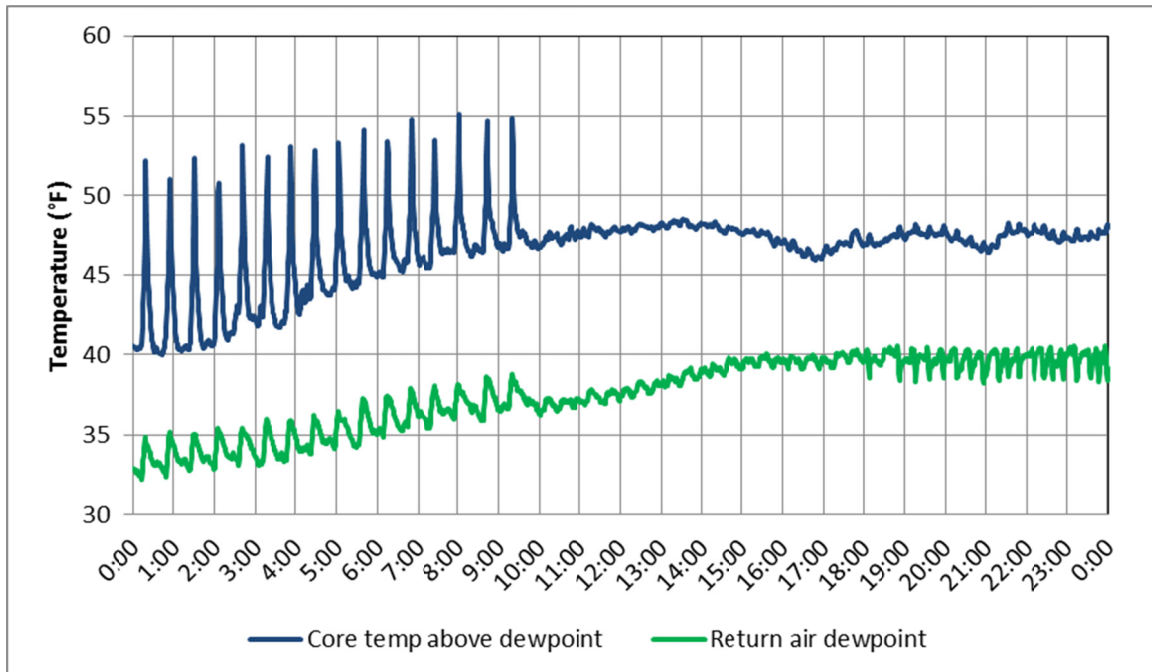


Figure 19. Temperatures in the Broan for December 30, 2018. The calculated dew point of the return air is shown, as well as the temperature of the exhaust (core).



A somewhat different picture emerges from the same data taken approximately a week earlier, shown in Figure 20. During that time, the exhaust (core) temperature dropped below the calculated dew point at certain points.

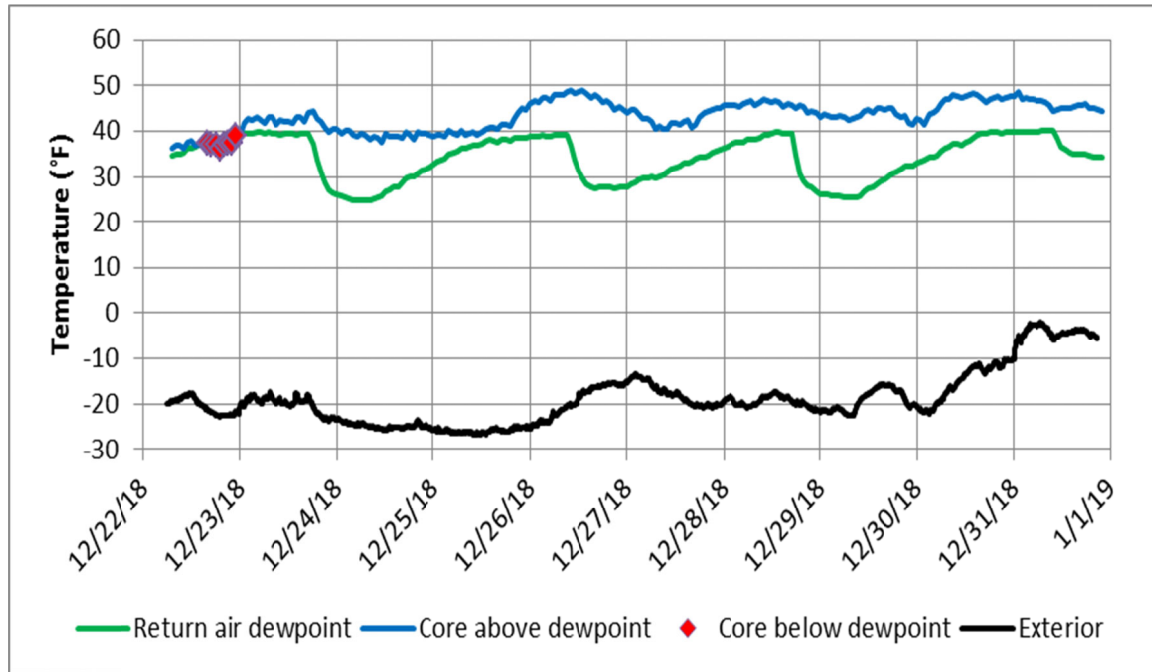


Figure 20. The freezing potential for the Broan HRV core. Even though the exhaust (core) temperature dipped below the dew point a few times, the exhaust (core) temperature was always above freezing in this period so there was no freezing potential.

Lunos E2

The Lunos E2 was installed in a 1000 ft² home with a single occupant. ASHRAE recommended a whole-house ventilation rate of 45 CFM for this house. The Lunos E2 is installed as two through-wall units—one upstairs and one downstairs. The units are designed to work in tandem with one exhausting for 70 seconds while the other supplies; then they reverse. The maximum supply air from either unit is 16 CFM and the maximum exhaust is 24 CFM. The two units do not have balanced exhaust and supply flows as shown in Table 4. The Lunos data specifications state the E2 has 90.6% sensible heat recovery and 20-30% latent recovery. The heat recovery efficiency was not evaluated for this case.

Table 4. Lunos E2 flow.

Unit	Mode (Speed)	Exhaust (cfm)	Supply (cfm)
1st Floor Lunos	4	14	16
	3	10	12
	2	LO	10
	1	LO	LO
2nd Floor Lunos	4	24	16
	3	17	10
	2	13	LO
	1	LO	LO



This unit did not freeze closed during this study. However, the exterior vent did collect significant ice (Figure 21). Some of this could be explained by the temperature sensor installed against the grill, which may have been blocking some of the flow.

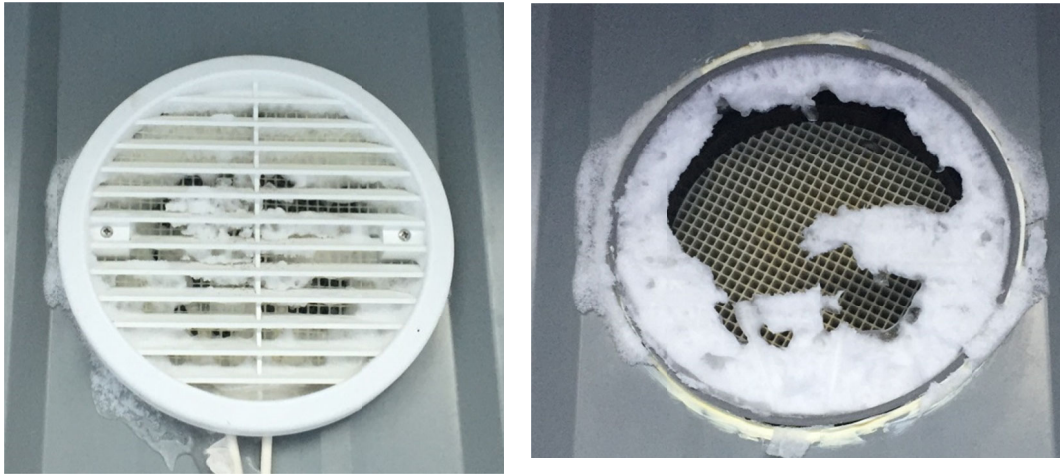


Figure 21. Lunos E2 exterior hood. Ice developed around the outer vent, but it did not extend to the core and did not cut off air supply.

Figure 22 displays the interior conditions for the E2 home. The interior temperature appears to remain constant around an average temperature of 67°F during the tested time period. A healthy range in relative humidity, but lower than 40%, is achieved by the Lunos E2 with the exception of the readings on December 15. Both relative humidity and interior CO₂ experienced an increase during this time as a result of the homeowner hosting a party. It is unknown how many guests were in the home, but it was enough to produce the maximum level of carbon dioxide (5000 ppm) that the data logger could read. Shortly after the party, it did not take long for the ventilation system to correct for the high levels in relative humidity and carbon dioxide.

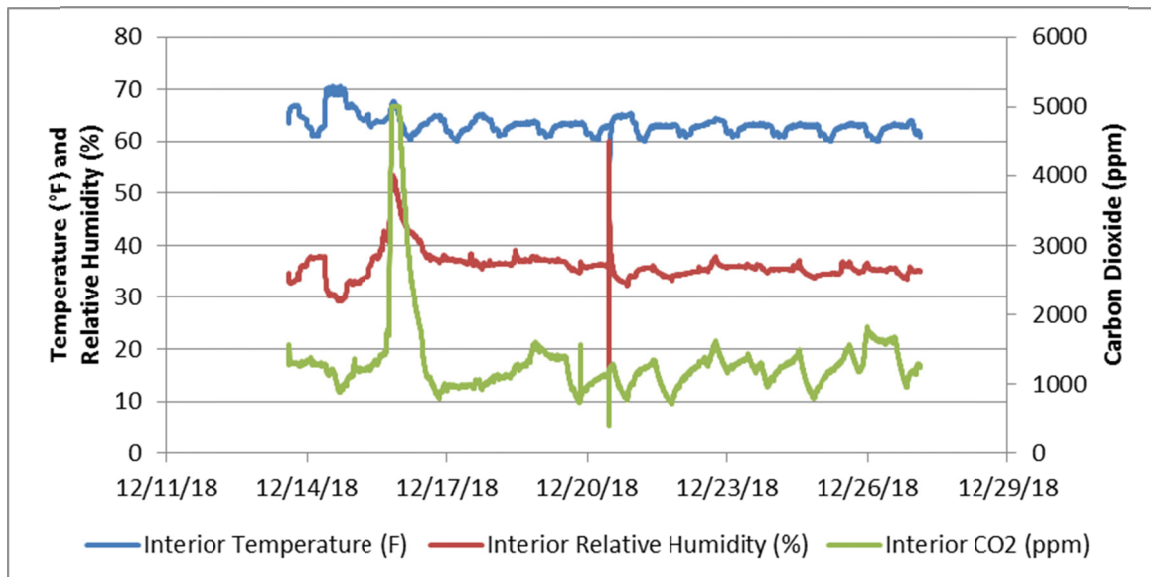


Figure 22. Lunos E2 interior conditions over a 2-week time period. Note that the spike in relative humidity on December 20th is an error.



Figure 23 shows the inner and outer temperatures for the downstairs E2 unit. The 70-second cycles are apparent in the changes in temperature. There is a certain amount of heat recovery visible in the inner core temperature; it does not drop much below 45°F when the outside air (at 0°F or colder) is entering the space.

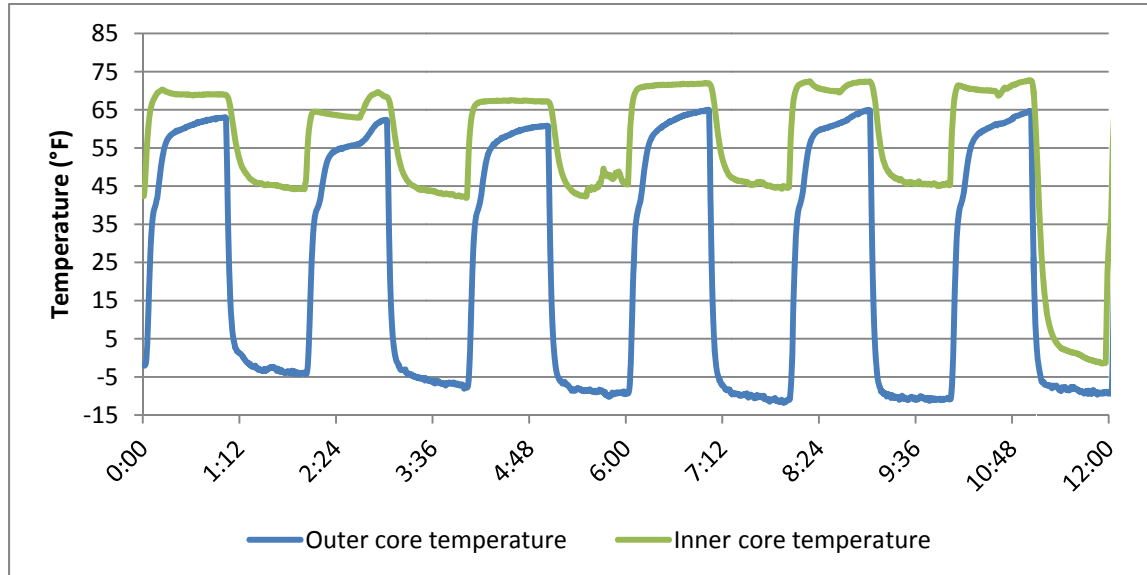


Figure 23. Downstairs E2 conditions on 12/17/2018. The alternating supply and exhaust cycles are readily apparent.

Figure 24 shows the inner core temperature for the upstairs and downstairs E2 units. They are well synced in their exhaust and supply cycles. The downstairs unit is warmer than the upstairs unit, which could be due to variation in airflow or could simply be in a warmer part of the house.

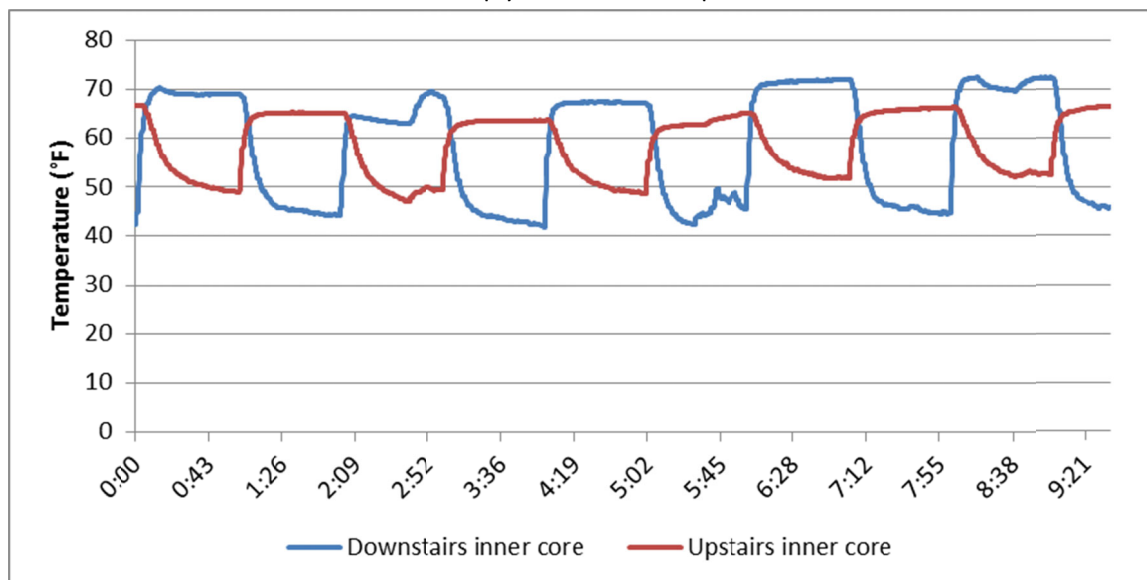


Figure 24. Both E2 units cycling on 12/17/2018. There is very little difference in the lowest and highest temperatures in each unit (about 6°F).



Lunos Ego

This private home has a Lunos Ego, with a range hood exhaust (evaluated at 52 CFM) and a passive make-up air vent. The Ego runs 24 hours a day and the range hood is used intermittently. This is a tiny house that is only 280 ft² and has three occupants. The ASHRAE recommended whole building ventilation rate is 25.3 CFM. The building envelope is very tight, running at 1.2 air changes per hour at 50 Pa (only about 2.5 CFM of natural infiltration). The Ego only introduces 10 CFM of air to the living space when running properly. Lunos technical specs state that the Ego has 85% sensible recovery and 20% latent recovery while delivering 3 to 12 CFM of air.

While this unit did not freeze during the test, the homeowners reported frequent freezing during the previous winter. Based on the tests of the TwinFresh in the MTL, it is likely that the exhaust hood on this unit freezes and the core remains mostly free of ice (Figure 25).



Figure 25. The Lunos Ego exhaust hood at the end of the data collection period. This hood remained free of ice during the data collection period mainly due to warmer-than-typical temperatures.

Figure 26 shows the interior conditions during the Lunos Ego study period. The CO₂ is elevated when the building is occupied. The CO₂ should ideally be below 1200 ppm. In this house the CO₂ is consistently above 1200 ppm, indicating the house is not getting enough ventilation. The relative humidity is also higher than a typical Fairbanks house (around 20%), averaging 45% most of the time. There is limited data on the ventilator performance due to the restrictions on collecting data outside of this home.

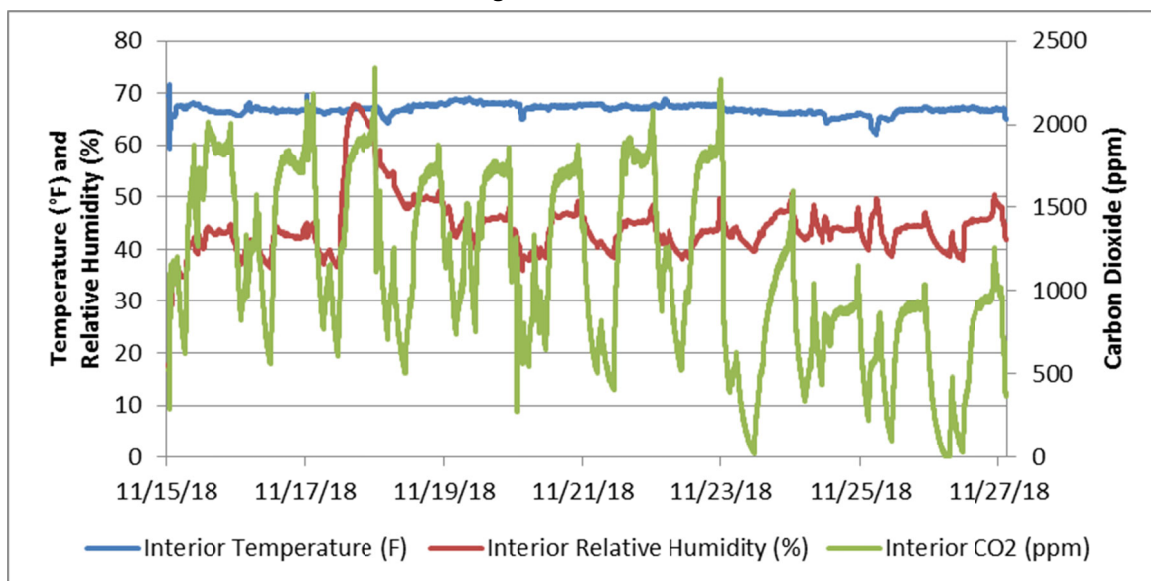




Figure 26. Lunos Ego interior conditions. The spike in relative humidity on 11/18/2018 is unexplained but is probably the result of occupant behavior.

Exhaust system

This home had an exhaust fan with tempered make-up air vents with recirculating fans in them. The system was designed by Robert Crosby (2001) for prototype homes in Dillingham, Alaska. This whole-house ventilation system relies on an exhaust fan (typically a bath fan). For make-up air, it has in-wall ducts that bring in air from outside and temper it with inside air (Figure 27). The tested system had two make-up air ducts with small fans installed, each blowing 11 CFM of air into the space, however it is uncertain how much was fresh air. The only exhaust is the fan on the pellet stove and the intermittently used kitchen range hood (the range hood backdrafts the pellet stove when in operation).



Figure 27. Supply openings. On the left are the two supplies near the ceiling circled in red. The right photo shows the full length of one of the supply ducts (outlined in blue).

The current ventilation strategy is not adequate to maintain healthy indoor air. Figure 28 shows indoor air conditions over the course of the study. The CO₂ reached above 2000 ppm when the house was occupied. In order to know if IAQ is healthy, the CO₂ should be below 1200 ppm when occupied. High CO₂ is an indication of high concentrations of other indoor pollutants, not just CO₂. The relative humidity is high for a Fairbanks house with an average of 41%; however, it is within the recommended healthy range (Sterling et al., 1984).

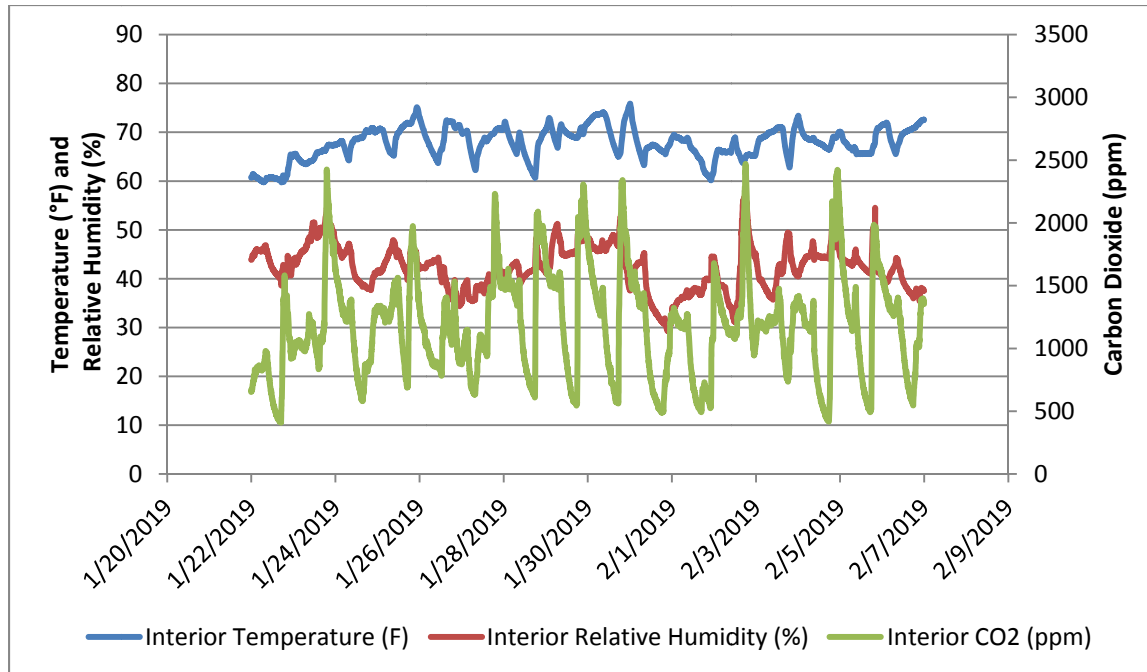


Figure 28. Exhaust system house interior conditions. The high CO₂ indicates a lack of adequate ventilation. The house is humidified.

The custom ventilation system does not seem to be bringing in any outside air in its current configuration. Figure 29 shows the data from all four data points in the house; two were at the inlet of the mixing port, one was at the grille for the room supply and the other was in the living space. The temperatures are all identical and the RH is within 5% (the error on the sensor). It looks like the mixing port on the supply is “short-circuiting” any fresh air introduction.

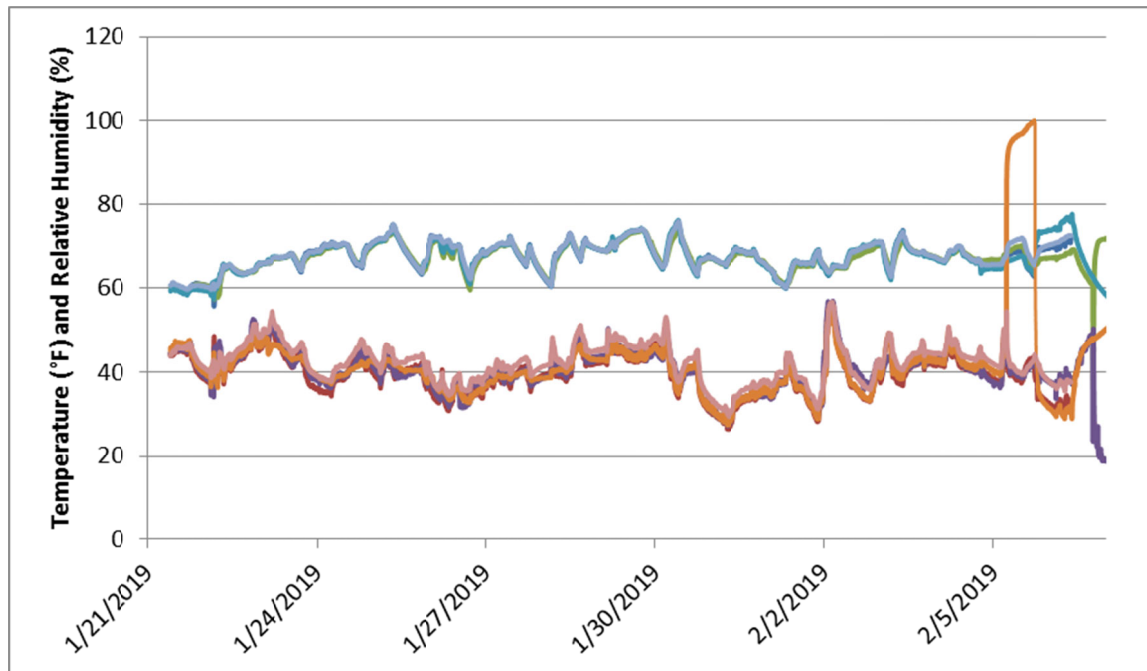


Figure 29. Temperature and RH in the custom exhaust system house. The upper 4 lines are temperature and the bottom 4 lines are relative humidity.



Discussion

Airflow of small through-wall ventilators

During the initial survey for this project, several respondents asked if the through-wall ventilators delivered enough air and if they “threw” the air far enough into the room. The two Lunos systems in the private homes delivered near their specifications. The Ego was delivering about 10 CFM to the living space the day it was tested, less than half the ASHRAE recommended amount of air for this particular house. The air in the living space had high CO₂ indicative of poor air quality, which is to be expected with only half the recommended fresh air entering the living space.

The E2 was installed in a larger house with lower occupancy. Larger than the other through-wall ventilators, the E2 exhausted a maximum of 24 CFM during this test. While the ASHRAE recommendation is 45 CFM, the low occupancy of this house keeps the CO₂ low. As a verification of adequate air changes, CO₂ is a poor metric for healthy air in this case. Although, the one instance the CO₂ went above the danger zone on 12/15/2018 it only took about 10 hours for the CO₂ to return to decent levels. If the E2 was the only ventilation running at the time, this is a good indicator of how well it was ventilating (Figure 22). The E2 units did not have equal supply and exhaust airflow rates, which could lead to a pressure imbalance across the building envelope and could backdraft combustion appliances.

The airflow in the TwinFresh came close to the maximum specified flow of 29 CFM at 43°F outside, but it was only 11.5 CFM when it was 21°F outside. The two units were within 1 CFM of each other, leading to a slightly more balanced system than the E2. There was a 5-person meeting in the MTL in May to try to create an instance of elevated CO₂. In the 30 minute meeting, the CO₂ only rose to a maximum of 1398 ppm and following the meeting it dropped rapidly back to ambient (Figure 30). For comparison, the CO₂ directly in the incoming and exiting air of the TwinFresh was also recorded. When it was supplying air in the room the CO₂ dropped almost back to ambient and when it was exhausting it was less than 200 ppm difference from the room CO₂. From this data it appears that the TwinFresh is an effective room ventilator.

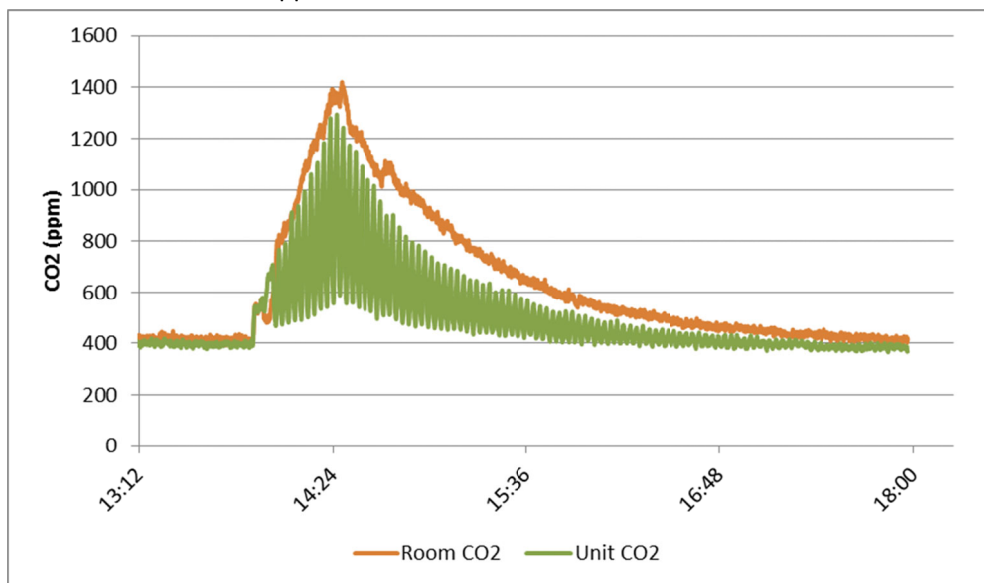


Figure 30. CO₂ in the MTL after a 5-person meeting. The jump in CO₂ around 14:45 is due to the humidifier being restarted.



Freezing potential

Of all the units studied, only the Broan and the Lunos E2 did not have freezing events (or anecdotal evidence of freezing events). The Broan certainly had condensing events but they all occurred above the freezing point due to the Broan's relatively low sensible recovery efficiency keeping the exhausted air relatively warm. The Lunos E2 developed some ice around the outer hood and had the potential to freeze had the interior relative humidity inside been higher.

The TwinFresh through-wall ventilators had the most scrutiny of all systems in this study. They were monitored off and on over the entire winter. The exhaust hood for the TwinFresh started to freeze at temperatures below 20°F. Using a different exhaust hood has the potential to resolve this issue. This study did not have enough time to fully evaluate the second exhaust hood, but it showed promise.

The Lunos Ego did not freeze during this project, but the homeowners reported repeated instances of the system freezing closed the previous winter. The exhaust hood developed some ice during the study and it is possible to see how it could be a problem with longer use. This unit does not have the option of a simple exhaust hood because the incoming and exhausting air streams need to be separated to prevent short-cycling.

The Lifebreath suffered from a faulty installation but also had ice in the core far away from the condensate drains. The test on this unit will need to be rerun to verify the extent of freezing and how much is the result of the incorrect drain installation.

Efficiency

Only the efficiency of the TwinFresh was evaluated in this study. The HRVs already have laboratory-evaluated efficiencies down to -13°F; the three private home systems were not able to provide enough data to determine efficiency. From -2°F to 28°F the TwinFresh efficiency was 35-45% when the hood was clear of ice and between 24 and 42°F the efficiency was 45-55%, far below the 82-97% the manufacturer claims.

Electrical use

Of the ventilation units tested, the TwinFresh RA1-50-2 model had the most unpredictable electrical performance when compared to the manufacturer's specification. Though rated to perform at -22°F, the TwinFresh reliably experienced icing in the exterior hoods at temperatures below 20°F. Once frozen, the TwinFresh would be rendered non-operational, as evidenced by prolonged periods of complete power loss. Once cleared of ice by researchers, the TwinFresh would resume operation, but would again lose functionality due to icing events within several days of exposure to incoming air temperatures less than 20°F. Furthermore, the power usage of the TwinFresh was roughly 30% higher than manufacturer-specified values. There was one exception to this power consumption trend at the beginning of the data collection period, when incoming air temperatures were consistently above 25°F, at which point the TwinFresh consumed only marginally more power than projected for the highest fan speed. Given that the temperature range during the data collection period was almost entirely below 20°F, and given the frequency of icing events, it is theorized that the introduction of ice in the air path may have caused the motor to compensate for the declining amount of air delivered, causing an increase in power consumption. The TwinFresh were otherwise consistent in their patterns of operation. During the entire data collection period, with exceptions only for warmer temperature periods and icing events, the TwinFresh cycled continuously between 10 and 14W, with the supply and exhaust cycle.

The Lifebreath RNC4-TPD operated during a period when incoming air temperatures were consistently



below 0°F, with one 5-day exception during which incoming air temperatures stayed above 0°F. During the colder periods, the Lifebreath operated continuously at low speed with one high-speed recirculation periodic cycle every 30 minutes lasting roughly five minutes. Power consumption during such colder periods was lower than the manufacturer-specified power consumption by roughly 20% at both high and low speeds. During the warmer period, the Lifebreath operated continuously at high speed for four days before returning to a continuous low speed with no high-speed periodic recirculation cycling for one day. Power consumption during this warmer period did not change, and both high and low speeds consumed roughly 20% less power than the manufacturer-specified values. Once incoming air temperatures fell below 0°F, the Lifebreath resumed operating at continuous low speed with periodic high-speed recirculation cycles.

The Broan HRV 80T operated continuously over the course of the data collection period without icing events, and throughout a diverse range of temperature conditions, including prolonged periods when incoming air temperatures were below -13°F. During colder periods, when incoming air temperatures were consistently below 10°F, the Broan operated stably at low speed with one high-speed periodic cycle lasting 5-10 minutes occurring every 45-60 minutes. During colder periods, the power consumption of the Broan at low speeds was roughly 30% less than manufacturer-specified values. Power consumption at high speeds was roughly 10% less than manufacturer-specified values. During warmer periods, when incoming air temperatures were predominantly between 25°F and 35°F, the Broan no longer experienced periodic recirculation cycles, but instead operated at a stable speed. During such warmer periods, the power consumption of the Broan was roughly 10% higher than manufacturer-specified values for high speed, but 20% lower for low speed.

To compare the operational power of the Broan to a comparable, larger model, the operational power consumption of the Venmar EKO 1.5 (an older version of the Broan HRV160ECM) was investigated. The Venmar was installed at a different location, but was subjected to similar environmental conditions. The Venmar EKO 1.5 was operational during a period when incoming air temperatures were predominantly above 32°F. During the first week of operation, the Venmar operated at high speed, and consumed roughly 40% less power than the manufacturer-specified value. When set to a lower speed during this warm period, the Venmar consumed roughly 10% less power than the manufacturer-specified value. Compared to the Broan, the power consumption of the Venmar was considerably less, which is to be expected given that the Venmar is designed to consume less power than the Broan. The Broan HRV 160 ECM is specified to use 24 to 32 W at 32°F outside, the HRV80 is specified to use 37 to 52 W at 32°F outside. This lower electrical use is due to a modulating fan motor that uses less energy and varies speed. This low electrical use might be one of the reasons the larger HRV is often installed.

Conclusion and Suggestions

Ventilation is a necessity to maintain adequate indoor air quality in tight Alaska homes. Smaller homes require less ventilation than can be delivered by some larger HRVs that are typically installed. Six smaller ventilation systems were evaluated and the results are summarized in Table 5.



Table 5. Results.

Unit	Air Delivered	Freezing Potential	Efficiency	Electrial Use
Lunos Ego	10 CFM which is within specifications but less than required for this house	Freezes on a regular basis according to the homeowners	Not evaluated	Not evaluated
Lunos E2	Delivered up to 24 CFM of air but the two units were unbalanced in supply and exhaust	These units developed ice on the exterior grille but did not freeze closed	Not evaluated	Not evaluated
TwinFresh Expert RA1-50-2	Delivered 29 CFM at 43°F and 11.5 CFM at 21°F but the two units were within 1 CFM of each other in supply and exhaust	The exterior hood of both units froze closed repeatedly	-2 to 28 °F efficiency was 35 to 45% From 24 to 42°F efficiency was 45 to 55%	30% higher than specified below 5°F
Lifebreath RNC4-TPD	Not evaluated	The core froze both times it ran, there were some installation problems that may have exacerabated to the freezing	Not evaluated	20% lower than specified power consumption
Broan HRV80T	Not evaluated	The defrost mechanism was sufficient to prevent freezing	Not evaluated	10 to 30% lower than specified power consumption
Exhaust system with tempered make- up air	The tempering vents short cycled this system not allowing much fresh air to enter the space	Had no freezing problems	Not evaluated	Not evaluated

Smaller HRV units are available, however they have higher energy demand and can have performance issues (one of the studied units froze closed). The through-wall ventilators demonstrate some promising results. The TwinFresh was not as efficient as expected but 45% heat recovery is better than an exhaust-only system (with 0% heat recovery). The outside hood design was problematic for freezing, but a different hood could potentially solve this problem. Longer cold weather testing on the alternative hood would help validate this potential.



References

- Alaska Housing Finance Corporation. (2012). Building and energy codes. Retrieved from <https://www.ahfc.us/efficiency/bees/>
- ARIS. (2018). Alaska Retrofit Information System. Alaska Housing Finance Corporation.
- American Society of Heating, Refrigerating and Air-Conditioning Engineers (2013). *Ventilation and acceptable indoor air quality in low-rise residential buildings*. Standard 62.2
- Crosby, R. (2001). A prototype alternative ventilation system for retrofit, rehab and renovation of rural Alaska homes. Retrieved from <https://biorealis.com/ventsystem/coldcomfort.pdf>
- Holladay, M. (2011). European product for building tight homes. Weblog Nov. 25, 2011, Retrieved from <https://www.greenbuildingadvisor.com/article/european-products-for-building-tight-homes>
- Manz, H., Huber, H., Schalin, A., Weber, A., Ferrazzini, M. & Studer, M. (2000). Performance of single room ventilation units with recuperative or regenerative heat recovery. *Energy and Buildings*, 31:37-47.
- Merzkirch, A., Maas, S., Scholzen, F., & Walmann, D. (2016). Field tests of centralized and decentralized ventilation units in residential buildings – Specific fan power, heat recovery efficiency, shortcuts and volume flow unbalances. *Energy and Buildings*, 116: 376-383
- Murgul, V., Vuksanovic, D., Vatin, N., & Pukhkal, V. (2014). Decentralized ventilation systems with exhaust air heat recovery in the case of residential buildings. *Applied Mechanics and Materials*. 680:524-258.
- Sherman, M. (2004). *ASHRAE's New Residential Ventilation Standard*. *ASHRAE Journal*. 46(1):S149-156.
- Sherman, M. (2013). What we know can hurt us. *ASHRAE Journal*, 55(2):75-77.
- Sherman, M. (2015). How ASHRAE set the rates for residential ventilation. *ASHRAE Journal*, 57(7):20-23.
- Sherman, M. H., & Hodgson, A. T. (2004). Formaldehyde as a basis for residential ventilation rates. *Indoor Air*, 14(1):2-8.
- Sterling, E. M., Arundel, A., & Sterling, T. D. (1985). Criteria for human exposure to humidity in occupied buildings. *ASHRAE Transactions*, 91(1):611-622.
- C. S. Swingley. (2019). Daily temperature, precipitation, and cloud cover, Fairbanks Airport, 2018-2019. Retrieved from https://swingleydev.com/weather/ninety_day_summary.php.