Comfort Management

HRV and Heat Pump
for Passive House
with Fresh Air Pre-conditioner
(based upon VanEEPassivePreHeaterDoc_V3.odt)
(and MontgueAirConditioningV0.odt
and MontagueAirConditioning V1.odt)

Comfort Conditions

Comfort means many things to many people. In the this document, comfort is largely defined by the criteria set out by the Passive House Institute. For more information see:

https://passivehouse.com/
https://passivehouse.com/01_passivehouseinstitute/01_passivehouseinstitute.htm

and many related sites on the Internet. Additional criteria are set out by other bodies associated with Building Design including Governments and Health Agencies. The most important of these will result in a healthy environment in which to live and work.

The motivation for the work of PHI and many other related associations has been to reduce our impact on the environment through by minimizing consumption of primary energy resources on an on-going basis and maximizing our utilization of renewable resources during the construction of facilities. In the simplest terms, comfort is delivered through providing an built environment that is energy efficient, built to high standards and operated to supply adequate fresh air, heating as well as cooling, at a very low long-term cost to the building owner and the environment.

Expressed in the more simple terms of human experience this may include:

- air temperatures controlled within a reasonable comfort range of more than 20 degrees C and less than 25 degrees C for the majority of time throughout the building;
- fresh air adequate to minimize odours associated with normal occupancy;
- minimum levels of mechanical noise and draft-free throughout;
- in its design and construction maximize the use of renewable resources and minimize the use of carbon-intensive materials; and,
- on an on-going basis consume as little energy and carbon as can be reasonably be provided.

Cost is also a significant factor and the ultimate target of this work is to design buildings that provide both short and long-term benefits through making appropriate design decisions. Ultimately these decisions should maximize value and minimize both construction and operating costs.

The particular context of this work is the retrofit and operation of a home constructed in 1947 in Winnipeg Canada. It is a classic “story and a half” post-war building located near the core of the city - one of many thousands of such homes in the area. The physical retrofit work was carried out while retaining virtually all of the existing “interior” of the home and it was occupied throughout the work.

The primary objective is to provide guidance for the operation of the home from the perspective of the occupants. A secondary objective is to document some of the equipment choices and why certain operations are required.

Comfort Management Devices

Air conditioning is provided by a range of devices designed to work as a system. These devices are:

- Heat Recovery Ventilator to provide fresh air to the home;
- Fresh air pre-conditioner that treats fresh air before it enters the HRV;
- Dehumidifier to manage levels of humidity;
- Heat Pump to provide cooling in the summer and heating during the shoulder seasons; and,
- Baseboard heaters to provide heating during the coldest period of winter.

There is no hot air furnace in the home, the domestic hot water is supplied by an electrically powered tank, there is no other stove or bathroom ventilation, the clothes dryer is an air-to-air heat-pump device, a dehumidifier is available and a Cold Climate Air Source Mini-Split heat pump was installed to provide heating during the shoulder seasons and air conditioning during the heat of summer. An HRV is responsible for the controlled movement of air into and out of the home. A vanEE Gold Series G2400H ECM HRV was selected for this application. It is managed primarily by a wall control installed near the bathroom door on the main floor of the house. A second wall control provides a boost in ventilation for 20/40/60 minute duration(s). The heat pump is controlled by the indoor unit based upon the re-circulated air drawn primarily from the Living Room area.

As fresh air enters the home it passes through a radiator that can warm the air in winter and cool the air in summer. The temperature of the radiator is controlled by glycol circulated through ground loops located just above the foundations around the exterior of the building. The circulating pump is turned on and off by a control system designed to adjust the fresh air temperature towards the specified comfort temperature for the home. The target comfort temperature is 20 degrees C and the controls are designed to provide comfort in the range of 18 to 25 degrees C. Under extreme circumstances the temperature may fall outside this range but the total duration is unlikely to exceed criteria set for Passive House standards.

Global warming has raised the temperature and increased the duration of extreme temperatures to the extent that the super-insulated home combined with fresh air cooling has been inadequate. When combined with widespread fires during the summer of 2021 the decision was taken to install the air-to-air heat pump. A Daikin unit with a rated capacity of 1-Ton was installed with the interior head installed in the main floor living area. This unit is designed to operate at an exterior temperature down to -25 degrees C. Even at these temperatures the heat pump can provide heat more efficiently than electric baseboard units. However, when winter temperatures drop further is necessary to use the baseboard heaters to provide heating for the home. The five baseboard heaters were installed early in the retrofit process and are rated for a total of 3 kW - this is more than adequate to meet peak heating requirements.

Monitor and Control

Monitor - to understand current status of the home............

Any control that is necessary in a Passive House is dependent upon and understanding of the temperatures in and around the home. In this home, one can monitor these temperatures by viewing the LCD mounted on the HRV Controller and the display(s) in the downstairs utility room . The display is updated frequently except during the period when the controller is collecting data or communicating with other devices in the system. The controller display will show the mode of operation for the controller, a series of individual temperatures and the temperature exchanges across several important physical interfaces within the system. Short descriptions follow:

1. Ext. Fresh In – Fresh air intake from outdoors (above conditioner radiator)
2. Cond Fresh – Conditioned Fresh air (below conditioner radiator)
3. Stale to Ext. - Stale air in Exhaust Pipe (above HRV and inside cabinet)
4. Glycol In – Glycol from the ground loop (at input to radiator)
5. Glycol Out – Glycol to ground loop (after the pump before exit)
6. Pump Core – Circulating pump core temperature
7. Cond Cabinet – Conditioner cabinet ambient temperature
8. Building Stale – Building stale air (in duct above HRV)
9. Building Fresh – Building fresh air (in duct above HRV)
10. D.Heater Fresh – Building fresh after the Duct Heater (no longer used)
11. Kitchen Stale – Stale air from Kitchen
12. 2nd Floor Stale – Stale air from the Second Floor (vent in Sewing Room, sensor in basement)
13. Other Stale – Stale from Bathroom (in vent below Bathroom)
14. Cold at DHW – Cold water (above Domestic Hot Water tank)
15. Mod.Hot at DHW – Hot water after Modulator (mixer)
16. Living Rm. Wall – Interior wall temperature (about 4 feet above floor level)
17. Base. Bath – Inside future basement Bathroom

18. Shop Ceiling – Inside shop
19. Exterior Exch. - Heat exchange with the atmosphere (Difference at Outdoor interface 3 - 1 above)
20. Cond. Exch. - Heat exchange with the ground loop (Difference across conditioning radiator 2 – 1 above)
21. HRV Ext. Exch. - Heat exchange on exterior side of the HRV (Difference at HRV Outdoor interface 3 – 2 above)
22. Build. Exch. - Heat exchange on interior side of the HRV (Difference at Building interface near HRV 9 – 8 above)
23. Duct Htr. Exch. - Heat provided by the duct heater (Difference 5 – 4 above)
24. Glycol Exch. - Difference in glycol temperature in and out of cabinet

Displays of data are likely to evolve over time.

Other Information:

Internal Relative Humidity

Internal Air Quality

UNO - temp monitor

MEGA - electrical consumption

- relative humidity

Pi4 - logger

- Modbus or BACnet controller

Knowing the state of comfort within the home as described above will enable you to control the system when and as required.

Heat Recovery and Ventilation

Primary control of the system is normally exercised through managing the fresh air flow into the building through the HRV and such control is the focus of this document. Controlling operation of the Heat Pump and the Baseboard heaters will occasionally be necessary and is discussed where appropriate below.

HRV Operating Modes

The vanEE HRV has a number of modes of operation as described in the associated documentation. For purposes of this document there are a few key states worth noting as follows.

A) **SMART** mode – operation of the HRV is dependent upon the temperature of fresh air at the intake, the stale air temperature and the relative humidity. This is a good general purpose mode of operation. It has been designed to work well under a wide range of circumstances.
B) **Cont** mode – continuous operation of the HRV at a steady low flow rate and which may be boosted to TURBO flow rates. By activating the wall control, located near the main floor washroom door, the air exchange can be boosted to deal with heat/moisture generated within the home.
C) **20 Min/hr** mode – the HRV exchanges air with the outdoors for 20 minutes followed by 40 minutes in either re-circulation mode or standby.
D) **Re-circ**ulation mode – the HRV continuously recirculates air within the house.
E) **Standby** mode – the HRV is shut down by the wall control. Use this mode when you change the HRV core, HEPA filter or carry out any maintenance procedures.

Additional Settings

TURBO – set to high speed air exchange for **4 hours**

TURBO **– for 3 seconds**, high speed air exchange **continuously**

DEHUMIDISTAT – manage indoor relative humidity excess. When %RH above the set value, turns on high speed air exchange until setting is reached. Enable with %HUM. Set with **%HUM for 3 seconds**, then press %HUM until desired level is indicated, then press %HUM for 3 seconds or wait 10 seconds to accept value. For Winter operations, set the control to 40% (or in the range of 32 to 40) – this will limit the freezing of stale exhaust during very cold periods. For summer operations a higher setting will be required. Controlling humidity levels with a dehumidifier has been a requirement at Montague. The need for this may be reduced with operation of the heat pump for cooling during the summer period - condensation on the cooling coils will reduce the humidity levels somewhat.

DEFROST – manage defrost cycle (in **20 Min/hr mode**). Set with **MODE for 3 seconds**, then select one of the re-circulation speeds (rE **CONT** or **TURBO**) followed by one of the defrost cycle types (PL), then %HUM to accept. This mode of operation works best when temperatures are in the range of +10 to -15 Degrees C range.

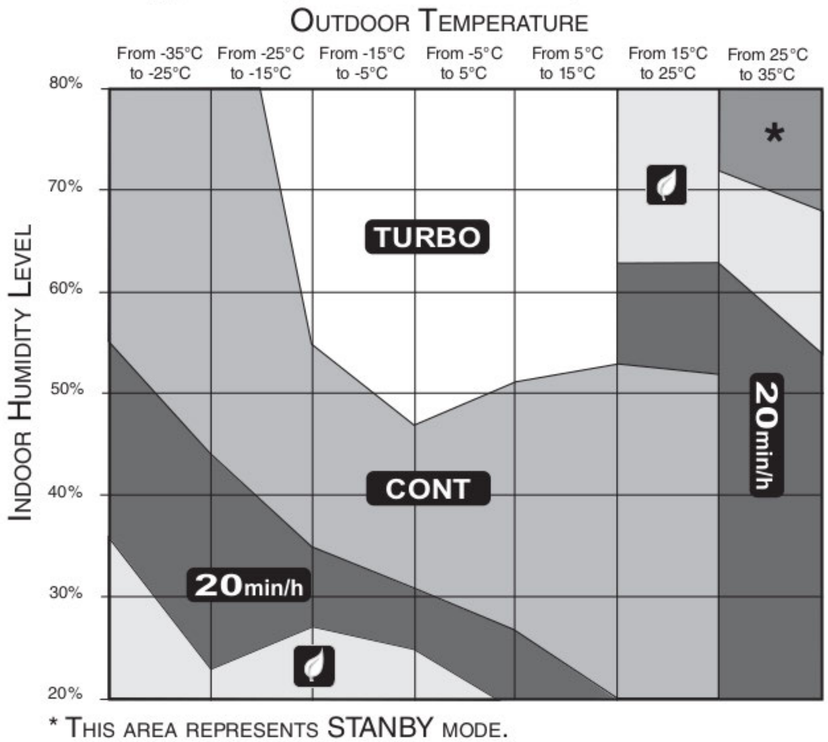
PROTECTION – if fresh air intake colder than -25 deg C. The HRV will go into Recirc Mode and display a snowflake.

MAINTENANCE – Reminder to perform maintenance (Triangle with M at bottom left). Clear with MODE and TURBO keys simultaneously.

And finally,

SMART MODE - See Figure Below taken from VanEE Wall Controls User Guide.

The chart below shows the operating modes called by SMART mode, according to the indoor humidity percentage and the outdoor temperature.



* THIS AREA REPRESENTS STANBY MODE.

10

This is a good “default” mode for hands-off operation.

Fresh Air Pre-Conditioner

Introduction of the pre-conditioner improves the performance of the system but somewhat increases the complexity of operating the system. A **controller** has been developed to automate some operations and this requires only occasional attention.

During periods of the year when outdoor temperatures fall below the comfort zine, use of the pre-conditioner will warm the incoming fresh air to reduce heating demand and also limit the demand for re-circulation to prevent the HRV core from freezing when it gets very cold. Also, during the heat of the summer, the pre-conditioner is used to cool fresh air to reduce internal temperatures in the home. This can avoid using the heat pump for cooling until after daytime temperatures exceed about 30 degrees C and provides this service and only requires approximately 8 Watts of power for pumping.

The **controller** for the pre-conditioner is an Arduino device operating as a stand-alone process controller. The selected Arduino, herein referred to as MEGA, is a “MEGA or MEGA ADK” device. This controller is running a program (called a sketch) that has been developed using the Arduino software environment. This program uses a number of sensors to determine when the circulating pump for the pre-conditioner should operate.

The MEGA obtains temperature information using a set of temperature sensors located strategically throughout the home and in the exterior walls. It is also capable of communicating with an additional UNO compatible Arduino that can provide temperatures from other parts of the system, primarily the walls and roof of the house.

There are two relays that control power to the pump and the HRV. The MEGA provides operating signals to optically isolated relays that switch 120 Vac on and off as appropriate.

The grey electrical box in which the **controller** is installed is equipped with a series of LEDs used to inform the user of the general state of the system. It also has buttons to reset the MEGA as well as a UNO located on the second floor of the home. There is also a **switch** used to indicate whether the system is operating in Winter or Summer Mode. In addition to the two-line LCD information display described earlier it has five LEDs mounted in the end of the controller box. These can be monitored to quickly assess the state of the system. These LEDs are as follows:

1) The **white** “Heartbeat” LED – flashing indicates that the controller is operating normally.
2) The **red** “HRV” LED – illuminated indicates that the HRV has been turned OFF by the software.
3) The **white** “Pump” LED – illuminated indicates that the pre-conditioner pump has been turned ON by the software.
4) The **green** “Logger” LED – when illuminated the controller is writing information to the logger memory card.
5) The **blue** “Communication” LED – when illuminated the controller is connected via Serial or Ethernet to a monitoring device.

Information on operations is available by monitoring the frequency of flashing of an individual LED or combinations of LEDs as follows:

1) When the Heartbeat LED is flashing rapidly (say once per second) or very slowly (say 10 seconds) then the controller is fully occupied with taking measurements or processing information. When this LED is flashing every five seconds the controller is available for communications with other devices.
2) When both the Heartbeat and Pump LEDs are flashing, with the Pump LED flashing at twice the frequency of the Heartbeat LED, conditions are such that the Windows in the home should open to aid in reducing temperatures overnight.
3) When both the Heartbeat and HRV LEDs are flashing at the same frequency, the controller believes the HRV is Recirculating.
4) The green logger LED flashes when data is written to the logfile.
5) The blue communications LED flashes during UNO communications (via serial communications over Cat5e conductor) or Ethernet communications with PC computers (not yet fully functional)

Additional instruction on the operation of this system is described later in this document.

Dehumidification

Operation of a dehumidifier throughout the year is highly recommended. Moisture in the air is a by-product of many activities in the home such as food preparation and clothes washing. In keeping with Passive House recommendations, a front-load clothes washer and a heat pump clothes dryer have been installed in the Utility Room in the basement. In the winter final drying of clothes inside the home will increase the humidity levels. Much of the moisture within the home will be exhausted through normal ventilation using the HRV. However, when it is very cold and HRV operations are reduced, buildup of moisture levels can be significant. Other times in the year the outdoor humidity levels can be higher than desired and using the dehumidifier can make the home more comfortable.

Throughout the Winter the **Humidity** set-point may be set in the 30-40% range. In the summer it may be more appropriate to be in the 50-60% range. During the shoulder season the set-point should likely be in the **40-50**% range. You are likely to find these humidity levels to be more comfortable. (NOTE: 2020 Passive House recommendations are now for 40-50% in winter as well to reduce frequency of respiratory issues)   You may also select either the SMART mode or the 20 MIN/H mode to manage HRV ventilation rates depending upon intake fresh air temperature and indoor relative humidity.

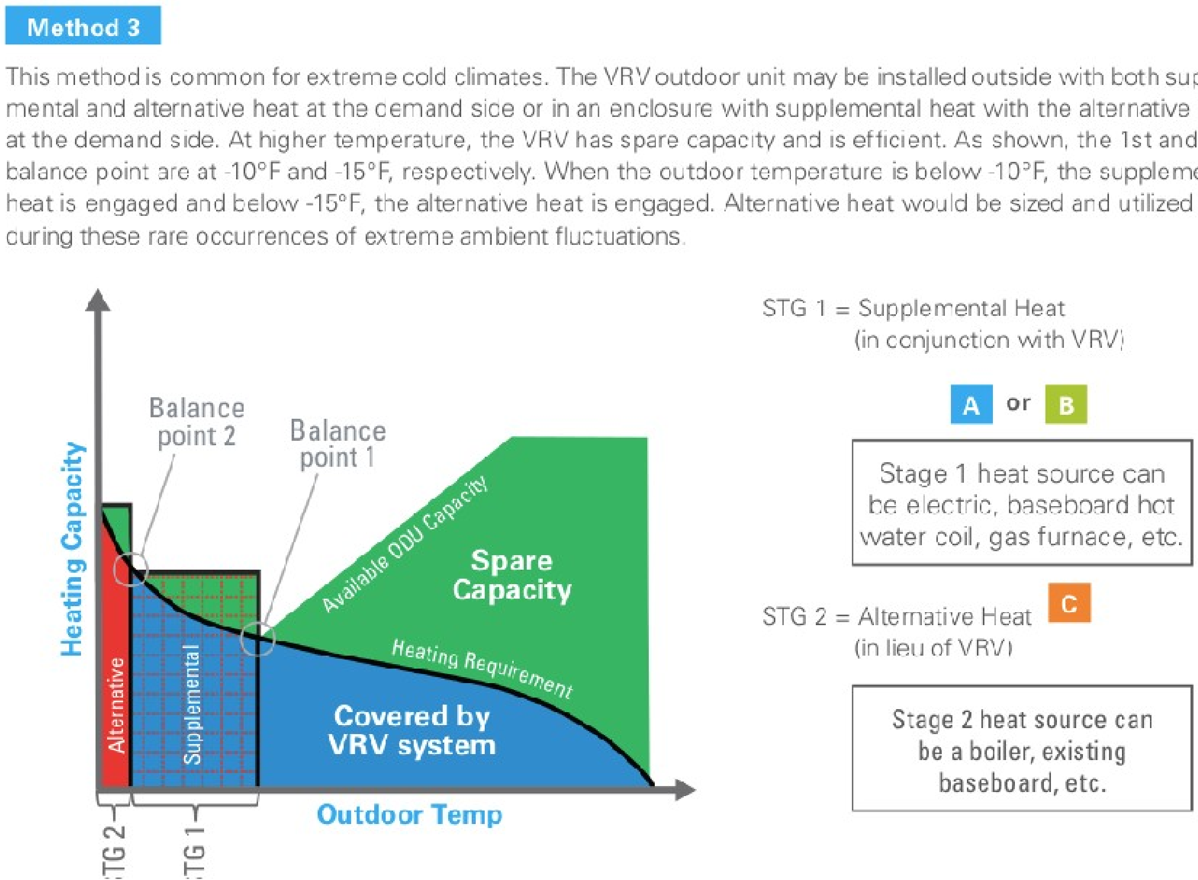
Experience to date indicates there is no need for humidification under prevailing conditions.

Baseboard Heaters and Heat Pump

Provision of heating during the retrofit of this home required the installation of electrical baseboard heaters that were capable of heating the home during design conditions. The peak demand for heating, as calculated using the Passive House PHPP software, was slightly in excess of 2 kW. Understanding that these early estimates may have underestimated the demand, and that after the old gas-fired furnace was removed additional heating would be required, a total of 3 kW of baseboard heaters were installed under the larger windows on the main and second floor of the home (none in the basement). Experience over the initial five years of operation indicates that this capacity has been more than capable of providing all the heat required to maintain comfort in the home.

During the summer of 2021 it became impossible to ventilate the home adequately during the evening and overnight hours due to the heavy smoke produced by extensive forest fires in Western Canada. Interior temperatures exceeded the comfort zone (25 Degrees C) for more than the allowable Passive House specified conditions for excessive periods of time. The decision was made to install an air conditioner or heat pump system that would be capable of cooling the home under such conditions. About this same time the Canada Greener Homes initiative was launched by Natural Resources Canada and the related literature proved to be valuable in evaluating recommended systems. It became clear that recently developed Cold Climate Air Source Heat Pumps (CCASHP) would be capable of providing not only cooling but also supplemental heating down to approximately -25 Degrees C during the Winter.

The following figure was extracted from related literature and summarizes how this combination of a heat pump system supplemented by baseboard heaters would work.



In the case of the best available CCASHP systems, Balance Point 2 is at -25 Degrees C and, in the case of this home, Balance Point 1 would be defined by the "need" for heat in the home at an average outdoor temperature of about 10 - 15 Degrees C. So the "red" Alternative area when Stage 2 (Electrical Baseboard) heating is required would be relatively short in duration and the "blue" cross-hatched Supplemental area when Stage 1 (Heat Pump) heating would be used would cover much of the remaining heating requirements. Part of the "blue - Covered by VRV system" area would be provided by using the fresh air pre-conditioner to warm incoming fresh air whenever that fresh air is at a temperature below that of the glycol in the external ground loop. Experience has shown that this is quite effective all the way down to the point where the glycol reaches freezing temperatures. The pre-conditioner should not be used in this way as it would lead to freezing the foundation of the home.

The selected heat pump system was a "1-Ton" floor mounted Daikin heat pump system (FVXS12NVJU / RXL12QMVJU). While this unit is more than capable of meeting current cooling requirements it has the advantage of providing very high performance over a wide range of conditions and is expected to be able to meet increasing demands brought on by global warming.

The interior wall mounted unit is installed in a wall exposed to the Living Room area on the main floor. During the first winter of operation it has been shown to operate under all conditions down to minus 25 Degrees C. When forecast conditions were below this temperature the unit was turned off with the controls and then turned back on during the day when temperatures rose above this limit. In the event that the temperature does drop below the limit the unit will shut itself down - and the breaker will need to be reset on the panel before the unit will start again.

Experience has shown that if the heat pump is set to 19 or 20 Degrees C and the electrical baseboard heaters are set to operate at temperatures below 18 Degrees C the combination of these two heating resources will work without manual intervention.

Operating Guidelines for the HRV

For normal operation with minimal or no intervention it is best to operate the vanEE in Continuous mode (CONT). Under normal external temperature conditions the pre-conditioner **controller** software was designed to react to changes in various temperatures in this mode of operation.

Winter Operation

In the fall, after harvest time you should consider preparing for WINTER! Preparation of the HRV and the controller require a number of steps including:

Change from Bypass core to HRV core and Clean core filters;

1. Clean pre-conditioner intake filters;
2. Remove the HEPA filter;
3. Reset HRV operational settings for HRV core without HEPA filter;
4. Set controller to Winter Mode;
5. Restart the controller;
6. Make sure the heat pump is set to heating mode (Set to desired temperature - suggest 19 or 20 Degrees C);
7. Make sure the baseboard heaters are functional and set the individual temperature controls appropriately (Leave the breaker on the Power Panel OFF until overnight temperatures drop down below -20 Degrees C).
8. React to extreme cold weather as may be required. It is likely that, at some point, you will need to manually operate the port on the Stale Air exhaust from the HRV to prevent freeze-up of the HRV. While this port is closed the HRV should be set to Re-circulation Mode.

In addition, it is recommended that you clean the gutters to remove leaves and debris and set up **heat tape** in the gutter above the front door in preparation for snow-melt next Spring!

Change HRV core and Clean Filters

Filters for the HRV core are washable. Rinse them in soapy luke warm water to remove loose material, then rinse them with warm water. Set them on edge in the utility sink until excess water has drained out of the filters. If the summer bypass core has been in use, it should be removed and replaced by the vanEE supplied HRV core.

Filters above the pre-conditioner radiator must be accessed by removing the front cover of the pre-conditioner. Use a medium or heavy screw driver to remove the brass screws around the edge of the door. Then remove the foam insulation covering the right compartment of the pre-conditioner. After removing a few pieces of insulation around the top of the opening reach in and remove the filters. Vacuum these filters to remove dust, leaves and other debris from summer operation.

Remove HEPA Filter

The HEPA filter (if it has been installed) is located below and to the right of the core. When used, this is the final stage of filtering before air is pumped into the supply lines of the ventilation system.

It is quite likely that this filter will be damaged during winter operation if it is left in the machine. As the temperature drops during the winter there will be times when condensation forms in the air as it moves through the HRV core. This tends to increase the humidity in the HRV and, in the past, has deformed the cardboard core around the HEPA filter. Simply remove this core and store it in a dry location until Spring.

Under extenuating circumstances, like smoke or pollen or extreme dust in the air, you may **temporarily** operate using the HEPA filter. In this case, use the HRV settings provided under HRV Balance Details below.

Reset HRV Settings for Winter Operation

Reset HRV fan settings for Winter operation (See vanEE Installation instructions starting on Page 21 for further information). In order to keep the pressure in the house balanced with the outdoors it by following these steps:

1. Enter Program Mode (press **HUM** and **TURBO** simultaneously for **10 seconds**, then press any key to enter program mode)
2. Select Custom Speeds option (- -:)
3. Press TURBO key to access custom speed settings, then %HUM to accept value
4. MODE will raise value, TURBO will drop value, %HUM will accept value
5. Set stale air TURBO speed (or press %HUM to keep as is) to **66**%
6. Set fresh air TURBO speed (or press %HUM to keep as is) to **68%**

7. Set CONT speed to **29%**
8. Set 20/40/60 speed to **69%** to 93%
9. Set RECIRC speed up to **93%** (Only the supply fan operates to move all the air – any value between **69%** and 93% would be acceptable)

A more complete description of this process is included in the Installation Guide for the vanEE Gold Series G2400H ECM machine.

Set Controller to Winter Mode

Move the black switch on the right hand edge of the controller towards the **back**. This will notify the MEGA controller that you have gone through the previous steps and are ready to restart.

Restart the Controller

Press the RED button on the bottom central section of the controller to reboot the system. Follow instructions on the LCD display.

You will be prompted to reboot the UNO soon after the system starts operation. At this point press the BLACK button on the bottom left end of the controller. The white LED will blink until the UNO has rebooted and established communications with the controller.

The system will then go through a start-up cycle where both the HRV and the pre-conditioner pump will be in operation for a few minutes. Then, depending upon ambient temperature conditions, the control system will start to operate dependent upon the temperatures near the HRV and in the rest of the house.

Cold Weather Operation

During the coldest times during the winter he pre-conditioner may have used much of the available heat in the ground around the house. As the temperatures in the HRV drop it is important to ensure that humidity in the air within the house is reduced to 35%-40% range using the **dehumidifier**. If the stale air being removed by the HRV contains too much moisture it is possible that ice will accumulate on or around the shroud of the stale air exhaust fan – first becoming noisy and eventually causing the fan to lock up and eventually fail. If this happens, the HRV will stop and display an error message on the HRV wall control by the bathroom door.

As the glycol temperature (Glycol IN) drops to near freezing it will be necessary to take manual control the HRV operation. A **damper** has been installed above the HRV stale air exhaust and the cabinet above. Under extreme conditions this damper should be operated to positively block flow from the HRV and prevent convective heat loss through the duct to the exterior of the home.

Depending upon the situation, it may be necessary to alternate between the **Recirc** mode and **Cont** ventilation modes as described in the following procedure.

Steps to enter cold weather **Recirc** mode are:

1. Set the HRV to OFF using the wall control near the bathroom door.
2. Unscrew knobs on the front of the stale air damper and pull the slide out to block the stale air. This will prevent cold exterior air from entering the HRV during re-circulation AND prevent boosting exhaust air using the 20/40/60 wall control near the bathroom door. **DO NOT activate this control when the stale air damper is closed**.
3. Turn the HRV to Recirc mode using the wall control near the bathroom door. If you have been using Humidity control, turn it OFF.
4. Soon afterwards the HRV should detect re-circulation and turn off the glycol re-circulation pump.
5. The HRV will move air within the house from room to room to maintain comfort to the extent possible. Note that the white “Heartbeat” LED and red “HRV LED” will flash at the same time under these conditions. As the air moves through the HRV it will be cooled further – so under really extreme circumstances you may wish to turn the HRV turned OFF with the wall control.

To go back to **Cont** or **Smart** mode (when exterior temperatures have moderated) go through the following steps:

1. Unscrew knobs on the front of the stale air damper and push the slide in to un-block the stale air exhaust.
2. Reset the HRV operating mode using the wall control near the bathroom door. If you have been using Humidity control, turn it back ON (with the Humidity set-point in the 30-40% range).
3. Soon afterwards the HRV should detect that the system is no longer recirculating and will turn on the glycol re-circulation pump.
4. After a few minutes note the intake glycol temperature in particular – if it remains near zero you should plan to go back into **Recirc** mode within an hour or two.

NOTE: if the controller fails to detect the change from Recirc to Cont (or any other change at the wall control) you may need to restart the controller to resume operation in the correct mode.

When the outdoor temperatures are expected to be **very low** it will become necessary to operate in **Recirc** mode at night and use **Cont/Smart** mode once or twice during the day when showering/bathing and/or during food preparation on the kitchen. Keep the dehumidifier working in the basement as the humidity levels may build up in the house under these conditions. This process has been used successfully since the damper was installed.

Under extreme conditions it is possible that the glycol temperature will drop below zero degrees C. In this situation the controller will turn off the pump and go into Operating Mode 11. The display will indicate “Glycol Near Zero” and it will remain in this state until the controller is rebooted. If the temperature of the glycol loop has not recovered above zero when the reboot takes place, it will again go into Operating Mode 11. At that point you must follow the first instruction for entering Recirc mode, let the HRV warm up and then complete those instructions. Under these extreme conditions attempt to estimate the HRV core temperature - if it ever drops below zero for very long you may have to cut the Turbo and Cont air flow percentages in half to keep the HRV fan motors warm enough to operate smoothly.

Eventually the temperatures will moderate, you will be able to use increasing amounts of **Cont** ventilation and spring will come before too long...

Shoulder Seasons

Keep track of outdoor temperatures and monitor the temperature in the roof in an attempt to predict snow avalanches from the South roof. On or before this event you should plug in the **heat tape** installed in the south gutter and turn on the breaker in the basement. This heat in the gutter will prevent ice dams from forming – otherwise snow melt from the roof will overflow the gutter – ice on the front steps will become dangerous!

Between Winter and Summer there is a period where average temperatures are below the comfort temperature and some heating is still required in the house. At these times it is most cost effective to use the **heat pump** in heating mode to provide any required heat. In all likelihood, the circuit breaker for the baseboard heaters can be turned off.

Some minor adjustments to HRV controls are possible that may improve comfort levels. These are related to the set point for **Humidity** and the re-circulation rate. It may be desirable to recirculate at a higher rate to keep temperatures more uniform within the house. Overheating in the upstairs is not unusual due to intense sunlight on the West facing window in the late afternoon. This will be somewhat mitigated by setting the **re-circulation** to a value in the **50-60%+** range. If you use the 20/40 mode using this same setting would be appropriate.

The **heat pump** will likely remain in heating mode. If it is not possible to control higher temperatures with ventilation then it is time to switch to Summer operation.

Summer Operation

In the Spring, when temperatures are *no longer dropping below freezing* at night, it may be time to insert the HEPA filter to remove pollen and mould spores from the incoming fresh air. Also, when the average daily temperature has risen in the Spring to the point where *heating* in the house is *no longer required* and/or overheating is experienced in the afternoons it will be time to change HRV operation to Summer mode. Note that this switch will alter the management of the glycol pump to keep the glycol temperature as low as possible - this may result in cooling the house more than desired if you made this switch too early.

In general, the following steps reverse several of the Winter mode actions. In general you want to:

1. Clean filters for the HRV core (if required – visual inspection) and insert summer bypass core;
2. Place the HEPA air intake filter in the HRV;

3. Reset HRV operational settings for the HRV Core with the HEPA filter (see HRV Balance Details below);
4. Leave the Pre-conditioner controller set to Winter mode;
5. Restart the controller.

Insert Summer Bypass Core

When the average daily temperature exceeds approximately 15 degrees it is time to switch over to full summer settings. The primary design purpose of the HRV, that is to preserve heat within the building, is no longer important. To maximize the value of the overall system during the summer the summer bypass core should be installed and replaces the vanEE supplied core (otherwise with the HRV core any pre-cooled the air will simply cool the stale air as it is exhausted and have limited effect inside the home).

The pre-conditioner will now be used to provide basic air conditioning during the summer.

Insert HEPA Filter

The HEPA filter should be installed below and to the right of the HRV core. This will now be the final stage of filtering before air is pumped into the supply lines of the ventilation system.

Reset HRV Settings for Summer Operation

Since the HEPA filter has been inserted in the previous step, resistance to air flow has been increased on the fresh air supply side of the system. In order to keep the pressure in the house balanced with the outdoors it is necessary to reset the HRV fan settings by following these steps:

1. Enter Program Mode (press **HUM** and **TURBO** simultaneously for **10 seconds**, then press any key to enter program mode)
2. Select Custom Speeds option (- -:)
3. Press TURBO key to access custom speed settings, then %HUM to accept value
4. MODE will raise value, TURBO will drop value, %HUM will accept value
5. Set stale air TURBO speed (or press %HUM to keep as is) to **60%**
6. Set fresh air TURBO speed (or press %HUM to keep as is) to **66%**
7. Set CONT speed to **27%**
8. Set 20/40/60 speed to **67%** (up to 90)(This will boost flow at Washroom significantly)
9. Set RECIRC speed to **90%** (Suggest between 50% and 90% depending upon situation)

Set Controller to Summer Mode

Move the black switch on the right hand edge of the controller towards the **front**. This will notify the MEGA controller that you have gone through the previous steps appropriately.

Restart the Controller

Press the RED button on the bottom central section of the controller to reboot the system. Follow instructions on the LCD display.

You will be prompted to reboot the UNO soon after the system starts operation. At this point press the BLACK button on the bottom left end of the controller. The white LED will blink until the UNO has rebooted and established communications with the controller.

The system will then go through a start-up cycle where both the HRV and the pre-conditioner pump will be in operation for a few minutes. Then, depending upon ambient temperature conditions, the control system will start to operate dependent upon the temperatures near the HRV and in the rest of the house.

HEAT of the Summer

Always open windows when the outdoor temperature drops below the comfort temperature. This has proven to be most effective in reducing the core temperature of the house and aiding in cooling down the glycol after several days of high temperatures.

When temperatures rise above approximately 28 degrees C an additional measure is recommended to help maintain comfortable temperatures in the house (typically considered to be between 20 and 25 degrees C). That is to adjust the glycol circulating pump to operate on the second speed (two bars). This will increase the pre-cooling of fresh air. Operation of the heat pump to cool air within the house is recommended along with operation on 20 MIN/H mode during the heat of the day.

During periods in the day when temperatures are lower than the stale air within the home it is recommended that you operate the HRV in TURBO mode - typically during the evening, overnight or the morning. This will cool the home to the extent possible at a higher ventilation rate. If temperatures drop to the extent that you can open windows to ventilate the home, you may wish to return to CONT mode and turn off the heat pump when the internal temperature of the house drops into the comfort zone. (See the note under Basic Settings regarding use of TURBO mode)

As the heat builds up during the day, when the LED information display indicates that the incoming fresh air temperature exceeds the stale air exhaust temperature then you should likely switch the HRV back to CONT or 20 MIN/H mode. This will reduce the overall volume of extremely hot air injected into the home but maintain minimum ventilation rates and provide some cooling. During extreme temperatures during the day, set the HRV to Re-circulation mode until the temperatures drop below about 30 degrees C.

When forecast low temperatures will be below the temperature of the glycol run in TURBO mode overnight. At any time there is an opportunity to lower the glycol temperature the controller will turn the pump on. By increasing the flow to Turbo levels you will both increase the intake of cool air and maximize the cooling of glycol.

As the average daily temperatures drop down into the 15 degrees C range, switch to Shoulder Season operations. (When you plant the garlic, prepare for Winter).

Additional Operating Notes

To exercise more control over where the heat goes within the house during Winter you may wish to adjust dampers to increase flow on supply ducts to the living room as well as the dining room and bedroom. Depending upon levels of activity in the basement, you may wish to increase fresh air flow into the utility room (for plants), the shop (for shop workers), the boot rack or the storage room/bathroom area. These dampers are all located on the fresh air supply ducts in the basement.

To exercise more control over where the fresh air flows within the house during the Summer you may wish to adjust dampers to decrease flow on supply ducts to the living room as well as the dinning room and bedroom. You are also unlikely to require significant cooling air flow into the basement and may want to decrease fresh air flow into the utility room, the shop, and the boot rack.

With the addition of the heat pump to the initial system these adjustments to the duct system should not be necessary. Under extreme conditions, in either winter or summer, temperatures within the house can be moderated by recirculating internal air with the HRV.

Since the air flow in and out of the house should be balanced, several of the differential temperatures of air displayed by the LCD are an approximation to the flow of energy between the outdoors, the building and within the air conditioning components in the vicinity of the HRV. The glycol exchange provides an idea of how much the glycol is heating up (or cooling down) during operations within the building – the difference in heat content is absorbed by (or provided by) the soil in the vicinity of the ground loop around the foundation of the building.

During re-circulation, several of the temperatures will begin to change to reflect changes in the flow patterns for air and glycol – they will no longer be representative of the temperature they were installed to monitor. For instance:

- Temperatures within the HRV will generally tend towards the temperature of the Building Stale temperature and the Pre-Conditioner Cabinet temperature;
- Building Fresh air temperature will tend toward Building Stale temperature, moderated by the Cabinet temperature and perhaps the Stale Air Exhaust temperature. These temperatures will generally be within a degree or two C. NOTE: Re-circulation will tend to slightly heat the building fresh air in summer and cool it in the winter. Reduce the rate to decrease this effect;
- Fresh air intake temperatures will tend to move towards the Cabinet temperature;
- If the pump is turned OFF then:
    - Glycol Out temperatures will tend towards the Cabinet temperature; and,
    - Glycol In temperatures will tend towards the Fresh Air Intake temperature;

- Once re-circulation finishes, temperatures will return to expected values and reflect the actual outdoor fresh air intake temperature, the stale air exhausted to the outdoors and the temperature of glycol in the ground loop.

HRV Balance Details

Any change in the duct system that increases or decreases the resistance to flows is likely to change the balance between fresh and stale air flows. If this happens, a pressure difference will develop between the indoor space and outdoors which is generally not desirable. The Montague system is equipped with several devices that may be used in multiple combinations that may cause such problems. These are:

- The HRV may have either the vanEE HRV core OR the summer bypass core installed;
- A HEPA filter may or may not be installed in the HRV; and,
- Dampers in the duct system may be open, closed or partially closed - this will change the head loss in related ducts and any closure will reduce related flows;

The primary advantage of the HRV core is during periods of the year with exterior temperatures below interior comfort levels. One of the disadvantages is that during periods when ventilation is required to reduce temperatures in the home this core prevents the intended cooling. A summer bypass core was designed and developed as a replacement for the HRV core at higher temperatures. Experience over a few years has indicated that when combined with the fresh air preconditioner the bypass core is effective whenever the average daily temperature is above approximately 15 degrees C.

The HEPA filter has proven to be very effective when dealing with dust, pollen and smoke from forest fires. Unfortunately the cardboard frame around this filter tends to degrade if it gets wet - and this does happen in the winter or any period when there is condensation forming on the HRV core. In the winter there is little need for filtering the fresh air to this extent and recommended operations remove the filter for this period.

With the installation of a mini-split heat pump, and with the interior head installed in the living room, it is anticipated that the performance of the house will be somewhat different than earlier. When extreme temperatures are experienced outdoors, it is likely that re-circulation will be more frequently used to achieve comfortable temperatures throughout the house. All the dampers on ductwork where completely opened when the HRV was re-balanced.

Taking the foregoing factors into account, re-balancing was carried out for three combinations of devices, in all cases the dampers were open except for the case of re-circulation - at which times the stale air exterior duct damper was closed. Of course, all the windows and doors were closed.

Refer to the HRV Installation Guide starting on Page 19. These procedures were used except for the measurement of airflow. Flow collars were installed on both the fresh and stale air ducts on the interior side of the HRV. These flow collars were monitored with a Dwyer Magnehelic Pressure gauge that measures zero through 0.25 inches of water differential.

With Bypass Core / With HEPA filter (recommended Summer Setup)

Mode	Duct	Control %	Inches H20	cfm	Target cfm
Turbo	Stale	60	0.067	130	130
	Fresh	66	0.067	130	130
Cont	Stale				
	Fresh	27	0.015	54	50
20/40/60	Fresh	67 (to 90)			
Recirc	Stale	90	0.098	158	170
(damper Open)	Fresh	90	0.118	172	170
Recirc	Stale	90 (or less)	0.088	146	
(damper Closed)	Fresh				

With HRV Core / With HEPA filter (smoke, dust or pollen issues in Winter Mode)

Mode	Duct	Control %	Inches H20	cfm	Target cfm
Turbo	Stale	66	0.067	130	130
	Fresh	72	0.067	130	130
Cont	Stale	30	0.012	47	50
	Fresh	30	0.012	47	50
20/40/60	Fresh	70 (to 90)	0.065	130	130
Recirc	Stale				
(damper Open)	Fresh				
Recirc	Stale				
(damper Closed)	Fresh	95 (or less)	0.095	154	170

With HRV Core / Without HEPA filter (recommended Winter Setup)

Mode	Duct	Control %	Inches H20	cfm	Target cfm
Turbo	Stale	66	0.067	130	130
	Fresh	68	0.068	130	130
Cont	Stale	29	0.013	49	50
	Fresh	29	0.013	49	50
20/40/60	Fresh	69 (to 93)	0.068	130	130
Recirc	Stale	93	0.095	153	170
(damper Open)	Fresh	93	0.120	174	
Recirc	Stale	93 (or less)	0.104	163	
(damper Closed)	Fresh	93	0.120	174	

A test of balance was carried out in Recirc mode for this last presented case - one with the stale exhaust damper open and one with it closed. Note that in this mode the fresh air fan moves all the air. In both cases the fresh air injection into the house was 174 cfm. In the case of damper open, the loss of air flow in the stale air return duct was 21 cfm. With the damper closed this loss was reduced to 11 cfm. This test confirmed that leakage through the stale air exhaust port was significant and is approximately equivalent to what must in some way be related to leakage in the building envelope.

Comparing the differences in settings for recommended Winter and Summer setups, the effects of the different cores and the HEPA filter are similar to what would have been expected.

NOTE that if you want to change the re-circulation rate for the 20 Min/hr mode, it must be done while re-setting the Defrost cycle.

What Would We Do Differently

How could the "Comfort" or "Operations" be improved?

Exterior Doors

Fibreglass Doors with tri-pane lights. These have not proven to be very good passive house doors. Some of the "seals" have detached in the corners and penetrations through the doors are certainly a weak point (that is hard to avoid in any case). Installation of front door was not "square" and the fit has got worse over time. They are essentially good "screen doors".

The best method of dealing with this situation will be to focus on re-building the solid wood interior doors. The current doors are providing more “insulation” value than the exterior doors. Rebuild with double seal/vapour barriers, vapour seal the “reveal” of the door, fit and finish plywood panels on the jambs and head and install a solid wood sill.

Glycol Loop

The fresh air pre-conditioner runs out of heating capacity in the second half of winter and cooling at mid-summer. The ground loop works but would have been much better if installed in a bore-hole giving access to deeper heat-storage-capacity. Not much can be done to mitigate this situation with the existing system - not enough time was spent thinking about (or attempting to calculate) how this system would work.

This turns out to be similar in many ways to the inability of the heat pump to meet the full range of heating requirements. Supplemental conditioning of fresh air will be required from another source. Likely options may include electrical resistance heating elements or an additional potable-water radiator interconnected with the domestic hot water system.

HRV configuration

A VanEE HRV unit was selected for use in the home. Significant features of this machine included:

- Ability to recirculate stale air to thaw the core during very cold periods during the winter;
- Smart mode of operation under a wide range of conditions;
- HEPA fresh air filtration;
- ECM motors on the fans (good control and low power consumption); and,
- More than enough ventilation capacity for the home.

A “summer by-pass core” was fabricated to provide the ability to ventilate fresh air during night and early morning hours. This proved to be quite effective when working in conjunction with the glycol-based pre-conditioner system.

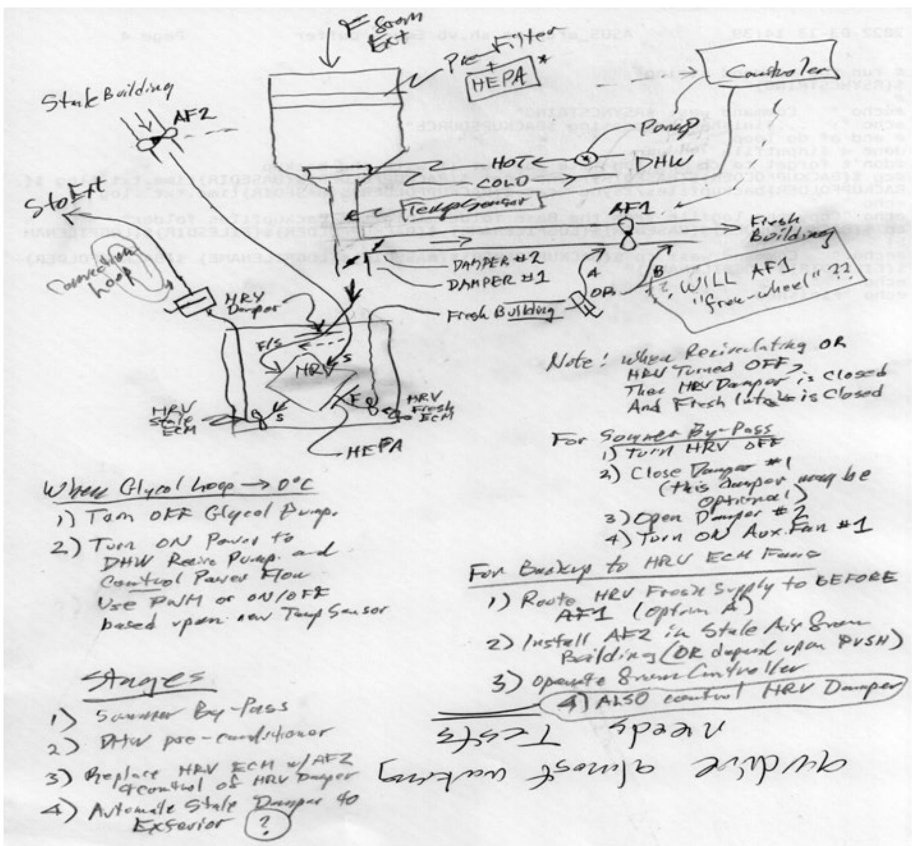
The original concepts proved to be well founded - but the performance could still be improved. One problem that was encountered was the evident development of a convection flow within the stale air exhaust duct between the HRV and the exterior vent. This is driven by the cold exterior air flowing down along the bottom of the duct right down into the bottom of the HRV and warmer air from the interior of the HRV moving upward through the top of the duct towards the vent. This cooling effect could be observed with the existing temperature sensor in the duct located about half way between the HRV and the vent. Eventually, under <u>extreme conditions</u>, this leads to a build up of frost/ice on the stale air fan shroud to the point that the fan is immobilized. This is detected by the HRV and the system shuts down. A manually operated damper was installed near the HRV to limit or prevent this convective flow. During these events, the HRV was typically operated in Re-circulation mode full time with short intermittent operation in Continuous mode to bring in fresh air (typically late in the afternoon when maximum temperatures were expected outdoors). However, repeated events of this type eventually lead to the failure of the stale air fan motor. At times the fresh air fan motor has developed similar "noisy" operation when the HRV core has dropped to very low temperatures - this was mitigated by reducing the rate of flow for Continuous operation and has prevented failure of this fan motor (to date 220510).

HRV Retrofit

Two options are available:

- replace the existing HRV with another that offers the desired features; or
- improve the performance of the existing HRV by working "around" it.

As most of the features of the existing HRV are desired, the second option is now being considered. The retrofit would be limited to upgrading the air flow system in the area around the HRV and adapting the "Controller" to suit these changes. (See following Figure for rough concept)



The **first stage** of this work would consist of providing secondary heating powered by the domestic hot water system. A potable-water radiator would be located in the lower section of the pre-conditioner which would be interconnected with hot and cold water lines located nearby. A controllable circulating pump would be installed in one of the lines that would operate when the temperature of the air falls below the (to be determined) threshold. The intention is to attempt to keep the core of the HRV above freezing. [It is expected that this will mitigate deep-winter issues described above]

The **second stage** of work would consist of creating an explicit summer by-pass circulation loop that would allow the HRV to operate normally. This would involve dropping the HRV unit towards the floor and installing a Tee in the fresh air duct between the pre-conditioner and the HRV. The side-branch would be equipped with a tight-sealing damper (#1), the HRV fresh air duct to the building would Y into this new branch and be followed by a fan (#1) that reconnects to the fresh air duct into the building. To operate this by-pass one would:

1. Turn the HRV off with the controller;
2. Open damper #1;
3. Turn on the auxiliary fan #1 and manage its speed with the controller.

Note that when the HRV is switched off, an internal damper in the HRV automatically closes off the fresh air intake and enables stale air re-circulation. It is likely that the majority of the flow injected by the by-pass system will flow into the house and exit through open windows within the building. However, any stale air that does flow back towards the HRV will pass through as if it was being recirculated and then back to the Y junction just upstream of auxiliary fan #1. The majority of the flow should come from the pre-conditioner but it may be necessary to install a manual or automated damper between the HRV and the Y junction to restrict stale air circulation. (leave space for a damper...) [Ideally, the fan has an ECM motor and is controllable with a DC voltage - operate initially with a rheostat before automating]

While you are at it, procure alter as required, and install a HEPA filter above the existing radiator and below the existing filter. (This system will by-pass the HEPA filter in the HRV)

Once this system is functioning as intended, the Arduino controller should be re-programmed to turn the summer by-pass ON when the temperature of the fresh air entering the home is below that of the stale air temperature. When the temperature of the pre-conditioned air exceeds the threshold (to be determined) the summer by-pass fan #1 should be turned off, the HRV turned on and damper #1 closed. During the heat of the day, any air entering the building will be tempered by the stale air exiting and minimize the heat buildup within the home. When internal temperatures exceed a second threshold (to be determined) the ventilation system should be turned off and the home cooled with only the heat pump.

This second stage of work should improve the overall efficiency of operations during the summer and minimize the use of the heat pump, in particular during the shoulder seasons.

The concept of the **third stage** is less well thought out, and will be dependent upon success for previous stages, but would further automate controls for the system. The first two steps are relatively straightforward and could have been included in the second stage as that work progressed. However, more may be “possible” by:

- installing a well-sealed powered damper on the stale air exhaust between the HRV and the exterior (to replace the existing manual damper);
- installing a well-sealed powered damper on the fresh air supply between the HRV and fan #1 described above (if damping was judged to be required during second stage work); and,
- installing an auxiliary fan #2 (same specs as fan #1) on the stale air return to the HRV.

This work would also provide backup in the event of repeated failure of the ECM stale air fans located within the HRV (and subsequent shut-down of the VanEE controller). In order to operate without those fans and provide fresh air it will be necessary to find a way to automate operation of the VanEE HRV damper. [Note that in the event of an HRV shut-down due any internal failure, the summer by-pass option WILL provide re-circulation under these circumstances]

If this stage of the work is ever completed, it would also be possible to consider the use of different types of HRV cores. There is some evidence that counter-flow core designs are more thermally more efficient and there is also the possible considering the use of an ERV core to manage sensible heat (recovery or rejection). Counter-flow cores would require an new/different HRV “box” while sensible heat recovery would be possible while using the existing VanEE HRV unit. Additional temperature and humidity sensors should also be installed if either of these options are pursued.

Historical Design/Operation NOTES

Several variations in control functions have been investigated and may be of use or require modification/adjustment in the future.

Variable HRV shut-down time:

The pump will run for 20 minutes or more and, as outdoor temperatures rise, this duration will increase to as long as 55 minutes. (For the remainder of the hour both the pump and the hr v will be shut down – this requires modification/adjustment)

This mode has not been used significantly........... Alternative code was introduced.

Operation in 20 MIN/H mode:

In the event that daily forecast peak outdoor temperatures are in the 20 to 23 degree C range, it may be appropriate to use the 20 MIN/H mode on the vanEE. If you wish to do so, it is necessary to enter the 20 command on the Serial Monitor (or via the Ethernet connection) to inform the controller that a non-standard operation has been selected. During the 20 minute part of the cycle the pump will be in operation and the hrv will bring fresh air in at a slow rate. For the remaining 40 minutes the hrv will go into Re-circulation mode and will operate at the speed selected for this mode (set by the hrv wall control as per instructions). If/when you take the hrv out of this mode the 60 command should be entered to inform the controller that one of the other modes has been selected. (This could perhaps be automated as it is not very “convenient” to use, and may not be very effective. A longer cycle time should be considered and a means of automating this type of operation investigated)

Re-wire AC controls:

Currently control of the HRV on/off function has been disabled in the Controller software. This is due to failure in the existing relay module. When this relay is activated, the power draw on the Arduino is so large that the display dims.... NOT GOOD.

Rewire with individual relays for each plug (HRV and Pump) located in an separate “box” between the existing “outdoor” style plug box and the HRV/Pump box.

VERY ROUGH DRAFT OF INITIAL HARDWARE DETAILS FOLLOWS..........

Installation

<<<<<<<<<<<<<<<THE FOLLOWING NOTES ARE FAR FROM COMPLETE>>>>>>>>>>>>

Connections

The sketch has been written assuming that the normal condition is for the pump and hrv is to be in operation (relays NOT active). The relays should be active only when the pump and/or hrv should not be operating. In the event of a failure of the relay, or the Arduino, the pump and hrv will operate continuously.

Initial Sensor Testing Prior to Installation

Load the latest version of the Arduino IDE onto the PC that will be used for testing. Connect that machine to the MEGA via the USB port. Load and run the Arduino sketch titled "_______.ino".

In the event of problems with compiling or loading the sketch:

- check that the communication port is properly identified. Under Tools / Ports review the available ports and select the appropriate option.
- check that the device is properly identified (different Arduino boards have different capabilities). Look at the bottom right hand edge of the IDE to confirm. Under tools you can use "Get Board Info" to confirm the type of Arduino being used.
- there may be coding issues or device issues that must be dealt with by a knowledgeable individual.

When the sketch appears to have completed loading, activate the Serial Monitor and make a record of observed temperatures, hrv state and pump state. If inconsistencies appear, check all connections and compile/load the sketch after corrections have been made. Re-start the serial monitor again to observe operation.

"Heat" individual sensors with your hand to see if the Arduino is sensing the change in temperature that should result. Make sure the change in temperature is seen by the Arduino at the correct location –

[redacted]

if not, move the temperature sensors to the correct positions and restart the sketch. Alternatively, carefully modify the sketch to operate according to the actual physical connections and devices that are physically connected. Be forewarned, the code is a bit arcane...

Test combinations of temperature sensor values to confirm that the controller is understanding what it should be doing. Refer to the table earlier in this document to select temperatures. Use combinations of ice cubes, wet rags, hands and heat guns to get the desired combinations required to activate the different modes of operation.

Commissioning

Connect to the Arduino using a laptop. Using the Arduino IDE compile and upload the appropriate sketch. Turn on the Serial Monitor to observe operations of the controller.

Observe the LEDs ON THE RELAYS that control the flow of power to the circulating pump and hrv. The LED should be ON when the relay is in it’s un-powered position (and OFF when the relay is activated and power is flowing). Also observe the LEDs mounted on the relay in the case to confirm this situation. If the pump is on when it should be off, and visa-versa, the power connections to the pump may be on the wrong side of the relay. Test this by removing the power to the MEGA – the pump should operate if the relay is connected to the pump properly and the same for the hrv. If not, move the outboard wire on the relay to the screw terminal on the opposite side of the relay board and restart these tests.

In the event of operations that appear to be abnormal, run the MEGA sketch with “silent” set to false and deadQuiet also set to false. This will provide a verbose description of operations on the Serial Monitor. While this information may not be entirely informative, it may give you a clue to what is going wrong. You may need help...

Detecting Operating Modes in the Initial Design

Initial operating modes for the controller are described in the following table. Example temperatures are provided for particular sensors to indicate when a particular mode is active. Limiting values and cell values are for temperature in degrees C or “X” indicating when devices are OFF. The default mode is Mode 1. Sensors are checked for each subsequent mode to check if earlier test results should be over-ridden.

Sensor Limit Mode	Fresh Air In Summer 21	Fresh Air In Winter 5	Stale Air Re-Heat 17	Glycol	Pump Overheat 28	Pump Off	HRV Off	Description
1		4						Pre-heat Fresh
2	22							Pre-cool Fresh
3		2		-2		X		Soil too cold
4		8		-2				Cool but warm Soil
5	10		18	3				Shoulder warm soil
6	10		15	3		X		Heating season
7	10			7		X		Comfortable
8		4		2				Soil too cold
9		2		4				Cold pre-heat fresh
10					29	X		Pump overheating
11						X	X	HRV not running