ATTIC VENTILATION IN NORTHERN CANADIAN CLIMATES

Ahmad Kayello, Hua Ge, Andreas Athienitis

ABSTRACT

Housing in northern Canada faces unique climatic, environmental, and social challenges. Over the past half-century, housing shortages and failures due to unsuitable design have resulted in homelessness and overcrowding. For new houses to address these issues, they must be durable, especially the building envelope. One of the main concerns for the building envelope relates to attic design and ventilation. Fine, blowing arctic snow tends to accumulate in vented attics if not filtered, while unvented attics risk moisture build up if the ceiling is not airtight. This paper investigates the relative hygrothermal performance of various attic designs under arctic conditions.

Hygrothermal simulation software WUFI Plus is used to simulate the long-term performance of several types of attics designs under weather conditions of Iqaluit, Nunavut. Attics designs simulated include unvented, naturally ventilated, mechanically ventilated, and building-integrated photovoltaic/thermal (BIPV/T) ventilated attics. BIPV/T ventilation preheats the ventilation air behind a photovoltaic cladding system such that the air can remove more moisture. Various rates of air leakage from the indoor space to the attic spaces are applied. The attics are evaluated using the mold growth index. Unvented attics are found to be unsuitable for the arctic as they are highly sensitive to even small amounts of air leakage and prone to significant mold growth. Natural and mechanical ventilation are found to be effective, provided that snow infiltration is prevented with a filter membrane. BIPV/T ventilation provides the best results with regards to attic hygrothermal performance, and can simultaneously generate a considerable amount of electrical and useful thermal energy.

INTRODUCTION

The Inuit communities in Northern Canada have suffered from insufficient and inadequate housing since the establishment of wood frame housing by colonists in the 1950s and compulsory participation in residential schools. Widespread homelessness, trauma, as well as physical and psychological sickness have been the chronic consequences (Tester, 2009; Minich et al., 2011). The main issue with housing in the north is that there is generally not enough for the growing population, and that many existing houses are not designed to withstand the extreme climate, and so fail prematurely (Statistics Canada, 2008; Minich et al., 2011). A large part of the solution is ensuring that new housing construction is durable, easy and quick to build, energy efficient, inexpensive, and culturally appropriate (Thirunavukarasu et al., 2015). This paper looks into the challenge of attic ventilation in arctic climates.

In Nunavut, houses are generally fitted with cathedral ceilings to avoid dealing with attics. However, since attics are less expensive and can support more insulation, it is worthwhile to investigate potential

ventilation strategies, especially since energy costs are high and so is the dependence on fossil fuels (Government of Nunavut, 2007). The principal issue with ventilated attics in the north is that fine, blowing snow infiltrates into attic spaces and accumulates (Forgues, 1985; Lstiburek, 2009). This snow melts in the summertime, wetting the attic materials and increasing the overall humidity level. The added moisture can result in reduced performance of the insulation as well as mold growth and decay. Seeing that the main reason for venting is to remove excess moisture in the attic, this phenomenon is highly counterproductive. Conventional techniques of venting are simply not suitable for the arctic (Forgues, 1985).

To address this issue, attics in Nunavik houses are ventilated using a unique design tailored for northern climates (Baril et al., 2013). Instead of allowing the outdoor air to enter the attic directly through soffit vents, the attic vents are placed at the bottom of the cladding allowing the air to travel up between the cladding and the sheathing before reaching the attic space. Along this passage, polyester filter membranes are installed to filter the snow particles out and let the air through such that the attic can be ventilated without the risk of snow accumulation. This system is implemented in many houses in Nunavik with many variations on the design.

Another way to address the issue of snow infiltrating attic spaces is to seal the attic such that it is not ventilated. This design has been attempted in a high-performance SIP Duplex constructed in Iqaluit, Nunavut (Baril et al., 2013). The main issue with unvented attics, however, is that they are very sensitive to air leakage from the house (Fugler, 1999). The moisture added through air leakage escapes mainly via diffusion through the roof, and this process is relatively very slow.

Existing research suggests that an unvented attic can perform well in cold climates, given that air leakage is minimized. CMHC (1993) performed a two-year field study that includes an unvented attic in cold climate and showed that where the ceiling allows for significant air leakage, the unvented attic will have higher moisture levels in the materials than the vented attic. However, if the attic is nearly airtight, increasing the attic ventilation will result in higher moisture levels in the attic materials. Rose (1992) conducted a two-year field study of residential attics in Illinois and found that unvented and vented attics exhibited similar moisture performance when the ceiling was airtight. Samuelson (1998) performed a year-long field experiment in Sweden and found that if there is no air leakage from the indoor space to the attic, the relative humidity in the attic is around 5% drier without ventilation.

Considering that unvented attics do not allow moisture to escape easily and that ventilation can add moisture to an attic, an effective way to manage attic humidity is to ventilate only when the outdoor air has the potential to dry the attic. This type of ventilation, also known as adaptive ventilation, was tested both experimentally and via hygrothermal simulation in Sweden, and researchers have found that this method produces the best results compared to conventional ventilation techniques (Nik et al., 2012; Hagentoft & Sasic Kalagasidis, 2014).

Implementing renewable energy technologies is of key interest in the arctic to offset heavy fossil fuel dependency. Building-integrated photovoltaic/thermal (BIPV/T) systems generate solar power while heating outdoor air. The heated air cools the photovoltaic panels and can be used as preheated air for ventilating the housing, ideally combined with a heat recovery or energy recovery ventilator (Beattie et al., 2015). Chen et al. (2012) assessed the potential for implementing photovoltaic and solar thermal systems on vertical faces in high latitude locations experimentally and by simulation. It was found that significant amounts of heat (>2MJ/m^2) and electrical energy (~1000 kWh/kW) can be harvested. One way the heated

air can be used, at least partially, is attic ventilation, since the air would have a higher capacity to dry the attic. Because BIPV/T ventilation can slightly increase attic temperature, this kind of ventilation strategy may not be as useful in locations where there is heavy snowfall and ice damming is common. However, in the arctic where snow loads are generally low, there is much potential.

Many attic designs and ventilation strategies have the potential to perform well in extreme cold climates. This paper aims to investigate, using hygrothermal simulation, the relative performance of various ventilation strategies for the arctic.

METHODOLOGY

A hygrothermal model is created in WUFI Plus (Antretter et al., 2011) for the purpose of this study. The model was used to simulate the hygrothermal conditions of an experiment conducted in an environmental chamber using a full-scale test hut, described in (Kayello et al, 2013; Belleudy et al., 2015; Kayello et al., 2017). The model used here is composed of a 12 m by 10 m house with an attic space divided into 6 sections Figure 1. Each section has a specific ventilations strategy and there is no heat or moisture transfer between the attic bays. The attics are subjected to outdoor conditions of Iqaluit, Nunavut (Figure 2). The six ventilation strategies are as follows: 1) no ventilation, 2) mechanical ventilation, 3) natural ventilation, 4) BIPV/T (building-integrated photovoltaic/thermal) mechanical ventilation, 5) BIPV/T natural ventilation, and 6) RH controlled ventilation.

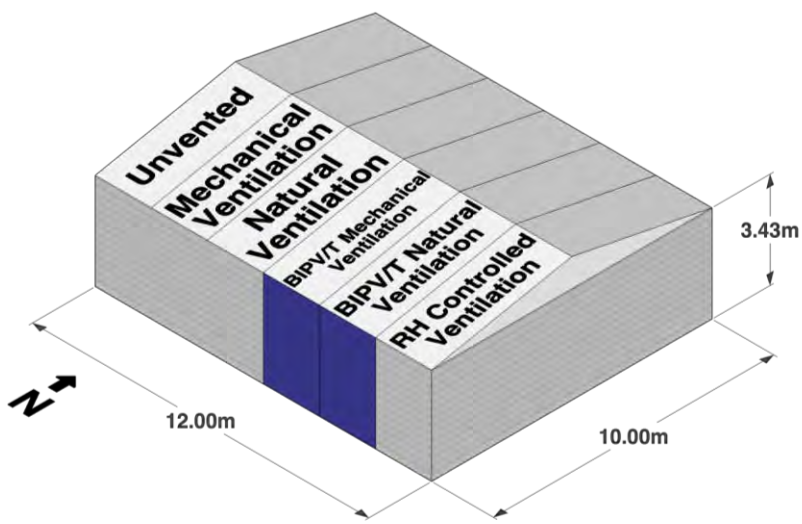

Figure 1: Model of Building with Six Attic Bays Simulated in WUFI Plus

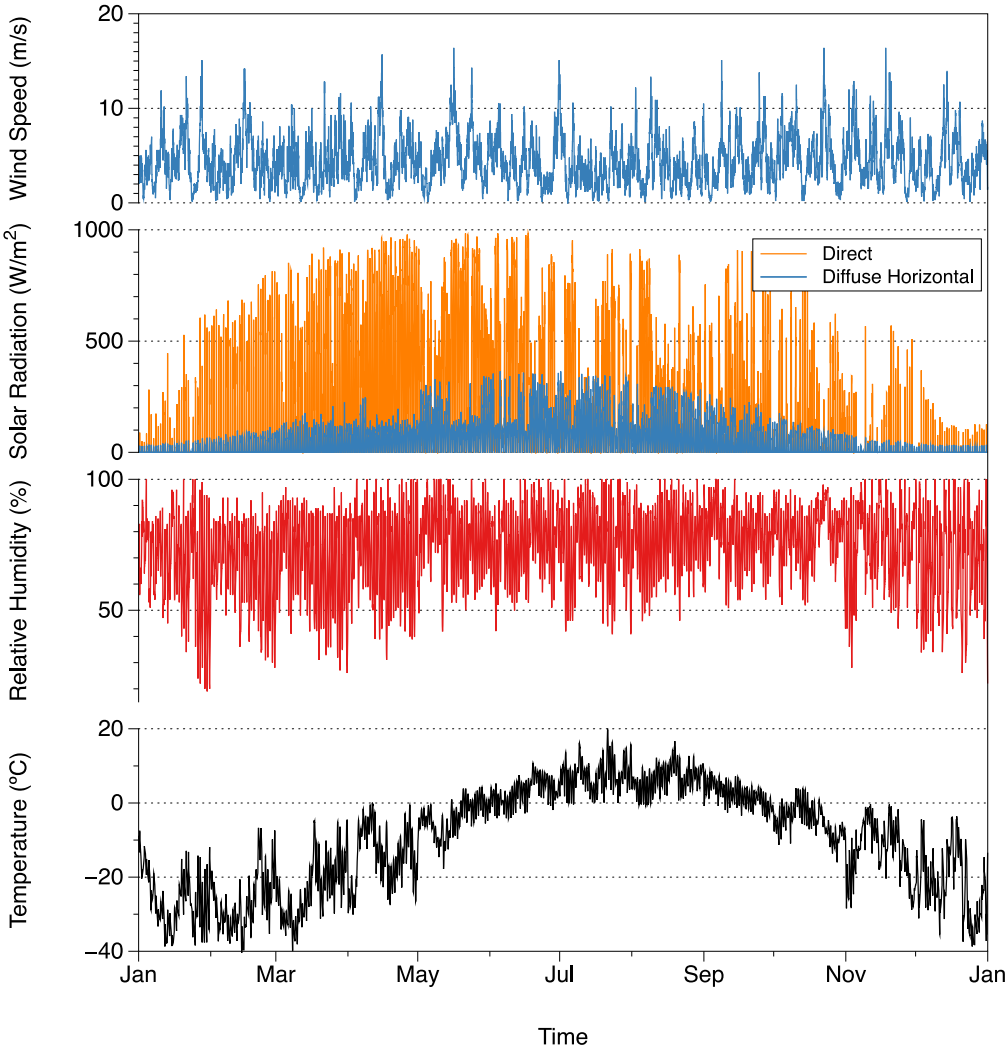

Figure 2: Iqaluit Weather Conditions for Typical Meteorological Year (TMY2)

The second attic is ventilated using an electrical fan exchanging the air in the attic with outside air at a constant rate. In this case, and in all cases with ventilation, the attic ventilation air drawn from an opening at the bottom of the facade, going through a snow filter membrane behind the cladding before reaching the attic, as shown in Figure 3. This way, it is assumed that there is no snow infiltration. This method of ventilating the attic is used in Inuit communities in Nunavik. The temperature and moisture conditions of the air entering the attic are assumed to be the same as the outdoor conditions.

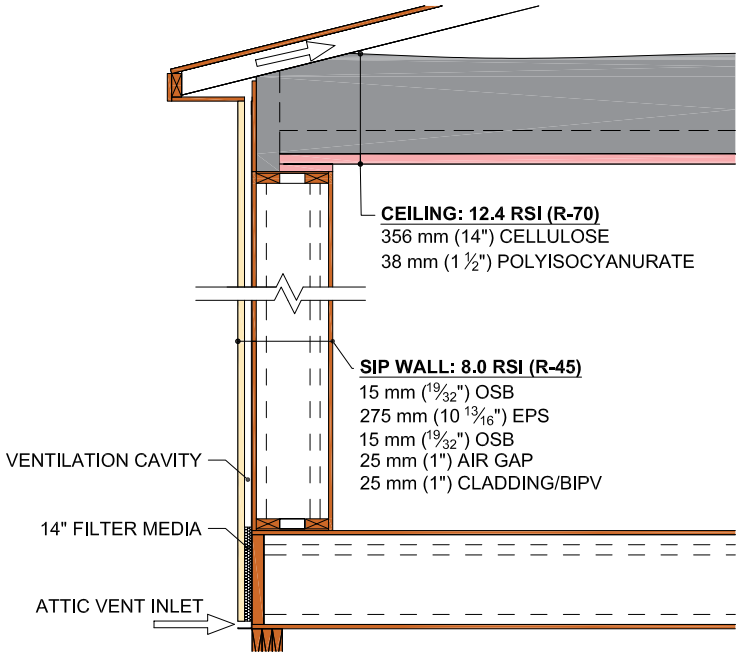

Figure 3: Section of House Showing Attic Ventilation Path and Filter Media

The third attic is ventilated naturally, such that the ventilation rate is dependent on the wind speed and direction. Since the use of the cavity behind the cladding as an attic ventilation path is not conventional, correlations between wind speed and direction and attic ventilation rate were developed for this specific case using computational fluid dynamics (Kayello et al., 2016). The study accounts for wind speeds between 1 m/s and 10 m/s, and at 0º, 45º, and 90º from normal. To calculate the airflow rate in the cavity at any wind speed and angle, symmetry is considered and the data is simply interpolated or extrapolated linearly. The temperature and moisture conditions of the air entering the inlet of the air cavity are assumed to be the same as the outdoor conditions.

The fourth attic is ventilated mechanically and the south-facing cladding is replaced by a BIPV/T system. In this configuration, the BIPV/T system generates electricity while the air drawn in the cavity cools the solar panels, increasing their efficiency. The air that ventilates the attic is therefore heated by the BIPV/T system and consequently has a higher capacity to dry the attic. For this case, the fan ventilates the attic at a rate of 9 ACH only when there is solar radiation incident on the panels. At night, the fan turns off and ventilation is prevented. It is assumed that the air entering the attic is warmed by the BIPV/T system, but the humidity ratio is the same as the outdoors.

The fifth attic is ventilated naturally, as with the third attic, though in this case the cladding is replaced with a BIPV/T system as with the fourth case. The temperature of the air entering the attic is therefore affected by the BIPV/T system, though the ventilation rate is strictly wind-dependent. It is assumed, based on the results obtained by Kayello et al. (2016), that the buoyancy driven air is negligible.

The sixth attic is ventilated mechanically with humidity control. This means that the attic is ventilated only when the difference in outdoor and attic humidity ratio is greater than 0.5 g/m^3. This is similar to the idea of adaptive ventilation, mentioned earlier, though the main distinction is that in this case the attic is ventilated even when the outdoor humidity ratio is higher than the attic humidity ratio. Of course, this is not intentional or beneficial, but rather it is a limitation of the WUFI Plus software. Even though this

ventilation strategy does not function as an adaptive ventilator should, it is nevertheless considered in the simulation to compare.

The hourly outlet temperature conditions for the BIPV/T airflow are needed for the hygrothermal simulation. Using a weather file for Iqaluit, which includes hourly temperature, relative humidity, wind speed, and solar radiation, the required values are calculated as follows. The equation below (Athienitis et al., 2004) is applied to determine the air temperature in a cavity of finite length and width.

$$T_a(x) = \frac{T_w + T_b}{2} + \left[T_o - \frac{T_w + T_b}{2}\right] \cdot e^{\frac{-2x}{A}} \tag{1}$$

$$A = \frac{Mc\rho}{Wh} \tag{2}$$

Where T_a is the temperature of the air in the cavity, T_w is the BIPV/Cladding temperature, T_b is the back plate/sheathing temperature, T_o is the outdoor temperature, x is the upward vertical distance from the bottom of the vented cavity, M is the volume flow rate, c is the specific heat of air, ρ is the air density, W is the width of the wall (2 m), and h is the cavity surface convective heat transfer coefficient. An initial guess is made for the cavity wall temperatures to execute the equation and find the mean air temperature in the cavity. That value is used in the energy balance equations below to check if the initial guesses for wall temperatures are reasonable, making this an iterative process.

$$T_w = \frac{U_o T_o + U_c T_{a(mean)} + U_r T_b + S\alpha A_{wall}(1-\eta)}{U_o + U_c + U_r} \tag{3}$$

Above is the energy balance equation for the BIPV/T cladding, where U_o is the outdoor heat transfer coefficient, U_c is the cavity convection coefficient, U_r is the cavity radiation coefficient, S is the incident solar radiation on the BIPV panels (obtained from the weather file), α is the absorptance of the panels (0.95), A_{wall} is the area of the panels, and η is the electrical efficiency of the panels.

$$T_b = \frac{U_c T_{a(mean)} + U_r T_w + U_w T_r}{U_c + U_r + U_w} \tag{4}$$

Above is the energy balance equation is the energy balance equation for the backplate/sheathing, where U_w is the conductance of the wall (resistance of the wall assumed to be 8 RSI) and T_r is the indoor temperature (22 ºC). These balance equations are solved iteratively until the error in the temperature value is less than 0.001 ºC.

The value of U_c is determined using correlations for calculating the Nusselt number for BIPV/T system, obtained by Candanedo et. al (2011), shown below:

$$U_c = \left(\frac{kNu}{D_h}\right) A_{wall} \tag{5}$$

$$Nu = 0.052 Re^{0.78} Pr^{0.4} \tag{6}$$

where k is the thermal conductivity of the air, D_h is the hydraulic diameter, Re is the Reynolds number, and Pr is the Prandtl number. U_r is calculated with the following, linearized equation:

$$U_r = \frac{4\sigma(\frac{T_w+T_b}{2})^3}{1/\epsilon_w + 1/\epsilon_b - 1} A_{wall} \tag{7}$$

where σ is the Stefan-Boltzmann constant, while ε_w and ε_b are the emissivity values for the BIPV and the backplate/sheathing, assumed to be 0.9. U_o is calculated with the following equation, combining convective and radiative components:

$$U_o = (h_o + h_{ro}) A_{wall} \tag{8}$$

The value of h_o, the convective component, is obtained using correlations provided by Test at al. (1981):

$$h_o = 8.55 + 2.56 V_{wind} \tag{9}$$

Where V_{wind} is the wind speed. h_{ro} is the calculated in a similar fashion as U_r, exchanging T_b for T_o and omitting A_{wall}. The electrical efficiency of the BIPV system is that of typical poly-Si panels (PikeResearch, 2012) which is temperature dependent:

$$\eta = 0.15\,[1 - 0.45(T_w - 20)] \tag{10}$$

The electrical energy production is calculated as follows.

$$E_{PV} = S\alpha\eta A_{wall} \tag{11}$$

The heat gained by the air flowing behind the BIPV/T system is calculated using the value of T_a at the outlet, which is the inlet of the attic.

$$Q = \dot{m} c_p (T_{a(outlet)} - T_o) \tag{12}$$

where $\dot{m}$ is the flow rate and c_p is the specific heat of air.

Hygrothermal simulations with WUFI Plus provide the hourly temperature and relative humidity conditions in each attic, for a total of three years. An important criterion in comparing the performance of the attics is the mold growth index developed by Hukka & Viitanen (1999). The mold growth index uses temperature and relative humidity conditions to determine the potential for mold growth on wood-based materials. The mold growth index is represented by a number between 0 and 6, where 0 indicates no mold growth and 6 indicates 100% mold coverage on a material. A mold growth index of 1 indicates the first stage of mold growth has been reached, while a mold growth index of 3 signifies mold growth that can be detected visually, implying system failure (ASHRAE, 2009). For every timestep in the simulation, a change in the mold growth index is calculated based on ASHRAE standard 160 (ASHRAE, 2009). The temperature and relative humidity conditions of the inner surface of the roof sheathing are used for this calculation. The initial value given to the mold growth index is 0.

Table 1 lists the details of the simulations. In terms of the envelope assemblies, the ceiling is composed of a sheet of polyisocyanurate (PIR) with 203 mm of loose fill cellulose insulation, which has a total resistance of 7 m^2K/W, the recommended value by the Government of Nunavut (2005). The roof is composed of a sheet of plywood covered with spun-bonded polyolefin, with metal roofing attached to 1" strapping. The indoor conditions are a constant 22 ºC, 40% relative humidity. The initial conditions of the attic space and materials are set to -20 ºC, since the simulation starts in January, and 80% relative humidity, which is typical for wood based materials. Four rates of air leakage are implemented: none; low, representing passive house standards (0.6 ACH@50Pa) (Passive House Institute, 2016); medium, representing Nunavut's recommendation for airtightness (1.5 ACH@50Pa) (Government of Nunavut, 2005), and high, which is twice the government recommended value (3.0 ACH@50Pa). The values are obtained by taking the air changes per hour at 50 Pa, dividing by 20 to get the natural air changes per hour, and assuming that half of the air leakage goes through the ceiling into the attic.

Table 1: Summary of Building Setup and Boundary Conditions for Hygrothermal Simulation

	Attic Ventilation Strategy					
Parameter	**Unvented**	**Mechanical Ventilation**	**Natural Ventilation**	**BIPV/T Mechanical Ventilation**	**BIPV/T Natural Ventilation**	**RH Controlled Ventilation**
Attic Volume	10 m^3					
Ventilation	0.05 ACH (0.5 m^3/h)	3 ACH (30 m^3/h)	Wind Dependent	9 ACH (90 m^3/h) Active only in the day	Wind Dependent	3 ACH Active when humidity difference > 0.5 g/m^3
Air Leakage Rates	None: 0 $m^3/h/m^2$, Low: 0.036 $m^3/h/m^2$, Medium: 0.09 $m^3/h/m^2$, High: 0.18 $m^3/h/m^2$					
Ceiling Assembly	203 mm of cellulose insulation and 38 mm PIR (equivalent to 7 RSI)					
Roof Assembly	Plywood, Spun-bonded Polyolefin, Air Space, Metal Roofing					
Indoor Environment	22 ºC, 40% RH					
Outdoor Environment	Iqaluit, Nunavut Typical Meteorological Year (TMY2) weather file					
Initial Attic Conditions	-20 ºC, 80% RH					
Simulation Duration	3 years starting January 1st					

For the unvented attic, a background, unintentional ventilation rate of 0.05 air changes per hour (ACH) is assigned. For the case of mechanical ventilation, the ventilation rate is a constant 3 ACH. For the case of BIPV/T mechanical ventilation, the attic is ventilated at a rate of 9 ACH only in the daytime. This value is chosen so that the airflow speed in the BIPV/T cavity is 0.5 m/s, which is within the acceptable range for BIPV/T's thermal and electricity generation. For the case of RH controlled ventilation, the attic ventilated at a rate of 3 ACH when the difference in humidity ratio between the attic and the outdoors is greater than 0.5 g/m^3. For both naturally ventilated attics, the ventilation rate is wind dependent as described earlier, and the average monthly ACH values for those attics are shown in Figure 4.

Also of interest is the potential of using only a portion of the preheated air from the BIPV/T mechanical ventilation case for attic ventilation, and the rest is directed elsewhere, potentially for ventilating the indoor space. Therefore simulations are carried out where only 1/3 and 1/6 of the air from the BIPV/T is used to

ventilate the attic, equivalent to 3 ACH and 1.5 ACH during the daytime, while the air leakage rate is set to high.

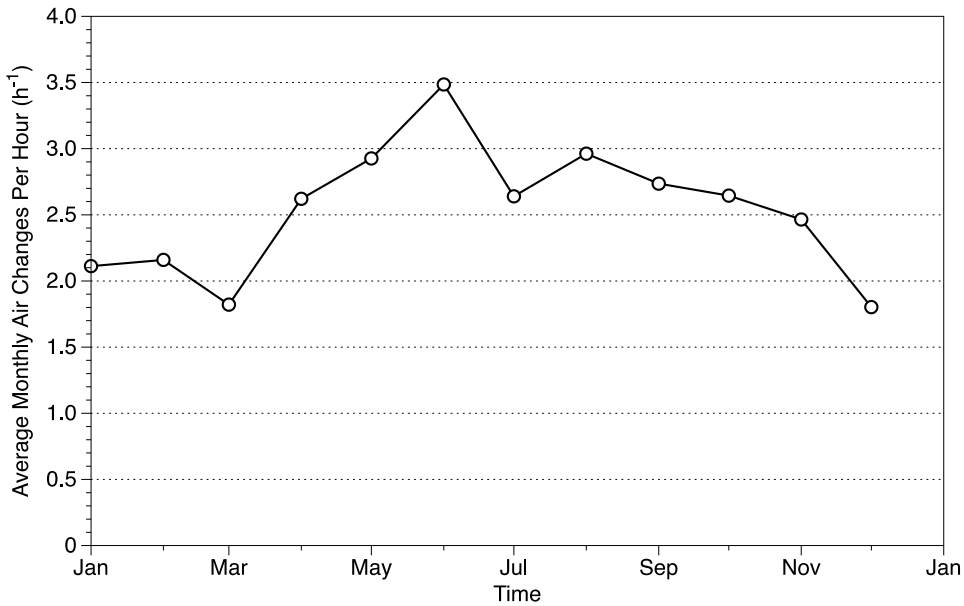

Figure 4: Average Monthly Attic Air Changes Per Hour for Naturally Ventilated Cases

RESULTS

The simulations provide the hourly temperature and relative humidity (RH) conditions for each attic. For convenience, the average monthly RH conditions are presented in Figure 5 through Figure 9. The temperature conditions in the attics are similar, within 3 ºC, so the RH conditions can be compared directly. The case with no air leakage is presented in Figure 5. It is clear that even without air leakage, the unvented attic maintains the highest RH levels throughout the simulation. Without ventilation, the attic has difficulty expelling moisture, though over the course of three years, the RH level in the attic does decrease by about 3%. This shows the importance of ensuring that the attic materials are kept as dry as possible during construction. Relatively, the ventilated attics exhibit much better performance. The case with RH controlled attic ventilation maintains the highest RH levels of the ventilated attics; of course, this is because the attic is ventilated even when the outdoor humidity is higher than the attic. The naturally ventilated cases perform well, though the incorporation of the BIPV/T system results in lower RH levels, up to 6% difference in the summer time. The mechanically ventilated case performs about as well as the naturally ventilated cases. This makes sense since the average natural ventilation rate, shown in Figure 4, is close to 3 ACH, which is the ventilation rate of the mechanically ventilated attic. BIPV/T mechanical ventilation provides the lowest RH levels of all cases by far.

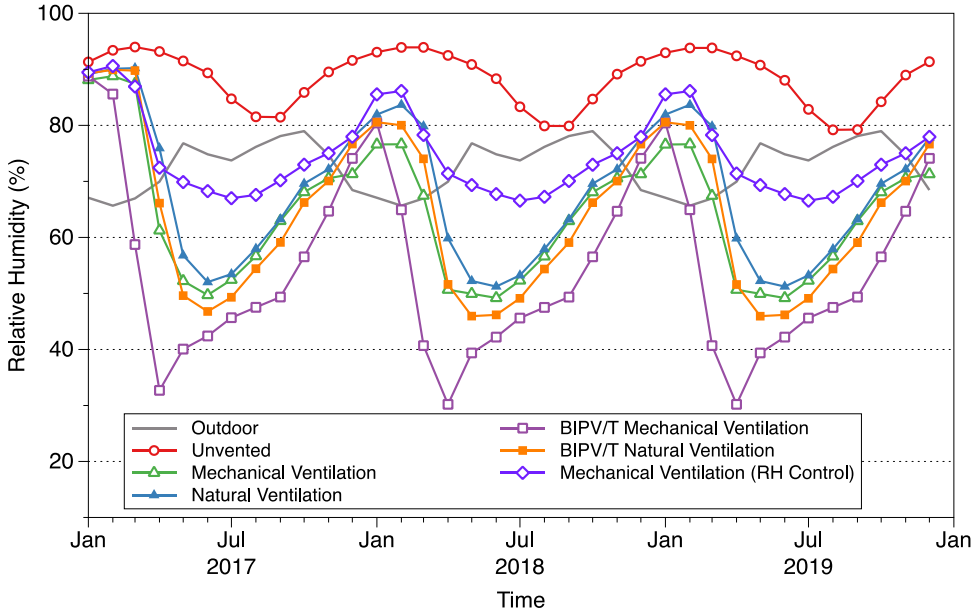

Figure 5: Average Monthly Relative Humidity of Attics With No Air Leakage

Figure 6 shows the RH levels in the attics with a low amount of air leakage. Even though the air leakage rate is low, the humidity levels in the unvented attic increase slowly over the years, and exceed 85% RH consistently. The RH level in the ventilated attics reach over 90% in the winter, but quickly decreases in the springtime. The natural ventilated attics and the mechanically ventilated attic reach as low as 50% RH by June, while the BIPV/T mechanically ventilated attic achieves less than 40% RH as early as April.

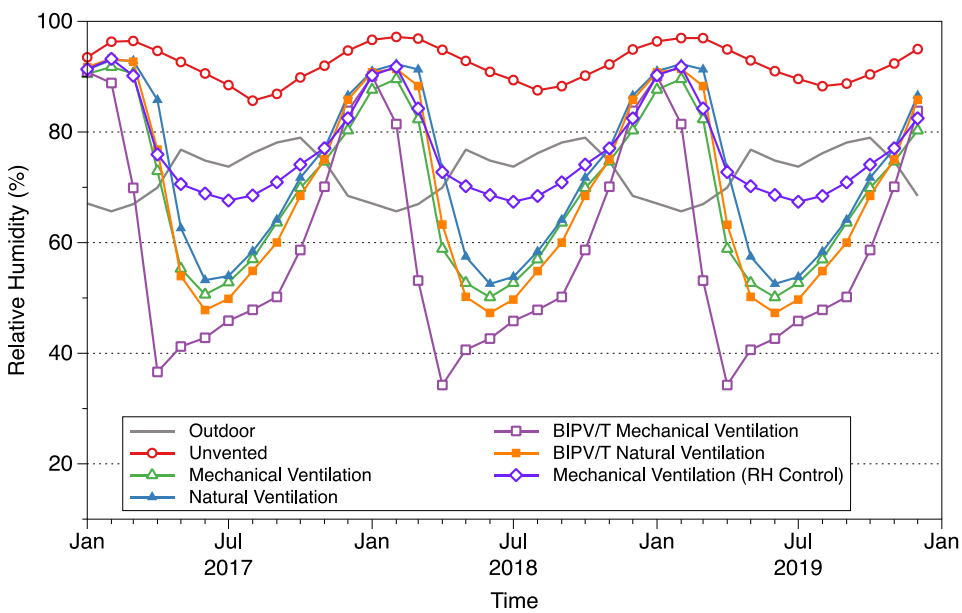

Figure 6: Average Monthly Relative Humidity of Attics With Low Air Leakage (0.036 $m^3/h/m^2$)

With medium air leakage, as shown in Figure 7, the RH levels in the unvented attic vary between 88% in summer and almost 100% in winter. The attic ventilated with RH control experiences a decrease in RH levels more rapidly than most other ventilated attics, which further indicates that outdoor air in the springtime is highly suitable for drying the attic. The BIPV/T mechanical ventilated attic exhibits the

lowest RH levels, reaching as low as 40% in the spring and as high a 93% in the winter. At high rates of air leakage, as shown in Figure 8, similar trends are observed. Almost all attics experience over 95% RH in winter, though are able to recover to less than 60% RH by spring.

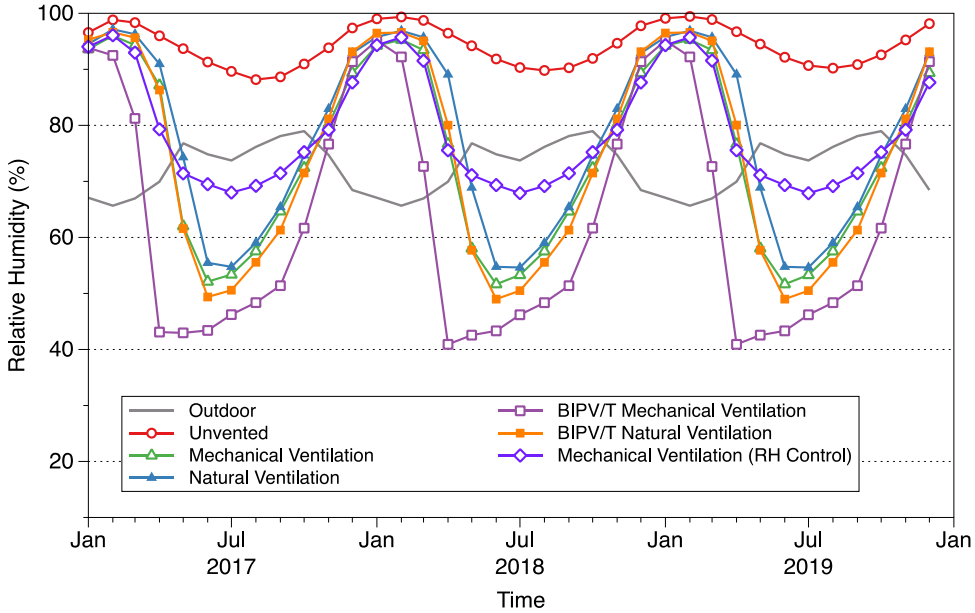

Figure 7: Average Monthly Relative Humidity of Attics With Medium Air Leakage (0.09 $m^3/h/m^2$)

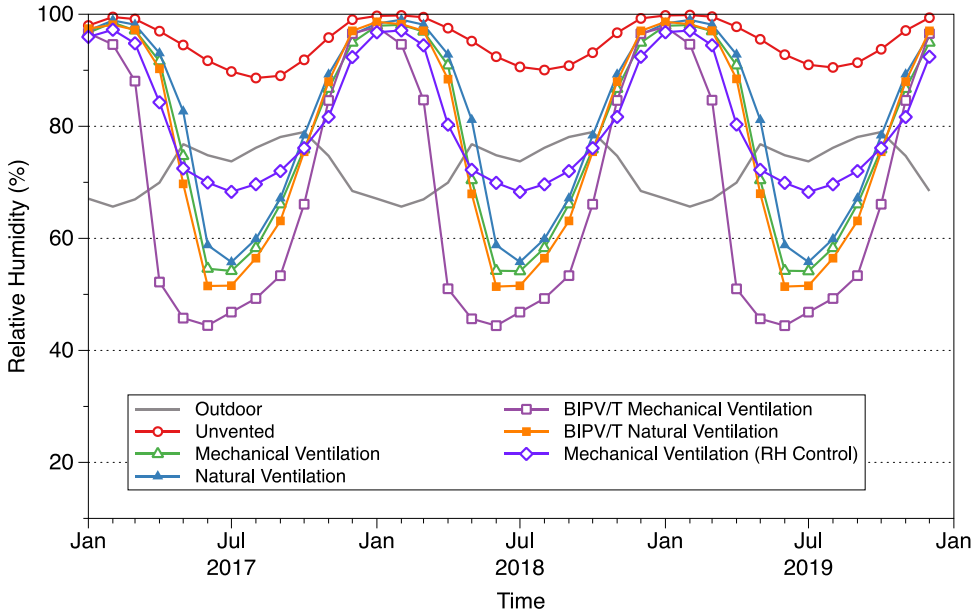

Figure 8: Average Monthly Relative Humidity of Attics With High Air Leakage (0.018 $m^3/h/m^2$)

The BIPV/T mechanically ventilated attic attained the lowest RH levels by far, so it is worthwhile to investigate the potential of using only a fraction of the BIPV/T outlet air for attic ventilation. Figure 9 shows the RH levels for the BIPV/T mechanically ventilated attic, with a high rate of air leakage, where 100%, 33% and 17% of the outlet air is used for ventilation. These values are equivalent to 9 ACH, 3 ACH, and 1.5 ACH respectively. It is clear that even with very low rates of attic ventilation, the RH levels in the attic can decrease to less than 60% in the warmer seasons. The main difference is how quickly this decrease

happens. At 9 ACH, the RH in the attic reaches less than 60% by April, at 3 ACH by June, and at 1.5 ACH by July. The results from the mechanical ventilation case (3 ACH) are also included in Figure 9 for comparison. At 33% flow into the attic with BIPV/T case (3 ACH in the daytime), the results are very similar to the mechanical ventilation case, which ventilates at 3 ACH continuously. This illustrates the benefit of the BIPV/T, where similar results can be attained while ventilating the attic half as much.

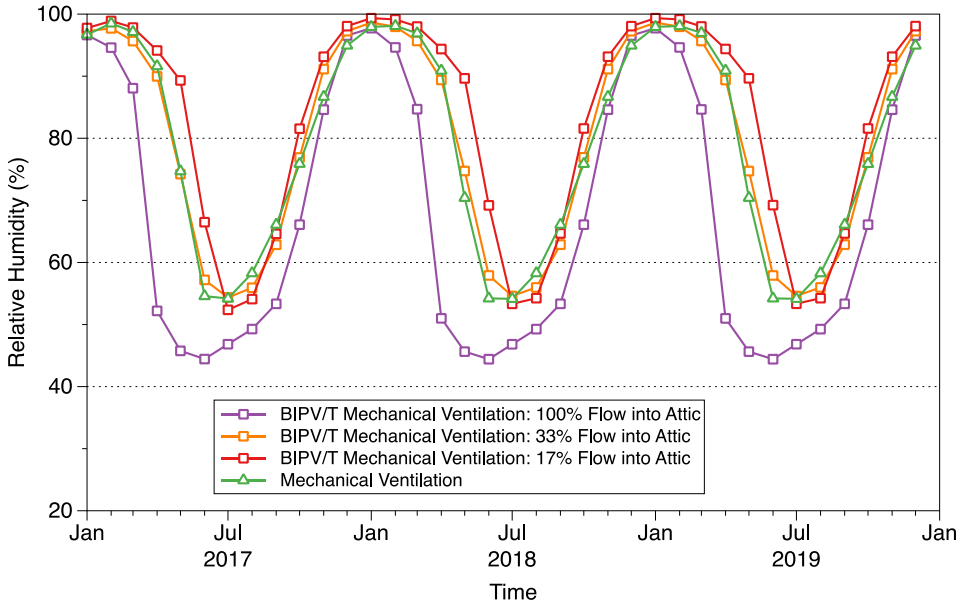

Figure 9: Average Monthly Relative Humidity of Attic with BIPV/T Mechanical Ventilation and High Air Leakage (0.18 $m^3/h/m^2$)

With attics, the biggest concern is moisture damage by mold growth and decay, so the mold growth index is a useful criterion for comparing the attic performance. Table 2 lists the highest mold growth index attained by each attic over the course of the three-year simulation. The unvented attic is actually the only attic that performed poorly. With no air leakage, the mold growth index exceeds 1, which implies that mold growth occurred microscopically. At even low rates of air leakage, the mold growth index exceeds 3, indicating visible mold growth and system failure. Figure 10 shows the change in mold growth index over time for the unvented attic. All other attics performed exceptionally well as the mold growth index remains very low, below 0.04, which is negligible. It is interesting to note that the only two attics where the mold growth index does not exceed zero are the BIPV/T mechanically ventilated attic and the RH controlled attic.

Table 2: Highest Mold Index Attained for Attics

	Highest Mold Growth Index Attained					
Air Leakage Rate	**Unvented**	**Mechanical Ventilation**	**Natural Ventilation**	**Mechanical BIPV/T Ventilation**	**Natural BIPV/T Ventilation**	**RH control**
None	1.65	0.00	0.00	0.00	0.00	0.00
Low	3.84	0.00	0.01	0.00	0.00	0.00
Medium	4.46	0.01	0.03	0.00	0.01	0.00
High	4.74	0.02	0.04	0.00	0.02	0.00

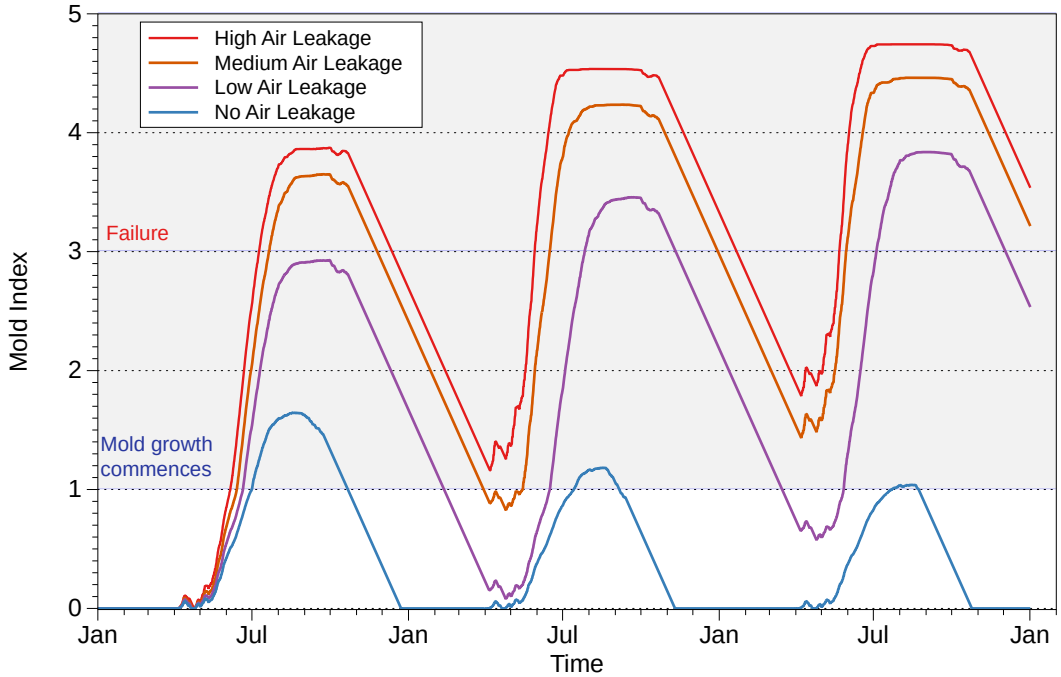

Figure 10: Mold Growth Index for the Unvented Attic

For the case with the BIPV/T mechanically ventilated attic where only a portion of the airflow is used for attic ventilation, the mold growth index results are shown in Table 3. When 1/3 of the air is used for attic ventilation, the mold growth index reaches only 0.01, which is negligible. When 1/6 of the air is used for attic ventilation, the mold growth index reaches 0.12, which is relatively much higher but still significantly low and well within the safe range. Of course, these results are for high rates of air leakage, which should not be expected in new houses. This shows that there is much potential for the BIPV/T outlet air to be used for other purposes. In fact, attic ventilation would likely be the secondary end use.

Table 3: Highest Mold Index Attained for Attic with BIPV/T Mechanical Ventilation and High Air Leakage Rate

Percentage flow into attic	Attic Air Changes	Highest Mold Growth Index
100%	9	0.00
33%	3	0.08
17%	1.5	0.32

The total monthly amount of thermal energy collected by the air passing through the BIPV/T system is visualized in Figure 11. In the case of natural ventilation, the heat gains are highest April through June, where over 20 kWh of heat are collected each month per meter width of BIPV/T. However, since airflow is only wind driven, it cannot really be used for any other means besides attic ventilation. In the case of mechanical ventilation, the heat gains are significantly higher since the air speed in the BIPV/T channel is much higher. In the late fall and early winter, November through January, the heat gains are below 20 kWh/m per month. However, from February through September, the heat gains exceed 50 kWh/m per month, reaching as high as 112 kWh/m in April. The total heat collected annually is 704 kWh/m; if the entire south face of the building was covered in BIPV/T, this would equal almost 8.5 MWh. The advantage

with mechanical ventilation is that the heated air can be used for other means. Considering that an energy efficient house of similar size in the arctic can require less than 15 MWh of space heating annually (Cornick, 2009; Vladykova et al., 2012; CMHC, 2017), the heat collected with the BIPV/T can potentially offset the heating requirements by over 50%. Of course, the peak heat generation does not correspond to peak heating requirements. Since heating is required almost year round, the heat collected by the BIPV/T would be most useful in the spring, summer, and fall. Coupling the BIPV/T system with a heat recovery or energy recovery ventilator may be one of the more effective methods of utilizing the heated air in this climate

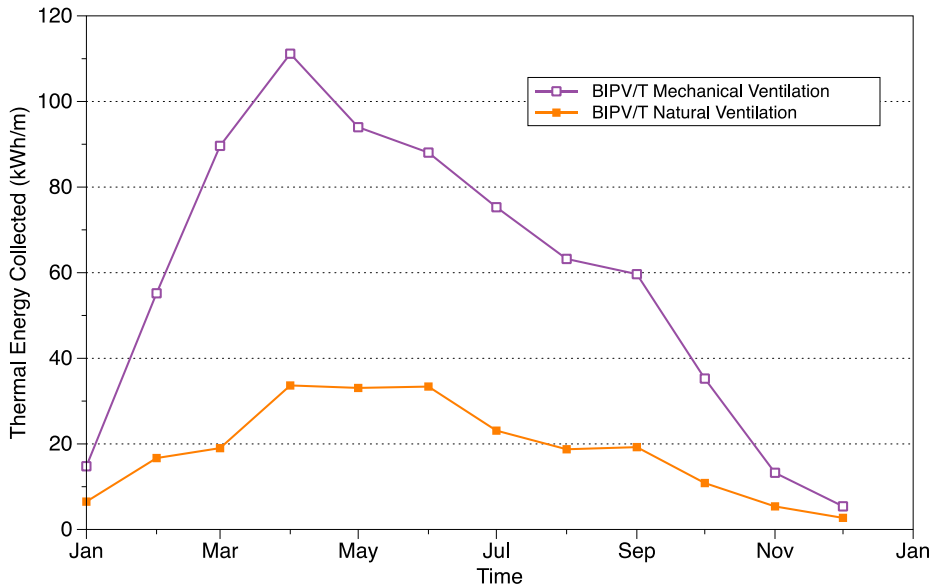

Figure 11: Monthly Thermal Energy Collected by Airflow behind BIPV/T Per Meter Width of BIPV/T Cladding

Figure 12 shows the total electrical energy produced by the BIPV/T each month. The results for the naturally ventilated and mechanically ventilated attics are very similar; mechanical ventilation achieves higher airflow rates, cooling the panels more and making them slightly more efficient. Peak energy production is in April with almost 108 kWh per meter width of BIPV/T per month. Annually, 683 kWh/m are produced with mechanical ventilation, and 668 kWh/m with natural ventilation. If the entire south face of the house is covered with BIPV/T, 8,196 kWh can be produced annually. This is equivalent to 68 kWh/m^2 for a 120 m^2 house. An energy efficient arctic house of similar size requires less than 40 kWh/m^2 per year for lighting, appliances and plug loads (CMHC, 2016). The power required by the fan to draw air through the 12 m wide BIPV/T at 0.5 m/s would be less than 10 watts, and would consume less than 50 kWh a year, which is not significant. Since electricity in the north is produced using fossil fuels, which also need to be delivered by sea from the south, offsetting the electrical loads with solar power would be very beneficial to the long term sustainability of northern housing.

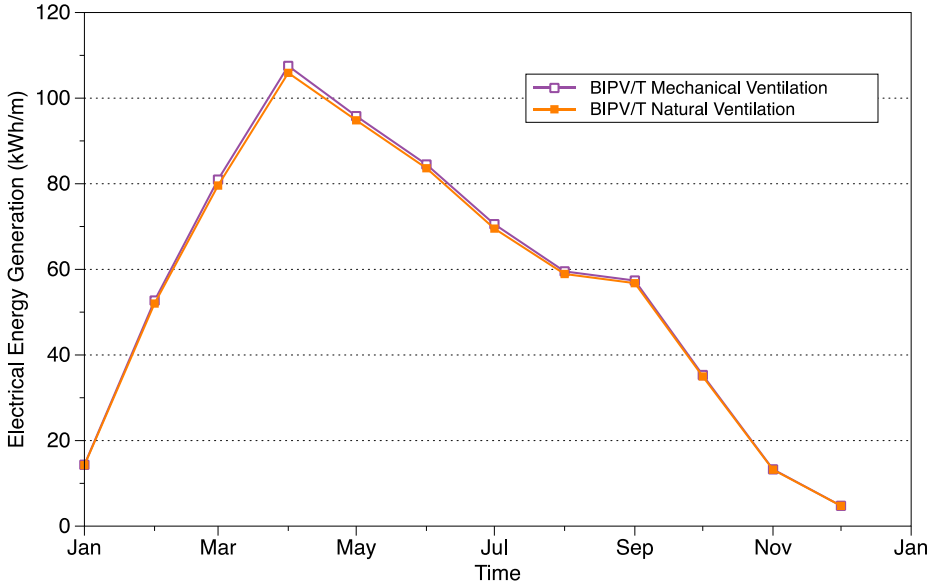

Figure 12: Monthly Electrical Energy Generation Per Meter Width of BIPV/T Cladding

CONCLUSION

Attic ventilation in arctic climates is a unique issue because of the extreme cold and drifting snow. This paper examines the performance of attics with several ventilation strategies using hygrothermal simulation. Unvented attics are found to be a high-risk design, even at low air leakage rates, since the moisture does not diffuse through the roof at a sufficient rate, and the likeliness of mold growth is high. Ventilating attics either mechanically or passively are shown to be effective at maintaining low humidity levels in the attics, provided that snow infiltration is prevented with filtration media along the ventilation path. The springtime is the most crucial and effective time to ventilate, so seasonal ventilation is a strategy worth exploring. Allowing the attic ventilation air to pass through a BIPV/T is shown to improve the performance of the attic further. BIPV/T mechanical ventilation provides the best results of all cases studied, and benefits from having electricity production and useful thermal energy. Only 1/3 or 1/6 of the air passing through the BIPV/T can be used for attic ventilation to maintain low humidity levels and avoid mold growth. The majority of the preheated air can be used for ventilating the indoor space, ideally with a heat recovery or energy recovery ventilator. If the entire south face of the building is clad with BIPV/T, 50% of annual heating needs and 150% of annual electrical needs can be produced, offsetting fossil fuel dependency.

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