Wintertime Solar Heat Production and Storage:

Residential Sunrooms as Low-Cost Thermal Generators

David Fright

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Thesis

Using temperature data collected from the “Bloomfield Greenhouse” on Almon Street in Halifax, Nova Scotia, I will demonstrate how a typical residential sunroom can be used as a low cost “solar thermal generator.” On one sunny day, while it was -12C outside, the temperature inside the Bloomfield greenhouse was 46.1C or 58.1C warmer than outside. Like a greenhouse, a sunroom is an insulated environment designed to admit large quantities of sunlight that can generate high temperatures. Because additions or renovations to a home tend to increase property value by more than their cost, sunrooms are an inexpensive alternative to solar hot water panels that all homes can have “for free”. Homes with existing sunrooms can begin to reduce their heating costs immediately without any investment. The warm environment inside a sunroom, or “solarium”, can also be used to increase the output of a heat pump or heat pump hot water heater (HPHW) by up to 10 times. Conversely, a heat pump operating inside a “solarium” can generate the same amount of heat using 90% less electricity than one operating in a cold outside environment. Temperatures inside the Bloomfield greenhouse were greater than 44C once every three days. Two days of thermal storage capacity would, therefore, allow all wintertime household heat and hot water to be produced by heat pumps operating at temperatures exceeding 44C and can virtually eliminate wintertime heat and hot water energy costs and their associated greenhouse gas emissions. In the summertime, the same system can significantly reduce hot water costs while providing “free” cooling, dehumidification, and fresh water production. [1]

Solariums carry with them significant additional benefits. Because long term thermal storage allows for all heat and hot water to be produced when the sun is shining, and temperatures within the solarium are at their highest, the electricity needed to run the system could be supplied by a small solar-electric power system that would have the added cost benefit of not requiring an extensive array of electrical storage batteries, unlike most solar-electric power systems. The same system could also supply electricity to run the heating system in the event of a power outage for up to two days using only two car batteries. Although Halifax is lucky in that we have a local solar hot water panel manufacturer, most municipalities are not so fortunate. Solariums offer a locally produced alternative to manufactured solar hot water panels that can be constructed by any number of firms operating locally. As an alternative to imported fossil fuels, solariums offer further local employment and investment benefits.

[1] Waste Heat and Air Conditioning: 50% Lower Hot Water Costs and “Free” Cooling, Dehumidification, and Fresh Water Production. David Fright.

Figure 1.
"The Bloomfield Greenhouse"

Figure 2.
"Inside The Bloomfield Greenhouse"

Introduction

Over the course of 15 days, I measured temperatures inside the Bloomfield Greenhouse and was amazed to find that on any given sunny day, irrespective of the outside temperature, the temperature inside the greenhouse exceeded 44C. The first time I measured the temperature inside the greenhouse, it was 46.1C while outside it was -12C. Out of the 15 days that I studied temperatures inside the greenhouse, '7' (46%) of them exceeded 44C. '9' (60%) exceeded 36C, and '10' (67%) exceeded 20C. The lowest temperature I recorded was 9.7C. If it was sunny, the temperature inside the greenhouse was at least 44C. On a partially sunny day, the inside temperature was at least 36C. On a cloudy day, it was at least 20C. On a rainy or snowy day, it was at least 9C. The greatest temperature difference between the inside and the outside of the greenhouse during the period of study was 50.6C when it was 44.6C inside and -6C outside. The temperature difference represents the tremendous amount of energy provided by the Sun to the Earth, every day, winter and summer. The reason that the temperatures inside the greenhouse are so high on all sunny days, even very cold ones, is that the greenhouse is well insulated, and the large window area, designed to admit sunlight for plants to survive, also allows the tremendous amount of thermal energy contained within sunlight to enter unobstructed. For this reason, many older homes have a sunroom. It is a convenient place to dry wet jackets and winter boots, and being next to the warm environment created by the sunroom helps insulate the rest of the house against heat loss.

This neglected energy can be used by households and businesses to greatly reduce their heating and hot water energy costs. The highest temperature I recorded inside the greenhouse was 49.1C which is very near hot water faucet temperatures of 50C. A sunroom, therefore, can be used to pre-heat hot water as an inexpensive alternative to a solar hot water system. The warm environment inside a sunroom can also be used to greatly enhance the performance of heat pump-based heating and hot water systems. Heat pumps offer significant energy savings over other forms of home heating and hot water production. Rather than using electricity to produce heat, they use electricity to *move* heat from one environment to another and can do so cost effectively even when the temperature of the environment which they are drawing it from is -15C. However, a heat pump operating in an environment at 49C will produce more than 10 times the amount of heat using the same amount of electricity as one operating at -10C. Conversely, a sunroom can reduce heat pump electricity consumption by up to 90%.

The cost of refurbishing an existing sunroom in order to maximize its solar energy production is minimal. Because the cost of constructing a new sunroom can be entirely recouped by the increased property value or home equity it provides, all homes can have the equivalent of a solar heat and hot water system "for free". On a sunny day with a high temperature of 7C, the temperature inside one sunroom that was not particularly well insulated and somewhat drafty was 29.6C. A home with a pre-existing sunroom can reduce its energy cost immediately by simply circulating the warm air produced by the sunroom through the home's interior. When temperatures within the sunroom rise beyond a certain point, simply ventilating the warmer air in the sunroom with the colder air from the home will save the equivalent of $48 in heating costs a year and 318 pounds of C02 emissions "for free".

Because a heat pump operating in a warm solarium will require 90% less electricity than one operating in a cold outside environment, the electricity for a solar thermal generation system could be provided by a small solar photovoltaic power system that would not need an extensive array of expensive electrical storage batteries, unlike most photovoltaic power systems, because a solar thermal generator will consume electricity to produce heat primarily on sunny days when the solar-electric panels are also producing electricity. And, because of the low power requirements of a solarium thermal generator when not producing heat, but merely circulating it, it could also provide days worth of redundant home heating in case of electrical grid failure using nothing more than a couple car batteries.

To supply enough solar thermal energy for all a household's heating and hot water needs, existing sunrooms could be expanded or used in conjunction with solar hot water panels. A sunroom provides an excellent location for a heat pump hot water tank and additional thermal storage tanks, such as those used by "System 'C'" which I will discuss at the end of this document, which could be fed by pre-heated water supplied by solar hot water panels to reduce the heat requirements that would need to be supplied by a small sunroom alone. Larger sunrooms could be constructed for new homes to supply virtually all of the solar energy needed for wintertime household heating and hot water.

Method

Over the course of 15 days, I measured the maximum daily temperature inside the Bloomfield greenhouse using a digital thermometer. The accuracy of the thermometer was verified against a known good digital thermometer. The determination of the "kind" of day--sunny, partially sunny, cloudy, and rainy or snowy--was made based on weather trends prior to 2pm. The outside temperature was recorded at 2pm using data from environment Canada's weather station at the Stanfield International Airport which is typically within 1 or 2 degrees of the local temperature.

Observations

Date	Greenhouse Temperature	Outside Temperature	Temperature Difference	Weather Condition
17-Feb	44.6	-6	50.6	Sunny
18-Feb	9.7	-2	11.7	Cloudy
19-Feb	44.8	2	46.8	Sunny
20-Feb	11.5	5	6.5	Cloudy
21-Feb	12.3	4	8.3	Cloudy
22-Feb	46.4	0	46.4	Sunny
23-Feb	46.6	-2	48.6	Sunny
24-Feb	37	4	33	Partially Cloudy
25-Feb	19.6	-2	21.6	Cloudy
26-Feb	10.6	3	7.6	Cloudy
27-Feb	43.5	2	41.5	Sunny
28-Feb	49.1	7	42.1	Sunny
01-Mar	10.2	2	8.2	Cloudy
02-Mar	47.2	6	41.2	Sunny
03-Mar	36.3	8	28.3	Partially Cloudy

Figure 1.

Out of the '15' days of study, '7' (46%) had temperatures inside the greenhouse that exceeded 44C. '9' (60%) had inside temperatures that were above 30C. '10' (67%) had inside temperatures that were above 20C, and the remaining ‘4’ (27%) had inside temperatures above 9C. The temperature within the greenhouse varied with the weather conditions and not the outside temperature. The outside temperature on days when the temperature inside the greenhouse was above 44C ranged from -6C to +7C. On days when it was above 30C inside, the outside temperature ranged from -6C to +8C. On days when it was above 9C inside, the outside temperature ranged from -6C +8C.

The highest temperature I recorded inside the greenhouse was 49.1C on the warmest sunny day during the study period (8C). The greatest temperature difference between the inside and the outside of the greenhouse was 50.6C and occurred on the coldest sunny day during the study period (-6C). As previously noted, the greatest temperature difference, 58.1C, occurred outside the study period on a day in which the inside temperature was 46.1C and the outside temperature -12C. The lowest daytime temperature inside the green house was 9.7C on a cloudy but relatively warm (-2C) day. The coldest temperatures within the greenhouse were on cloudy days and tended to be the warmest outside. The warmest temperatures within the greenhouse were on sunny days. The greatest temperature differences between the inside and outside of the greenhouse occurred on the coldest sunny days.

Generally, on sunny days the temperature inside the greenhouse will be above 44C. On partially sunny days, it will be above 30C. On cloudy days it will be above 20C. On rainy or snowy days it will be above 9C. The predictability of the results makes it likely they can be used to estimate the minimum temperature within the greenhouse for each day of the year. Because the period in which the greenhouse temperatures were studied happened to be a particularly warm one, the temperature differences, and therefore the relative benefit, or “thermal output”, of the greenhouse would be even higher if the weather was typically colder at that time of year.

During the period of study, the greatest amount of time between sunny days when the greenhouse temperature was at least 44C was ‘3 ‘days. However, out of the ‘5’ periods between “44C days” , only ‘1’ of them lasted ‘3’ days. ‘1’ was ‘2’ days long, and the remaining ‘3’ were only ‘1’ day long. During the ‘3’ day span, the next warmest temperature I recorded inside the greenhouse was 37C. During all spans between 44C temperatures, the lowest temperature I recorded inside the greenhouse was 9C.

Energy Production

When temperatures within a solarium are higher that the interior temperatures of a home, hot air can simply be “ventilated” from the solarium into the home using a floor fan. Ventilate when the temperature inside the solarium rises beyond a certain point and stop when the temperature falls below a certain point. This simple system will supply an average of 1 hour of household heating per day which is equivalent to an annual energy cost savings of $53 and 318 pounds of CO2 emissions.[2],[3] It could also be used to preheat household hot water using a simple copper loop or coil and a valve to direct the flow of water away from the sunroom when temperatures within it fall below a certain point.

[2] In each sunny day there are 6 hours of 44C heat , or ¼ of a day, 1 out of every 3 days. A typical sunroom might provide a household with ½ of its total heating requirements. This equates to ½ x ¼ x 1/3=1/24th of a households daily heating requirements or the equivalent of 1 hour of daily total household heating.

[3] Out of 7 heating months, or 210 days, 1 hour a day, or 210 hours every year, this would save the equivalent of (48kwh/24) x 210 x$.155=$48 in electricity costs and 318 pounds of CO2.

Although this system has the advantage of being very inexpensive, it will only be able to produce heat down to point where the temperature of a solarium is equal to the interior temperature of a home (21C) which, depending on the time of the year, might still be much warmer than it is outside. A passive system like this would not be able to store heat effectively, either.

Heat pumps are able to draw heat cost-effectively from an outside environment as cold as -15C to warm the interior of a home that is 21C or more. However, using the same amount of electricity, a heat pump will be able to draw 10 times more heat from an environment that is 44C than one that is -10C. One of the coldest days of the winter (-12C) was one of the warmest inside the greenhouse (46.1C). A solarium offers an "energy rich" environment from which a heat pump can draw heat at a much higher coefficient of performance. Even in the middle of winter it is possible to operate a heat pump inside a solarium at temperatures that are at least 44C '1' out of every '3' days.

Virtually all heat pump experiments, which study the effect that changes in outside temperature have on the coefficient of performance (COP), compare a constant interior household temperature against a varying outside temperature. This is because the interior of a home, ideally, is maintained at a constant temperature near 21C.[4] In contrast, hot water heat pump (HWHP) experiments tend to keep the outside, or surrounding, temperature constant against a varying inside "tank temperature". This data is especially useful for my study because it allows the effect of *temperature differences* between the exterior and interior of a home environment on heat pump COP to be studied when the exterior temperature is less than, equal to, or greater than the interior temperature. The Tank Temperature, or interior, of a hot water heat pump, therefore, is like a "micro climate" in which the effect of a change in *temperature difference* when the outside "operating environment" is both *colder* and *warmer* than the inside environment of a heat pump based heating system can be studied.

All heat pump studies that relate heat pump COP to varying outside temperatures stop at a maximum outside temperature of 15C. At temperatures much higher than this most households simply don't need heat, so there is no point studying COP levels beyond this point. Unlike the interior of a home which is maintained at 21C, it is typical for a HPHW tank to be completely drained and refilled with water that is much colder than the outside air temperature. HPHW tanks also heat hot water to much higher temperatures than the interior of a home. Therefore, a HPHW will frequently operate in conditions when the internal Tank Temperature is much colder or much hotter than the exterior environment which allows the COP for heat pumps operating in temperatures hotter than 15C to be studied.

[4] Coefficient of Performance (COP) is a measure for determining the amount of additional heat per unit of electricity a heat pump provides in comparison to a standard electric baseboard heater. A baseboard heater will produce 1kwh of heat using 1kwh of electricity and is assumed to have a coefficient of performance of '1'. A heat pump operating at a COP of '2' will produce the equivalent of 2kwh of heat using 1kwh of electricity. A heat pump operating at a COP of '4' will produce the equivalent of 4kwh of heat using 1kwh of electricity and so forth.

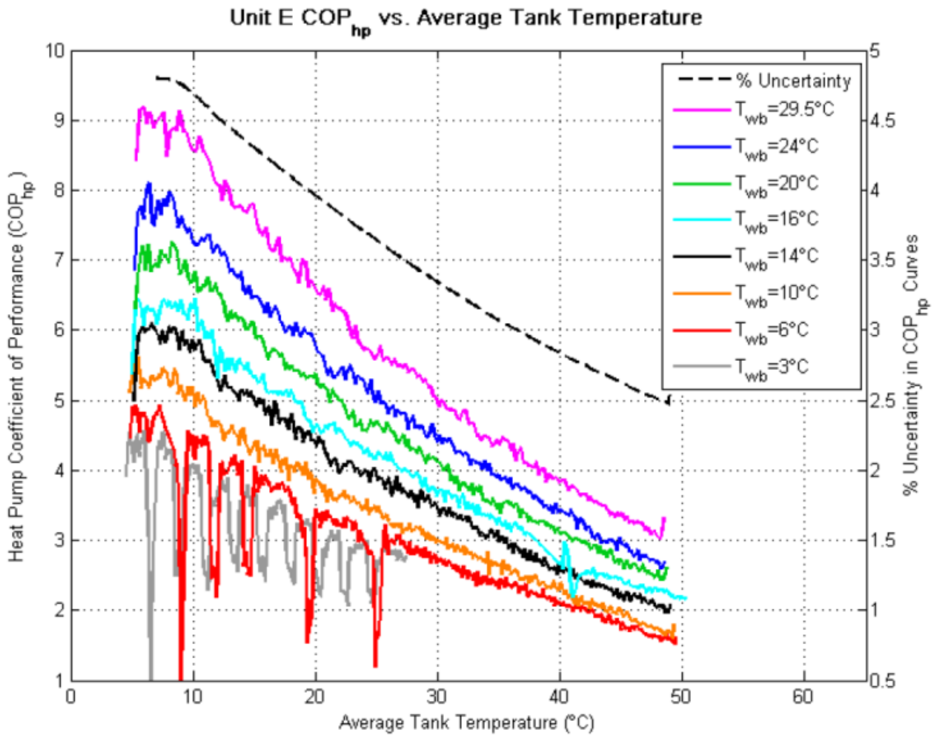

Figure 3.

Figure 3. shows data from a study that relates the COP for a HPHW tank at several different outside, or "Operating Temperatures", to the internal Tank Temperature of the HPHW.[5] As the graph demonstrates, the warmer the outside, Operating Temperature, the higher the HPHW's COP. For all Tank Temperatures, the Operating Temperature T=29.5C has the highest COP. However, as the Tank Temperature increases, the increase in COP as a result of an increase in the Operating Temperature decreases. At Tank Temperatures of 10C, the COP increases by '1' for every Operating Temperature increase of 4C at a rate of 1COP/4C. However, as the temperature inside the HPHW tank approaches 60C, the COP for all Operating Temperatures approaches '2' and the rate of increase '0'. Moving back along the X-axis from a Tank Temperature of 50C to a Tank Temperature of 10C, the COP increases as all Operating Temperatures become relatively hotter compared to the Tank Temperature. The hotter the Operating Temperature, the greater the COP. However, the hotter the Tank Temperature, the lower the resulting increase in COP due to an increase in Operating Temperature. This is because the *temperature difference* due to an increase in Operating Temperature is lower as the Tank Temperature increases. The colder the Tank Temperature, the greater the relative change in *temperature difference* due to an increase in Operating Temperature, and the greater the corresponding increase in COP.

[5]National Renewable Energy Laboratory. Laboratory Performance Evaluation of Residential Integrated Heat Pump Water Heaters. B. Sparn, K. Hudon, and D. Christensen.

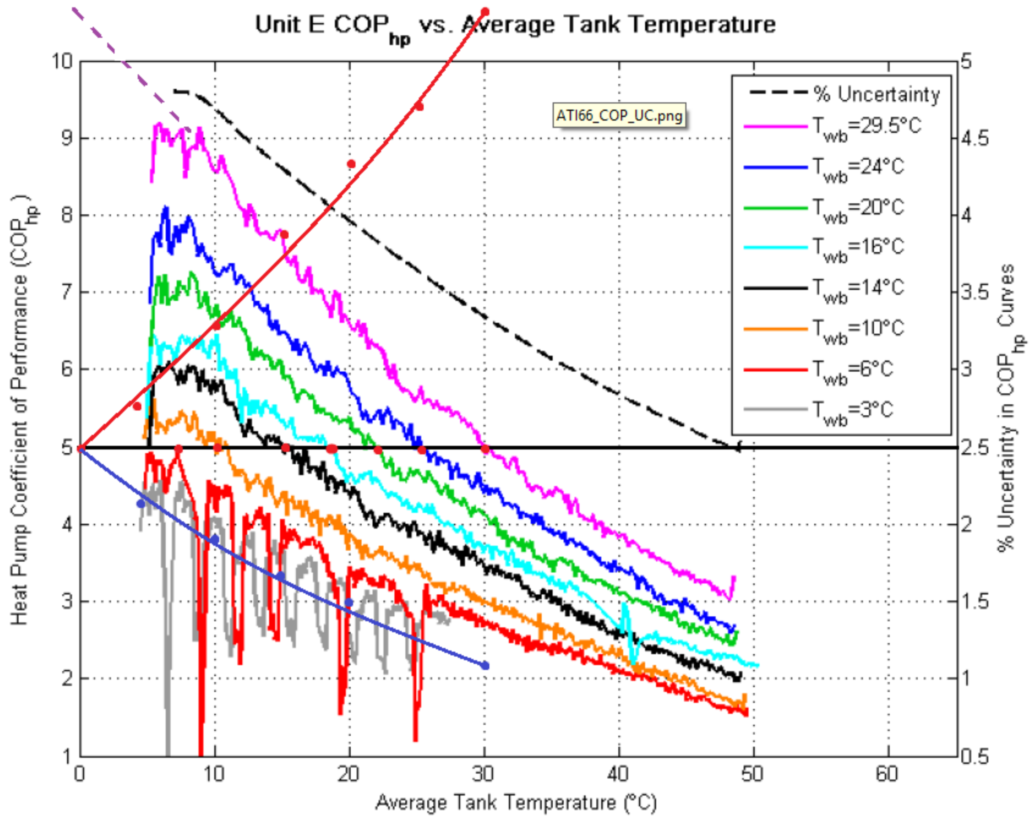

Figure 4.

Drawing a horizontal line at a COP of 5, and plotting the intersections with the COP vs. Tank Temperature curves for all Operating Temperatures, reveals that the COP approaches '5' when the Operating Temperatures and the Tank Temperature converge and are approximately equal (Fig.4). At a COP of '5', T=10C intersects at Tank Temperature=10C, T=20C intersects at Tank Temperature=22C, and T=29.5 intersects at Tank Temperature=30C. This relationship is true for all Operating Temperatures.

As the Tank Temperature increases beyond the Operating Temperature, the COP falls until it reaches '2' for all Operating Temperatures at Tank Temperature=60C when the Tank Temperature is 30C warmer than Operating Temperature T=29.5C. As the Operating Temperature increases beyond the Tank Temperature, the COP increases until it reaches 10 or 11 when the Operating Temperature T=29.5C is 30C higher than Tank Temperature=0C. The COP is highest at '11' when the Operating Temperature is highest, the Tank Temperature the lowest, and the *temperature difference* between the Operating Temperature and the Tank Temperature is +30C. The COP is lowest at '2' when the Operating Temperature is lowest, the Tank Temperature is highest, and the *temperature difference* is -30C between the Operating Temperature and the Tank Temperature. This is likely why the COP for most heat pumps ranges from '5' at exterior temperatures of 15C down to '2' at exterior temperatures of -10C or less. At 15C, the exterior temperature is more or less equal to the interior household temperature of 21C. At -10C, the outside temperature is 31C colder than the inside temperature and corresponds to a COP of '2'. It is the *temperature difference* between a heat pump's exterior and interior environments that determines its COP and not the actual exterior and interior temperatures.

The *temperature difference* between the Operating Temperature of the HPHW in *Figure 3.* at T=29.5 and Tank Temperature=30C is '0' and corresponds to a COP of '5'. The *temperature difference* between T=29.5C and Tank Temperature=20 is 9.5C and corresponds to a COP of '6.5'. The *temperature difference* between the T=29.5C and Tank Temperature=10 is 19.5C and corresponds to a COP of '9.7'. The *temperature difference* between the T=29.5C and Tank Temperature=0 is 30C and corresponds to an estimated COP of '11'. Plotting these results on the same graph produces the *Temperature Difference* vs. COP curve shown in *Figure 4.* for Operating Temperatures greater or equal to Tank Temperature. The curve ranges from a COP of '5' at a *temperature difference* of '0C' to '11' at a *temperature difference* of +30C. Holding the Tank Temperature constant at 10C, and plotting the *temperature difference* between each Operating Temperature and its corresponding COP, produces the same curve, indicating that it is, indeed, the *temperature difference* between the exterior and interior heat pump environment that affects the COP and not if it is as the result of a change in interior temperature or exterior temperature.

The same curve can also be plotted for *temperature differences* when the Operating Temperature is colder than the Tank Temperature. At T=10, and Tank Temperature=10C, the *temperature difference* is '0C' and corresponds to a COP of '5'. At T=10 and Tank Temperature=19C, the *temperature difference* is -9C and corresponds to a COP of '4'. At T=10 and Tank Temperature=30C, *the temperature difference* is -20C and corresponds to a COP of '3'. At T=10 and Tank Temperature=40C, the *temperature difference* is -30C and corresponds to a COP of '2.2'. Plotting these results on the same graph produces the *Temperature Difference* vs. COP curve for Operating Temperatures equal or less than Tank Temperatures shown in *Figure 4.* The curve ranges from a COP of '5' at a *temperature difference* of '0C' to '2.2' at a t*emperature difference* of -30C. These results, based upon t*emperature difference*, can likely be generalize for all heat pumps. At Operating Temperatures of -10C, which are 30C colder than the interior, or "Tank Temperature", of a home, the expected COP would be approximately '2'which is, indeed, the case. A COP of '11', therefore, could also be expected when the interior of a solarium at 50C is 30C warmer than interior household temperatures. Transposing the results from this last curve across the "Y-Axis" produces the Total Temperature Difference vs. COP curve shown in *Figure 5*.

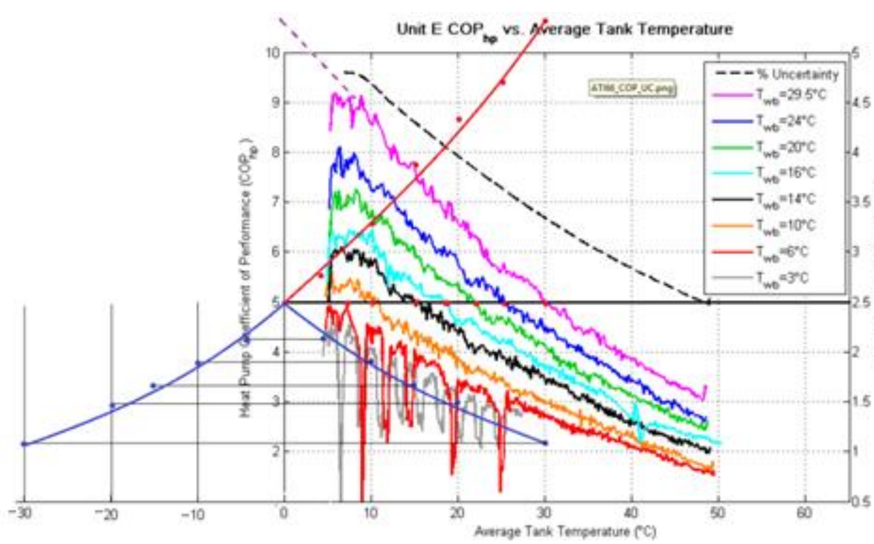

Figure 5.

The *temperature differences* between the interior of the Bloomfield greenhouse and household interior temperatures approached 30C '1' out of every '3' days, and a COP of '11' could, therefore, be expected from a heat pump operating inside it on these days. Compared to an outside temperature of -10C and a COP of '2', a heat pump operating inside a solarium at temperatures greater than 44C will produce 10x more heat or will produce same amount of heat using 90% less electricity.[6] If the maximum output of a heat pump operating at -10C is 18,000BTU, at 10x the output level the same heat pump will produce 180,000BTU of heat. In '8' hours of operation, this is equal to an average over a three day period of 20,000BTU per hour.[7] To produce enough heat and hot water for '3' days during a single '8' hour period, a heat pump will have to produce 9x times the amount of heat and hot water needed during that single time period.[8] At 10x the output, a heat pump will be able to produce and store all the heat required for an entire '3' day period in '8' hours of operation. However, only one of the periods between 44C days lasted '2' days. Out of 15 days, 7 had temperatures higher than 44C inside the greenhouse. Therefore, '7' 44C days would produce an average hourly output of 28,000BTU/hour over a 15 day period.[9] An additional '2' days had temperatures of 30C or greater inside the greenhouse, a *temperature difference* of 10C above interior temperatures corresponding to a COP 6.5. Another day had temperatures of 20C inside the greenhouse, a *temperature difference* of '0' above interior household temperatures corresponding to a COP of '5'. The remaining days were 10C lower inside the greenhouse than household interior temperatures and correspond to a COP of 4.5. On all days during the '15' day study period, a heat pump could operate inside the greenhouse at a COP of 4.5, or greater, in comparison to the same heat pump operating outside at -10C and a COP of '2'. A single heat pump installed inside a solarium and operating only on 44C days could produce all the heat and hot water a household needs using 90% less electricity and operating at average output level that is 36% higher than a typical heat pump system.[10] Operating on days that are not as hot as 44C, a heat pump could produce perhaps twice the output of one operating in a colder environment although at lower COPs and correspondingly lower levels of increased energy efficiency.[11] A solarium, therefore, can reduce heat pump capital costs by 36% to 50% in addition to reducing electricity costs by 90%.

Energy Storage

Because solariums tend to be very warm environments, they are an excellent place to locate hot water tanks as well as washing machines and dryers. Simply by being in a very warm environment, a hot water tank will need less energy to operate. In addition, any heat lost by a hot water tank kept in a solarium will have the benefit of being recovered in the heating process. For this reason, a solarium is also a good location to house thermal storage tanks. Typically, this would be achieved by using hot water kept in insulated tanks for later household use as a heat source. The warm environment inside the solarium will slow heat loss from the thermal storage tanks as well as speed the heat storage process.

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6 11kwh-1kwh>2kwh-1kwh=10kwh>1kwh=10>1.
7 (180,000BTU x 8hours)/72hours=20,000BTU
8 8 hours is 1/9th of a 72 hour period and represents 1/9th of the total heat required during this period.
9 (180,000BTU*8hours*7days)/15days/24hours=28,000BTU/hour.
10 (28,000-18,000)/28,000=36%
11 Based on a heat pump operating at COPs of 4.5 or greater. The total output would be higher by operating on more days, but the total amount of electricity savings would be lower than only operating at a COP of 11.

Heat storage allows all heat and hot water to be produced by a solar thermal generation system on days when temperatures inside the solarium are at their greatest and thereby maximizing the heat produced per kilowatt-hour of electricity. Based on the results of this study, the maximum amount of heat storage needed for all household heat and hot water to be produced on days when the temperature inside a solarium is at least 44C would be '3' days. However, the next warmest day during the only '3' day period in the study was 37C. Including it as a "44C day", the maximum amount of thermal storage needed for all household heat and hot water to be produced when temperatures inside the solarium are at least of 44C or greater is '2' days. Compared to the coldest day during the '3' day period, (-2C), heat produced on the warmest preceding day (46.6C) will be done so at a COP of 11 instead of '2.8' and require 82% less electricity per equivalent kwh of electric heat.[12]

During '8' hours of sunshine on a sunny winter day, a solar thermal generator would need to produce 9x more heat for a '72' hour period than is needed for a single '8' hour period. Since the output of a heat pump at a *temperature difference* of +30C is 10x greater, the system will be able to store all the heat required within '8' hours. On colder days inside the solarium, the thermal generation system can still produce heat and hot water at positive *temperature differences* versus the outside. The lowest *temperature difference* between the outside and inside of the Bloomfield greenhouse during the study period was 6.5C. If additional heat is needed beyond what the thermal storage system can provide between all "44C days," more can be produced at COPs still greater than the outside environment.

Most households in Quebec use electricity for heating, because of the low cost of hydro electric power, which offers a good opportunity to get a sense of how much electricity would be used by a typical family home in Nova Scotia where most heating tends to be done with oil or natural gas and a direct comparison to heat pump electricity usage is difficult. According to Hydro Quebec's online "electricity use estimator", a typical family home in a multiplex uses 49% of its electricity for heating, out of a total annual electrical consumption 13,000kwh, or approximately 6370kwh a year of electricity for heat.[13] With a heating season that is roughly '5' months long, this works out to a daily average of 42kwh/day.[14] Two days of storage would, therefore, require 84kwh of equivalent electric heat.

My neighbor has a home heated by electricity of similar construction to that used in the Hydro Quebec estimator, although his home is older and is the end unit of a multiplex and so is less protected against heat loss. My neighbor estimates he spends $225 more per month on electricity in the winter. As hot water use is more or less constant throughout the year, I will assume this increase is due entirely to heating costs and is equivalent to 48kwh/day.[15] Two days of storage would, therefore, require 96kwh. A typical furnace oil tank has a volume of 1000L. 1000L of water heated from 20C to 50C contains roughly 35kwh of equivalent electric heat.[16] Therefore, it would take the equivalent volume of '2.4' furnace oil tanks to store '2' days of heat using the Hydro Quebec estimates and '2.7' furnace oil tanks to store '2'

[12] COP 11kwh-1kwh>2.8kwh-1kwh=10kwh>1.8kwh=5.55kwh>1kwh=5.5
[13] http://www.hydroquebec.com/residential/energy-wise/tools/electricity-use.html
[14] 1274kwh/month/30days=42kwh/day.
[15] $225/month / $.155/kwh=1451kwh/month or 1451/30days=48kwh/day.
[16] http://processheatingservices.com/water-heating-time-calculator/

days of heat using my neighbor’s estimates.[17] An average of ‘2.5’ furnace oil tanks would not require an excessive amount of space inside a solarium. A storage tank that is ‘2’ times taller and ‘1.25’ times longer would easily fit against the back wall. However, the amount of thermal storage required could be reduced using other storage measures which I will discuss later.

Solar Power

Because a solarium thermal generation system using long term thermal storage is designed to produce heat only on sunny days, photovoltaic solar panels can provide electricity for the system and thereby eliminate the pollution and greenhouse gas emissions associated with household heat and hot water energy production entirely. Because the electricity generated by the photovoltaic solar panels, when it is sunny, will be used by the thermal generation system to produce heat, when it is sunny, there is no need for expensive batteries to store electricity for when it is not sunny. When it is not sunny, the solar thermal generation system will not be producing heat but drawing it from its reserves and will require only a small amount of electricity to circulate the stored heat and to maintain the hot water at faucet temperatures. This electricity can be supplied by the grid or a small back up battery reserve fed by the solar panels which can also be used to provide backup electricity in the case of a power failure. While it requires a tremendous amount of electricity to run a conventional baseboard heater, because this system only requires electricity to circulate heat that was produced ahead of time, a single car battery could supply electricity for up to 24 hours of reserve heating in the event of a power outage.

Property Value and Total System Cost

As many older homes in Halifax already have sunrooms, the cost of renovating them to maximize their solar thermal output is minimal, while the cost of constructing a new solarium can be entirely reclaimed by the increased property value it will add. The warm environment inside it also makes it an efficient location for hot water heaters, washers, and dryers which frees up valuable space within the home. It can also be used as a sitting area to further increase the living area within a home.

While the costs of constructing or renovating a sunroom can be reclaimed by the increased property value it will add to a home, a sunroom will bear an annual cost in terms of the increased annual property tax that will result. Although the amount of additional annual property tax on a home due to an increase in property value of $5000 is quite small, municipal governments could encourage solarium development by waiving the property tax on sections of the home used as solariums. Alternatively, either local or provincial governments could offer financing or grants which would be reclaimed through increased property tax paid by the homeowner in subsequent years. Ultimately, encouraging solariums will create value for society through the energy savings and greenhouse gas reductions that will result for all future occupants of the home. A home might pass through several owners in its lifetime, and a solarium will continue to provide value for generations.

[17] 84kwh/35kwh & 96kwh/35kwh=2.4 & 2.7.

The costs of the system components will vary depending on the type of system used. However, they would be as simple as a mini-split heat pump or heat pump hot water heater, a heat storage hot water tank, and sections of copper piping used for solar hot water pre-heating.

Because a solarium can be constructed "for free", the net system cost is equal to that of a heat pump or HPHW tank installation but would be capable of producing heat and hot water using 90% less electricity. The same system could also offer significant summertime hot water energy cost savings in addition to providing "free" air conditioning, dehumidification, and fresh water production.[18]

Conclusion

Solariums can be used to dramatically increase the temperature in which a heat pump operates and thereby increase its output by up to 10 times. A heat pump in a solarium will be able to produce heat and hot water on all days of the study, during the middle of winter, operating at temperatures greater than 9C. Out of '10' of the days, it would be able to operate at temperature of at least 20C. Out of '9', it would be able to operate at temperatures of at least 30C. Out '7' days, it would be able to operate at temperatures of at least 44C. With '2' days of thermal storage, a solar thermal generation system will be able to produce heat and hot water at temperatures above 44C for every day of the winter irrespective of the outside temperature. Existing sunrooms can reduce immediately annual household heating and hot water costs and greenhouse gas emissions by $48 and 318 pounds of CO2. A heat pump operating at temperatures more than 30C warmer than the interior of a home will produce 10 times more heat, for the same amount of electricity, than one operating in an environment 30C colder and can reduce wintertime heat pump heating and hot water electricity usage by 90%. Solariums carry with them significant additional benefits beyond the production of heat. By producing heat only on sunny days, solar thermal generation is uniquely suited to work with photovoltaic solar power as its electricity source. Most localities aren't so fortunate as to have a manufacturer of solar hot water panels operating locally. Solariums provide an inexpensive substitute for solar hot water panels that can be produced by any number of construction firms operating locally and will increase local employment. As a substitute for imported fossil fuels, solariums offers further employment benefits and increased local investment.

Discussion

Now that I have established the potential for solariums to greatly reduce home heating and hot water energy costs, I will consider various solarium thermal generation system configurations to determine how to best harness the sun's energy for the least amount of cost.

Optimizing Solarium Construction for Thermal Energy Production & Storage

There are a few basic principles which should be followed in order to maximize solarium thermal energy production. A solarium should face south, and its interior wall on which the sun directly shines should be made out of a heat absorbent material. Green happens is the best color for absorbing heat. The interior wall could simply be painted green, or it could be clad in green corrugated steel roofing. The backing

[18] David Fright. Reclaiming the Waste Heat Produced by Air Conditioning: 50% Lower Hot Water Costs and "Free" Cooling, Dehumidification, and Fresh Water Production.

onto which the finishing material is mounted should be made out of brick or thick tile to absorb heat from the sun and release it back into the solarium as it cools at night or on cloudy days. Concrete flooring or tile set atop heavy insulation should be used for the same purpose.

On warm days, the interior temperature of the Bloomfield greenhouse was very near faucet temperatures. In order to reduce electricity usage as much as possible, and make as great of use of the high temperatures inside a solarium, “passive solar” techniques should be used to pre-heat cold water entering a HPHW tank by using a simple radiator constructed out of copper pipe.

As I have discussed, it would take the equivalent of ‘2.5’ “furnace oil” tanks to store enough hot water for ‘2’ days of heat and household hot water use. Although this would not require an excessive amount of space, in order to reduce the volume of water needed for household thermal storage, an interior “thermal barrage” “heat storage wall” could be constructed inside a home out of brick or cement with a heat exchanger unit built into it. Heat produced by the solar thermal generation system would circulate through the wall and warm it. The wall would take time to absorb heat to the point where it would begin radiating it into the interior of the home. The wall could also be insulated lightly to slow the rate at which this energy is released. In this way, the wall could store heat during 44C days and slowly release it back into the home over the 2 day storage period. Interior thermal barrage heat storage has an advantage in that any energy lost by the storage wall will be released into the interior of the home and won’t be wasted. The solarium, in contrast, will cool at night and on days when the sun isn’t shining. In this case, some heat will escape from the thermal storage system and be lost. A heat storage hot water tank could also be mounted directly inside a home. Perhaps ornamental in nature, it could take the place of the family hearth. Additional thermal barrage units could be place throughout the home such as small 100L hot water reservoirs encased in concrete to take the place of household radiators traditionally used for furnace-driven hot water or steam heat.

A typical residential sunroom might capture enough sunlight, with perhaps a larger window area, to produce all the hot water a household needs at 44C temperatures. All things being equal, doubling the amount of window space will double the amount of solar energy a solarium will collect. As the opaque plastic paneling used in the Bloomfield greenhouse is quite inexpensive, it could replace the entire exterior wall of a solarium. A sliding door could be used at one end of the solarium, perhaps near a seating area, to maximize the amount of sunlight entering the room while also providing access to an outside yard or cooking area. To provide a household with all the heat it needs, however, a solarium will need to be larger than a typical residential sunroom. “Glass houses”, would provide a much larger solar area and could also house heat pumps installed on multiple levels. A simple “lean-to” design could be used to greatly increase the interior volume of a sunroom. I have included examples of these at the end of the document. Solar hot water panels could also be used with existing sunrooms to pre-heat water to increase the output of smaller sunrooms for a household heating and hot-water system.

System Configurations

System A

A simple system for generating heat from a pre-existing sunroom could be created for no additional costs and would provide the equivalent of '1' hour per day of free home heating.[19] Most sunrooms have windows and a door between them and a household's interior. When the temperature within a sunroom goes above a certain point, say 26C, simply opening the windows and door to let the warm air from the sunroom circulate with the cooler air from the rest of the house might provide enough heat to warm the entire lower level of a three bedroom home for up to '6' hours. However, once the temperature within the sunroom is equal to that of the rest of the house, or slightly above it, say at 23C, the doors and windows should be closed so as to prevent heat from the house keeping the sunroom warm. An inexpensive floor fan could be used to increase air circulation and drive the warm air from the sunroom deeper into the rest of the home. Based upon the household in the Hydro Quebec estimator that uses 42kwh of electricity a day for home heating, this is equivalent to $8.13 a month in electricity cost savings and 52.5 pounds of heat-related C02 emissions.[20] There are '5' winter heating months and '2' shoulder months with ½ the heating requirements of the winter months for a total of '6' heating months a year. A simple sunroom, with nothing more than some basic home repairs, will, therefore, save $48 and 315 pounds in annual heating costs and C02 emissions.

A typical residential sunroom will also slow household heat loss all other times of the day because the temperature is always warmer inside a sunroom than outside. Simple renovations such as caulking, weather stripping, and replacing or refinishing windows and doors will improve the performance of existing sunrooms. To reduce the upfront investment cost, construction of a solar thermal generation system can be done incrementally. First, build the solarium to circulate the hot air it produces for heating. Install a HPHW tank. Install a passive solar pre-heater. Install a hot water circulator for heat. Install a thermal storage tank. A more extensive version of the passive hot air system could also be built using ducted forced air. Where a household already has a forced air system, this might be a cost effective setup. However, forced air systems are generally less efficient because they tend to have greater heat losses than other systems. The problem with relying on passive solar power exclusively is that heat can only be supplied by a sunroom down to temperatures equal to the interior of the home. A heat pump, in contrast, can continue to extract heat down to its theoretical minimum operating temperatures. A sunroom at 21C still contains a lot more energy than outside at temperatures of -15C. A ducted heat pump system could be used with a forced air system and would be capable of using all of the energy produced by the sunroom down to temperatures that are equal to that of the outside. Forced air also has an advantage of working well with thermal energy storage systems. Hot water storage could be used to circulate stored heat through a hot water heat exchanger to supply heat for the return air in the forced air ducted system. In this case, a hot water heat pump could be used in combination with hot water storage tanks and a heat exchanger rather than a ducted heat pump.

[19] A typical residential sunroom could provide up to ½ a home's heating requirements for up to 6 hours a day, or ¼ of a day, 1 out of every 3 days for a daily average of ½ x ¼ x 1/3=1/24=1 hour/day.

[20] this represents 42kwh/24hours=1.75kwh/hour, 1.75kwh x $.155kwh x 30 hours/month=$8.13/month. 1kwh of electricity equals approximately 1 pound of C02 emissions=1.75kwh x 30hours/month=52.5 pounds of C02.

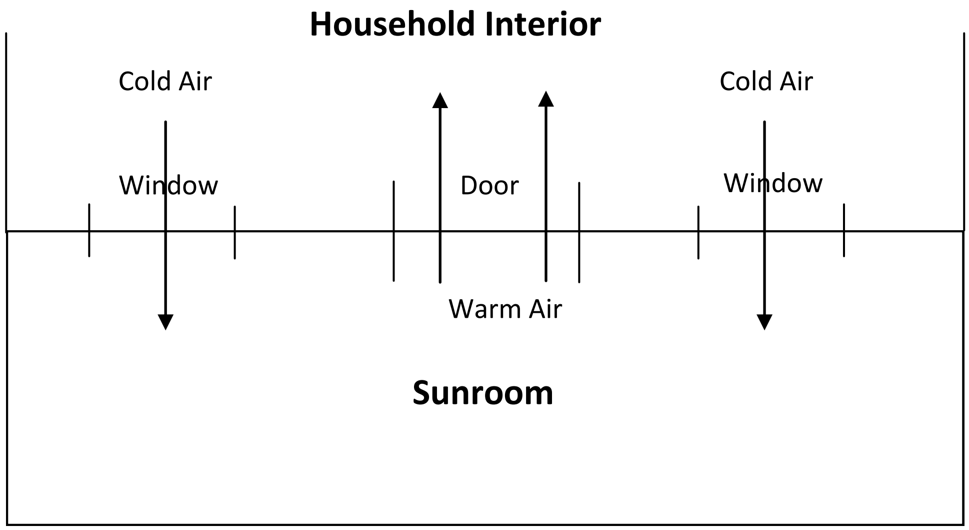

Figure 6.
"System A."

System B

A simple and effective option to make full use of the heat generated by a solar thermal generation system would be to install a heat pump in a solarium. Heat would be drawn from the much warmer solarium environment and offer significantly increased output. As there is always a positive temperature difference between a solarium and the outside environment, a heat pump could draw heat continuously on all days at higher levels of output inside a solarium than outside. Most heat pumps include a "desuper" function for pre-heating hot water. While this configuration would be more effective than a standard outside heat pump installation, it would not be able to conveniently store of heat and hot water, and the heat pump will only produce heat at higher levels of output on sunny days. On colder days, the increase in output will be lower. There is always some positive temperature difference between the inside of a solarium and out. However, an air-sourced heat pump will not be able to take full advantage of the heat produced by a solarium on extremely warm days by storing it, and it will not be able to reclaim summertime waste heat produced by air conditioning except to a small extent via the desuper function. It will also perform less well than a standard outside heat pump installation during the summer months because "rejected" heat from the interior of a home during cooling will become trapped in the solarium unless a more expensive air-to-water system is used. Air-to-water heat pumps are the "Cadillac" option for all household heating, hot water, and cooling requirements. They produce heat and hot water, capture waste heat from air conditioning in summer to heat hot water, and can store heat produced during warm days in the winter. However, they are also expensive.

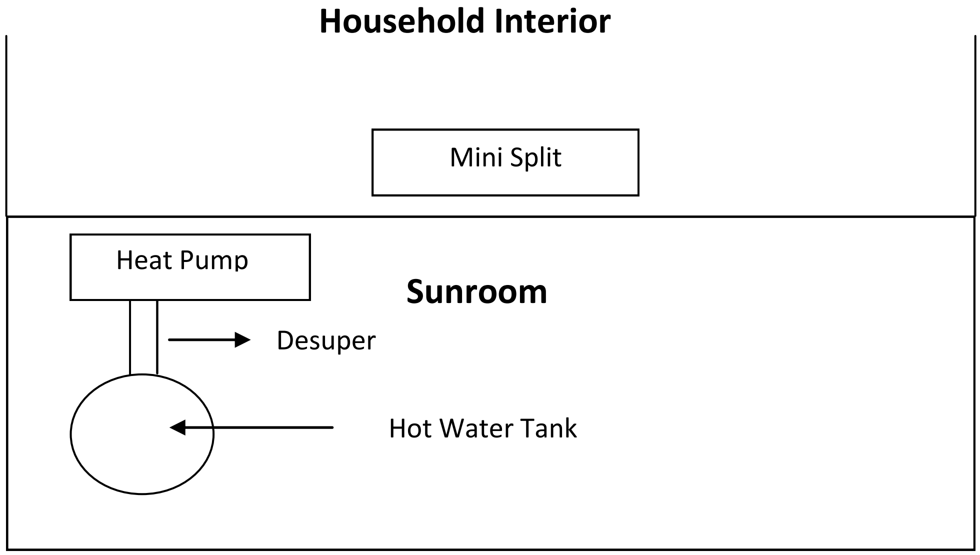

Figure 7.
"System B."

System C

A third option would be to use a hot water heat pump based system. A HPHW tank can greatly reduce electrical consumption in comparison to a conventional electric hot water heater. Unlike passive solar, it could make full use of all the heat produced by a solarium. It could also be used to produce and store heat for home heating by circulating hot water through the interior of a home using an electric pump and traditional hot water radiators. The advantage of this system is that it can easily produce heat and hot water for household use as well as store heat produced on sunny days. Because the electricity costs of circulating water short distances are so low, it would also be very cost effective. It costs roughly $.0001 to treat, process, distribute, and reclaim as waste 1L of municipal drinking water.[21] Circulating hot water a short distance through a home would use less than 1/100th of that. Hot water heat pumps are also comparable in price to air-to-air heat pump systems but they can produce hot water and store heat. Unlike an air-to-water heat pump, which can do these things, a HPHW system would do it at very low cost. Moreover, it could also make use of solar hot water preheating to further reduce electricity consumption. Because the output, or COP, is so much higher for a HPHW tank operating at temperatures of 44C, one unit can provide as much heat as two. Since most HPHW tanks do not run continuously in a typical hot water setup, they do not usually operate anywhere near even their rated capacity. One HPHW tank, operating continuously over an '8' hour period on a sunny day, might be able to supply all the heat and hot water needed by an entire household at significantly reduced system costs. Because of its low cost and versatility, I believe a HPHW based hot water heating system is the best option. It would also allow for air conditioner heat recovery for substantial summertime hot water energy cost savings as well as "free" cooling, dehumidification, and fresh water production.

[21] "Creating a Culture of Water and Energy Efficiency in Nova Scotia." Ecology Action Centre, Halifax. 2015.

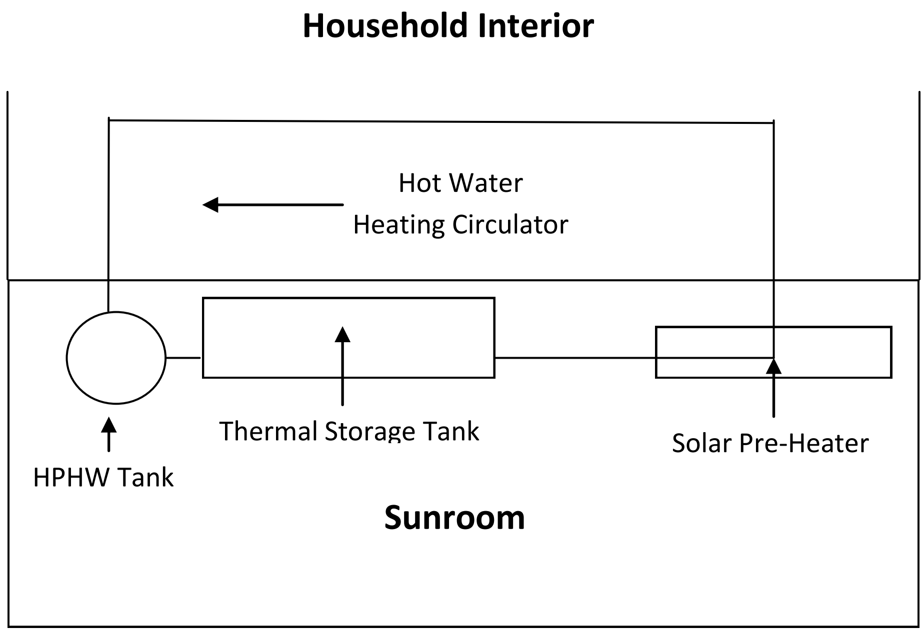

Figure 8.
"System C."

Solarium Design

As I have mentioned, "Glass houses" could be used instead of a solarium for solar thermal energy generation. A greenhouse effect could be created using a glass or plastic sheet with a 1 or 2 meter gap between it and the exterior wall of a house to form an air tight environment. It would require less floor space than a solarium, but would still have considerable internal volume. It would also allow each apartment or unit on multiple levels to have its own solar thermal generation system. Hot water for heat or household use could be stored inside each apartment or unit.

A simple "lean-to" design could be used to construct inexpensive sunrooms that would have a very large internal volume and could generate large amounts of solar thermal energy. It would also provide a space for heat pump heat and hot water equipment, thermal storage tanks, or a sitting area in which to enjoy the comfort of sunshine and warmth on a winter's day.

Solar hot water panels could also be used to a feed the HWHP tank used in system "C" installed in pre-existing sunrooms. Combined, these two systems could supply all household heat and hot water.

I have included examples of these in the following pages:

Figure 9.
“Glasshouse Before”

Figure 10.
“Glasshouse Afterwards”

Figure 11.
"Glasshouse Before"

Figure 12.
"Glasshouse Afterwards"

Figure 13.
"House with a Solar 'Lean-to'."

Please Note: This paper is provided free of charge and without expectation of any kind in the hope that it will encourage the changes required to reduce the negative impact on the natural environment as a result of energy production. However, if you would like to help support the continued development of this idea and other similar projects, a suggested donation of $50 would gratefully be accepted.

Please make your cheque payable to:

David Fright
6-2787 Agricola St.
Halifax, NS.
Canada B3K 4E3

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