Solar Air Heating Project Analysis

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SOLAR AIR HEATING PROJECT ANALYSIS

This course covers the analysis of potential solar air heating projects including a technology background and a detailed description of the calculation methods.

Solar Air Heating Background

The Solar Air Heating (SAH) technology is a well-known system for heating or preheating air in commercial and residential building. The system is frequently utilized as heat ventilation air in various buildings, but it has also been used in industrial applications such as crop processing and drying where heated air is an important component.

The world demand for this uncommon and specific system has risen over the past ten years. Years and decades of research, development and testing have resulted in new methods for heating air with solar power. Solar air heating technologies are starting to be used more and more for the “cladding” of exterior walls (which face the equator) on industrial, commercial and residential style buildings, as well as for single-family residences. Solar air heating technologies have been utilized for drying crops such as tealeaves, and their potential has been shown for a variety of other cultivated crops.

Usually, the most cost-effective implementations of solar air heating systems on residential buildings can be found in new construction since the solar collector cladding (or plate) allows the utilization of less costly wall cladding material as a backing, and no ventilation fan is needed. The second mostly used application is for retrofits when there are plans to modify or upgrade an existing wall, enhance indoor air quality, or add additional ventilation or makeup air to balance exhaust air. Many air heating systems can be retrofitted to include low-cost solar air preheating. In the case heating costs are considerable, solar air heating systems are usually financially appealing, even in retrofit situations that don’t satisfy the above criteria.

Description of Solar Air Heating Systems

The solar air heating system is comprised of two elements:

- A solar collector installed on the side of the building orientated to the equator

- A fan and an air distribution system mounted inside the building, as shown in Figure 1.

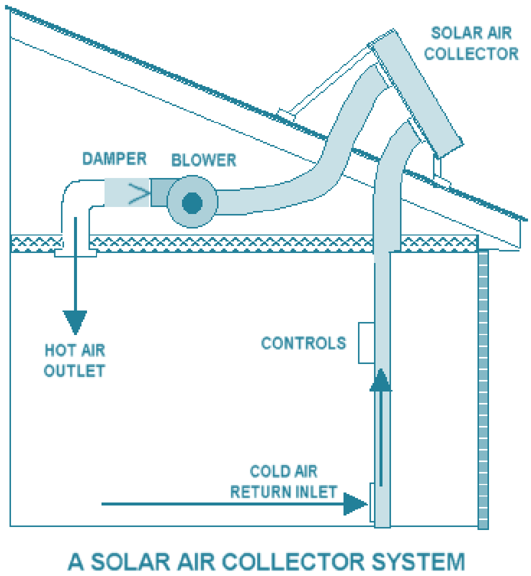

Figure 1. Typical solar air heating arrangement

A distinctive feature of the solar air heating system is that it utilizes a perforated plate (or transpired-plate) as the solar collector, negating the requirement for a glass cover that is usual in most other solar collectors used for heating applications. Air is drawn through small holes in the dark colored solar collector plate and is heated as it goes over and through the plate. The system is displayed in Figure 2.

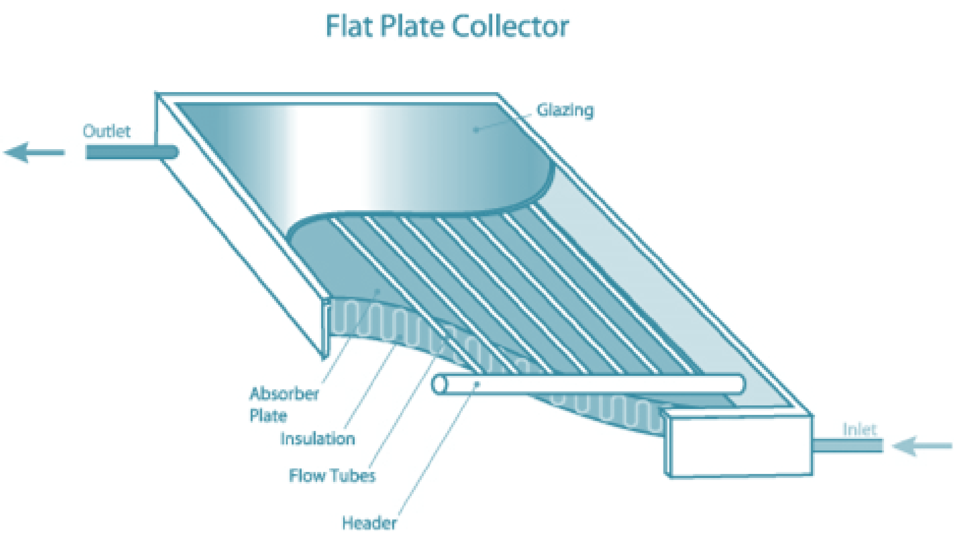

Figure 2. The typical plate solar collector

The air stays in a cavity between the solar collector and the building wall and is transferred into the building. High-efficiencies are achievable because the solar collector plate is only several degrees warmer than the outdoor air. Therefore, there is insignificant heat loss, and most of the solar radiation is transferred to warm the air.

Bypass dampers can be found in the face of the canopy. These dampers make possible for ambient air to be transferred directly into the building or process when no heating is needed. In ventilation usages, an adjustable thermostat that detects outdoor temperature controls the two-position damper. The thermostat is usually set to open the damper when the outdoor temperature is warm enough to cut the requirement for heating (typically above 15 to 20ºC). Figure 3 shows a diagram of a typical solar air heating system.

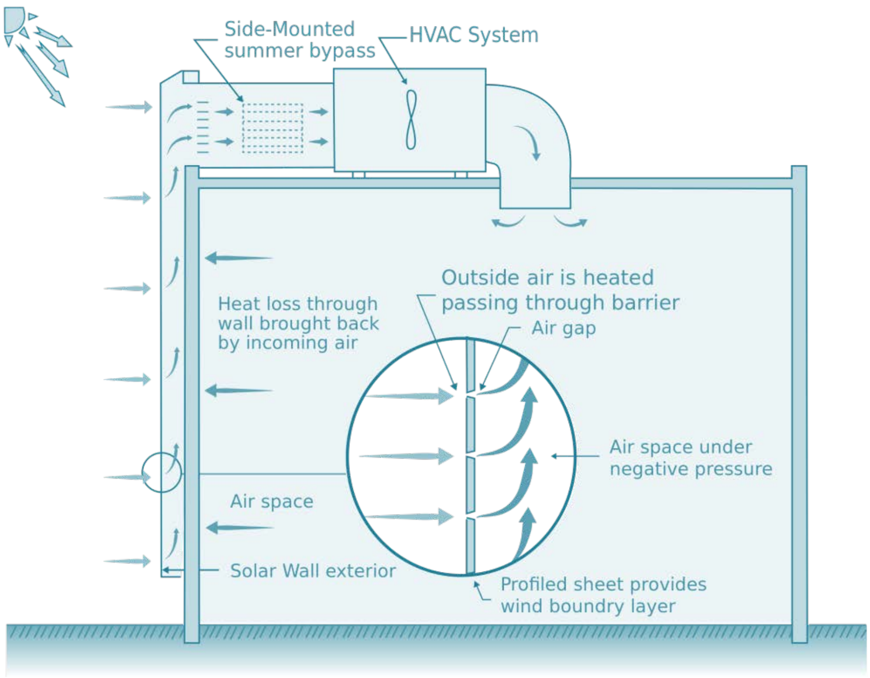

Figure 3. Typical solar air heating construction

The scale of solar air heating system collectors is dependent on the ventilation rate and wall area that can be used for solar collector mounting. Solar air heating systems are usually rated to provide either a high temperature rise or high solar collection efficiency. A high efficiency objective increases the annual energy savings and reduces the solar collector size. However, the mean air temperature increase will be decreased.

Solar Air Heating System Utilization

Solar air heating systems utilization include building air heating and process air heating. Technologies used for ventilation heating depend on the type of building on which the system will be mounted (e.g. industrial, commercial or residential). This is applicable to new construction and retrofit cases. The methodology of solar air heating system air delivery is dependent on the type of building and the air distribution system.

Commercial and residential buildings

Most commercial and residential buildings require ventilation air. Solar ventilation air preheating systems preheat air before transferring it into the building. An air-handling unit pulls ventilation air through the solar collector and transfers it throughout the building with conventional ductwork. During cold days, the solar collectors preheat the air, and a heater in the air-handling unit gives the remaining heat. On cool sunny days, the solar system can deliver required air heating. In the summer, a bypass damper is opened, thus avoiding an unrequired load on the air-conditioning system.

An extra advantage of putting the solar collector as a part of the building façade is that the collector can recapture the building wall heat loss. As the heat transfers out the building wall, it transfers to the collector air channel. At this point the ventilation air blowing through the channel uses this heat and blows it back into the building. Usually the ventilation air recaptures half of the wall heat loss.

Many commercial, multi-unit residential and institutional buildings have existing air handling systems. In few cases, the air handling installation is a separated ventilation system. In other buildings (e.g. offices), the air handling installation delivers space heating, cooling and ventilation with ventilation air making up around 10 to 20% of the total airflow. In any case, the solar air heating installation is linked to the outdoor air intake and the air is distributed through conventional ductwork. The solar air heating installation delivers a constant flow of outdoor air preheating the ventilation air.

Industrial buildings

Industrial ventilation air heating is applicable to buildings that require significant volumes of outdoor air to replace air exhausted from different industrial and manufacturing processes. Because of the wide-open industrial plant areas and high ceilings, it is possible to construct and size a solar heating system that can replace conventional make-up air heaters. Instead of using a conventional heater to give the extra necessary heat, solar make-up air heaters mix solar preheated air with warm building ceiling air and transfer this air to the building. The solar air-handling system is made to vary the amount of outdoor air and recirculated air to achieve a flow of constant temperature air (typically 15 to 18°C). As shown in Figure 4, in industrial buildings with no existing air distribution system, the solar air heating system interior elements consist of a constant-speed fan, a recirculation damper technology and a fabric distribution-duct.

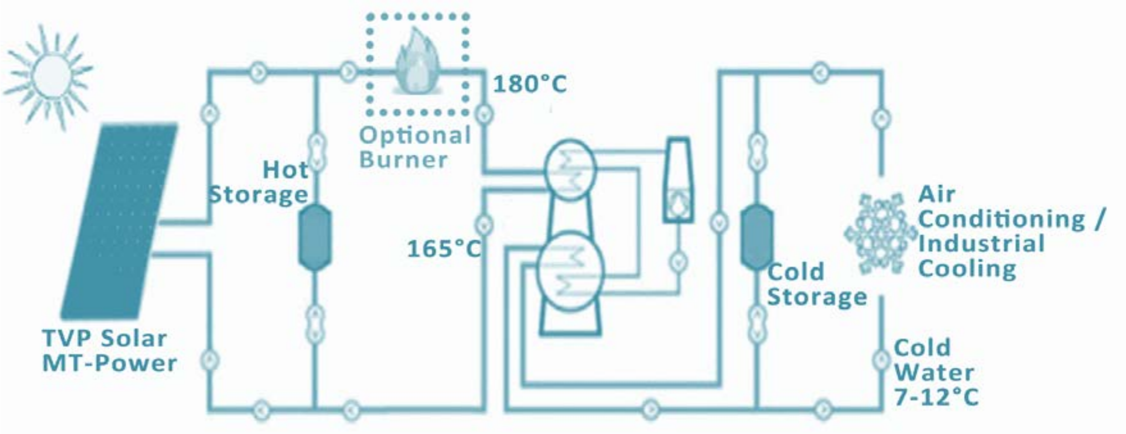

Figure 4. Industrial solar air heating/cooling schematic diagram

Perforated fabric ducting is a low-cost system of transferring make-up air throughout the building. A recirculation damper installation built into the fan section mixes warm indoor air with cooler solar collector air to level the constant delivered air temperature. The ratio of indoor (recirculated) air to solar air heating installation (outdoor) air ranges continuously with changes in the solar collector outlet air temperature, while a duct thermostat controls the damper elements.

The mixture of ventilation air and recirculated air is transferred to the plant through fabric ducts that can be found at ceiling level. Because the air from the ducting is cooler than air at the ceiling, the ventilation air cools the ceiling eliminating heat loss through the roof at the temperature of exhaust air and, therefore, the air falls, mixing and destratifying the building air.

Another advantage of the installation is that it can recapture the building wall heat loss if the collectors are installed on the building wall.

Process air

Considerable quantities of outdoor air are utilized for process air heating usages. Drying of agricultural products is a common application for solar energy, as the needed temperature rise has to be kept low to prevent harming the crops. Crops that are harvested often over the year are suitable because all the available solar radiation can be utilized. Solar installations can also be used as a preheater to (high temperature) industrial drying installations.

Solar process air heating installations are similar to ventilation air preheating installations. The perforated plate absorber can be found in any convenient location that has appropriate exposure to the sun. Sloped roofs and walls are good mounting structures. A constant air flow is taken through the collectors and is transferred into the air intake of the process. If required, extra heat can be used from auxiliary sources to deliver the needed air temperature, and process air can bypass the collectors if the air is above the set temperature.

Solar Air Heating Project Modelling

A solar air heating project model can be utilized to assess solar air heating installations, from larger scale developments to smaller scale residential usages. It is also possible to assess process air heating applications used in industrial applications. Solar air heating systems can reduce usage of conventional energy in three ways, depending upon the planned usage:

- Usage of solar energy through active solar air heating for buildings and processes;

- Recapture of equator side wall heat loss (heat lost out the original building wall is captured by the ventilation air and transferred back into the building); and

- Destratification of building air in buildings with high ceilings.

This paragraph provides the various methodologies used to assess, on a month-by-month basis, the energy reductions of solar air heating installation. A flowchart of the methodologies is displayed in Figure 5. The paragraphs below show the calculation of the three types of energy reductions:

- Collected solar energy reductions
- Building heat recapture reductions
- Destratification reductions

How these methods contribute to the overall energy reductions for non-industrial buildings and industrial buildings is demonstrated in the following sections.

The heat transfer in solar air heating installations is relatively challenging. It depends on the solar radiation, temperature and wind speed around the installation. Most solar air heating assessment tools use an hourly time step to track the changing solar and weather circumstances. The described methodology treats the performance on a monthly basis to show results quickly with a minimum of input details. This methodology is found applicable at the project development pre-feasibility stage.

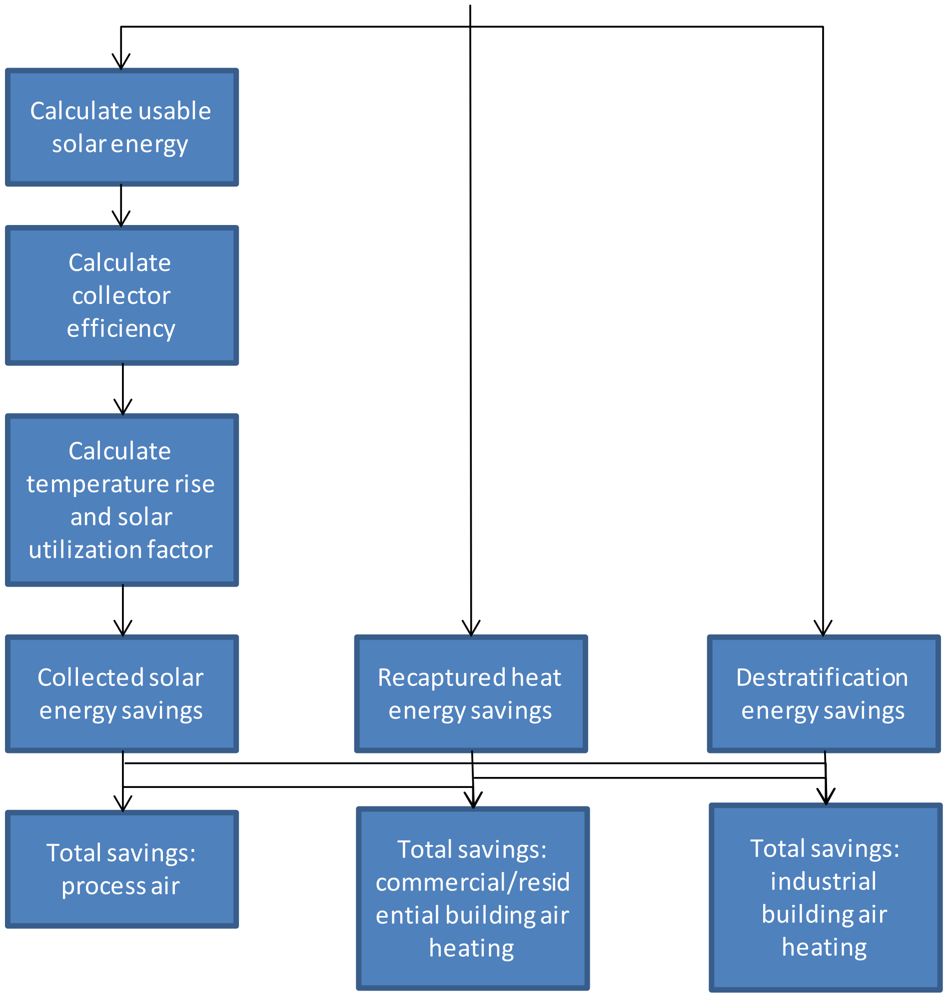

Figure 5. Solar air heating energy model calculation methodology

Process air heating is considered to benefit only from collected active solar energy reductions. It is assumed that the building does not need space heating and any reduction in wall or roof heat loss does not save energy. Also, because the heated air rises from the solar collector to the drying ovens, or other machines and equipment, there is no potential for destratifying the building air.

Commercial/residential buildings benefit from two types of energy reductions:

- Collected active solar energy reductions
- Recaptured heat reductions.

Industrial buildings, due to the system of air circulation on the building and the height of the ceilings, take advantage from all three systems of energy reductions.

Because of considered simplifications, used solar air heating model has several limitations:

- The ventilation method does not use a detailed energy consumption and make-up system assessment for the existing building. This minimized information need approach allows the user to easily prepare an analysis, but modelling correctness will be partially lowered.

- The method does not incorporate sophisticated heat recovery technologies under development for the solar air heating installation. Therefore, the model may understate the potential reductions of a combined sophisticated heat recovery/solar air heating installation.

- Finally, the model makes an assumption that industrial buildings have a balanced ventilation installation for the calculation of destratification reductions.

For the common applications, these limitations do not cause any unwanted consequence.

Collected Solar Energy Reductions

The solar radiation incident upon the tilted solar collector has to be calculated from information defined by the user, namely, daily solar radiation on a horizontal surface and operating multiplier. Energy collected by the solar collector is evaluated by multiplying the incident radiation by the average collector efficiency. However, only part of the collected energy can be used. The idea of solar utilization is described in the following paragraphs.

Usable incident solar energy assessment

For every month, i, the total quantity of solar energy usable by the collector, $G_{coll,i}$ is evaluated. This figure is determined from the average daily amount of solar energy incident on the collector, $G_{titlt,i}$, the collector area A_{coll} , and the operating schedule of the solar air heating system $f_{op,i}$:

$$G_{coll,i} = G_{titlt,i} A_{coll} f_{op,i} \quad (1)$$

The solar radiation incident on the collector, $G_{titlt,i}$, is determined from the defined average daily solar radiation on the horizontal surface, $G_{horz,i}$. The value for $f_{op,i}$ shows the necessity of the operating schedule to the total energy reductions of a solar air heating system. It is determined using:

$$f_{op,i} = n_{days,i} f_{sys,i} \frac{h_{op,daytime}}{h_{sunlight,i}} \frac{d_{op}}{7} \quad (2)$$

where $n_{days,i}$ is the number of days in month i, $f_{sys,i}$ is the fraction of the month used for running the system, $h_{op,daytime}$ is the number of hours of operation during sunlight hours, $h_{sunlight,i}$ is the number of hours of sunlight per day for month i, and d_{op} is the number of days in service per week.

When the system is shut down, energy cannot be captured. Therefore to take into account the weekly operating schedule, d_{op} is divided by 7 days a week in Equation (2). To take into account the daily operating schedule, the number of operating hours per day ($h_{op,daytime}$) is divided by the number of daylight hours on the "average" day of the month ($h_{sunlight,i}$). It should be taken into consideration, depending on the time of year and latitude, that during few months of the year the entered hours per day of operating time (h_{op}) may be higher than hours of daylight ($h_{sunlight,i}$). In this case the lesser of h_{op} and $h_{sunlight,i}$ is used for $h_{op,daytime}$. This assessment also takes into account an approximation since no consideration is provided to the actual service time.

Therefore, the relative intensity of solar radiation at different times of day is not accounted for. Service hours are assumed to be distributed evenly around noon.

Average collector efficiency

The solar energy incident on the perforated plate collector, as provided by Equation

(1), is used to heat or preheat air. The efficiency of a perforated plate solar collector is dependent on multiple variables. The more dominant variables are collector airflow and wind speed on the surface of the collector. Figure 6 displays the relationship between efficiency and collector airflow at several wind speeds.

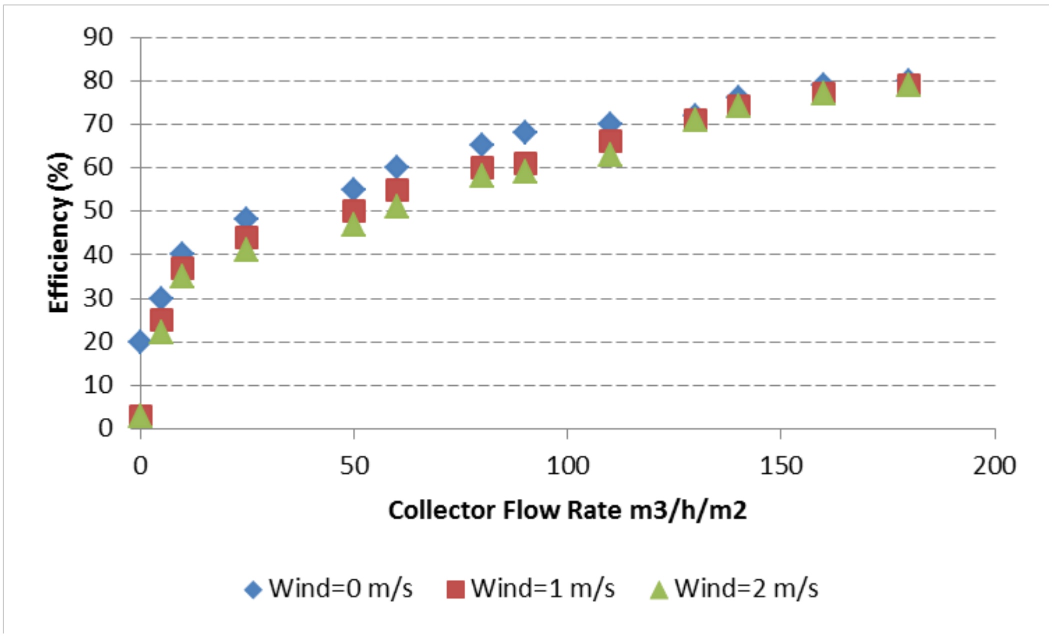

Figure 6. Solar collector efficiency vs. flow rate

A collector efficiency formula can be derived from a heat balance on the collector and can be shown in a simplified form.

If $\dot{Q}_{coll}$ is the airflow rate through the collector, and v'_{wind} the wind speed at the collector, collector efficiency η is provided by:

$$\eta = \frac{\alpha}{\left(1+\frac{\left(\frac{20v'_{wind}}{\dot{Q}_{coll}}\right)+7}{\dot{Q}_{coll}\rho C_p(1-0.005\dot{Q}_{coll})}\right)} \quad (3)$$

where α is the solar absorptivity of collector material, ρ is the density of air (assumed equal to 1.223 kg/m3), and C_p is the specific heat capacity of air (assumed equal to 1.005 kJ/kg-°C).

For subsequent calculations, monthly average wind speed at the collector v'_{wind} is related to the monthly average free stream wind velocity v_{wind} as follows:

$$v'_{wind} = 0.35\, v_{wind} \quad (4)$$

The wind speed correction factor is an assumed figure that does not take into account for sheltering or building orientation.

Solar utilization

Since solar energy in a solar air heating installation is used for heating, there will be times when energy is collected but cannot be used to offset heating loads. Only energy that can contribute to reduction of the heating load can be considered useable. Collection of non-useable solar energy is avoided in majority of solar air heating installations by installing a bypass damper that takes air directly from the outside instead of through the collector.

To assess this, a utilization factor $f_{util,i}$ is considered to determine the quantity of collected solar energy that would contribute to heating reductions. In order to quantify the utilization factor, both the average actual temperature increment through the collector (ΔT_{act}) and the available temperature increment (ΔT_{avl}) are calculated. The available temperature increment represents the increment in air temperature as it transfers through the collector provided there is no limitation on the needed outlet temperature. The real temperature increment is the increase in temperature after the control system has put a limit to the delivered air temperature to the prescribed maximum, $T_{del,max}$. The utilization factor $f_{util,i}$ is then provided by:

$$f_{util,i} = \frac{\Delta T_{act}}{\Delta T_{avl}} \quad (5)$$

The available temperature increment is determined using the collector efficiency and the collector airflow rate, $\dot{Q}_{coll}$. For month i:

$$\Delta T_{avl} = \frac{\eta G_{tilt,i}}{\dot{Q}_{coll} \rho C_p h_{sunlight,i}} \quad (6)$$

where, ρ and C_p are, as described previously, the density of air and the specific heat capacity of air, respectively.

The temperature increment is limited by conditions imposed on the temperature of the air leaving the collector, also known as delivered temperature. The delivered temperature $T_{del,act}$ is constrained so as not to exceed the maximum delivered air temperature, $T_{del,max}$, defined by the system user. Equations (7) to (9) demonstrate how T_{act} is determined:

$$T_{del,avl} = \left(T_{amb} + \Delta T_{offset}\right) + \Delta T_{avl} \qquad (7)$$

$$T_{del,act} = \min(T_{del,max}, T_{del,avl}) \qquad (8)$$

$$\Delta T_{act} = T_{del,act} - (T_{amb} + \Delta T_{offset}) \qquad (9)$$

where $T_{del,avl}$is the available delivered temperature and T_{amb} is the mean outside ambient temperature. ΔT_{offset} is a temperature offset of 3ºC added to the ambient temperature on the assumption that the daytime temperature is higher than the average temperature. A negative result is not allowed.

Active solar energy savings

Solar energy delivered over the year, Q_{sol}, is calculated by summing monthly contributions:

$$Q_{sol} = \sum_{i=1}^{12}\left[\eta_i \, G_{coll,i} \, f_{util,i}\right] \qquad (10)$$

where the monthly collector efficiency η_i is calculated from Equation (3), total amount of solar energy usable by the collector $G_{coll,i}$ is given by Equation (1), and the utilization factor $f_{util,i}$ is calculated through Equation (5).

Building Heat Recapture Reductions

When a solar air heating collector is put into service on a building, there is an additional benefit due to the return of lost building heat through the collector. If the collector is not operating, there is a small benefit related with a slightly higher RSI-value (thermal resistance) of the building wall. The method predicts building heat recapture reductions under three different operation scenarios: daytime operating, night-time operating, and during shutdown times. The net reductions Q_{recap} are determined by simply adding up these three quantities:

$$Q_{recap} = \sum_{i=1}^{12}\left[\left(Q_{recap,op,daytime,i} + Q_{recap,op,nighttime,i}\right)f_{sys,i} + Q_{recap,shutdown,i}\right] \quad (11)$$

where $Q_{recap,op,daytime,i}$ is the daytime heat recapture while the air handler is operating for month i, $Q_{recap,op,nightime,i}$ is the night-time heat recapture while the air handler is operating for month i, $Q_{recap,shutdown,i}$ is the heat recapture while the air handler is not operating for month i, and $f_{sys,i}$ is the defined fraction of month i used for system operation. Heat recapture for the three operating scenarios is calculated as follows:

$$Q_{recap,op,daytime,i} = \frac{d_{op}}{7} n_{days,i} h_{op,daytime,i}\left[\frac{A_{coll}}{R_{wall}}\left(T_{in} - T_{eff,i}\right)\right] \quad (12)$$

$$Q_{recap,op,nighttime,i} = \frac{d_{op}}{7} n_{days,i} h_{op,nighttime,i}\left[\frac{A_{coll}}{R_{wall}}\left(T_{in} - T_{amb,i}\right)\right] \quad (13)$$

$$Q_{recap,shutdown,i} = \frac{d_{op}}{7} n_{days,i}\left(24 - h_{op}\right)\left[\left(\frac{A_{coll}}{R_{wall}} - \frac{A_{coll}}{R_{wall}+R_{coll}}\right)\left(T_{in} - T_{amb,i}\right)\right] \quad (14)$$

where $n_{days,i}$ is the number of days in month i, $h_{op,daytime}$ is the number of hours of service during sunlight hours, $h_{op,nighttime}$ is the number of hours of service during night-time hours, and h_{op} is the number of hours of service ($h_{op} = h_{op,daytime,i} + h_{op,nighttime,i}$). R_{wall} is the user-defined insulation value for the wall, A_{coll} is the solar collector area, and R_{coll} is the additional insulation value provided by the collector, assumed to be equal to 0.33 m²-°C/W. T_{in} is the inside building air temperature, assumed equal to 21°C, and $T_{amb,i}$ is the average outside ambient temperature for month i. Finally, $T_{eff,i}$ represents an “effective temperature” that the building wall loses heat to. Results from performance monitoring imply that heat exchanges through the building wall are attributable to collector temperature and ambient temperature. Therefore:

$$T_{eff,i} = \frac{2}{3}T_{coll,i} + \frac{1}{3}T_{amb,i} \quad (15)$$

where $T_{coll,i}$ is the average collector leaving temperature for month i.

Destratification Reductions

Destratification reductions are usually only found in heating systems for industrial buildings. The high ceiling in common industrial buildings allows warm air to rise and settle near the ceiling. Cooler air flowing from the ventilation system near the ceiling mixes with this warm air to reduce the temperature difference between the floor and the ceiling. Accordingly, there is less heat loss through the roof and through rooftop exhaust vents. The corresponding destratification savings $Q_{destrat}$ are:

$$Q_{destrat} = \sum_{i=1}^{12} \frac{d_{op}}{7} n_{days,i} f_{sys,i} h_{op} (T'_{strat} - T_{strat}) \left(\dot{Q}_{design} \rho C_p + \frac{A_{floor}}{R_{roof}} \right) \quad (16)$$

where T_{strat} is the stratified ceiling air temperature before installation of the solar air heating, T'_{strat} is the stratified ceiling air temperature after installation of the solar air heating, $\dot{Q}_{design}$ is the design airflow rate through the collector, A_{floor} is the total floor area, and R_{roof} is the user-entered insulation value for the ceiling (all other variables have the same meaning as presented in the previous sections). T_{strat} is defined by the user; T'_{strat} is assumed to be related to T_{strat} through a relationship represented graphically in Figure 7. After the installation of the solar air heating, stratification is assumed to be reduced by at least 25% and not to exceed 5°C.

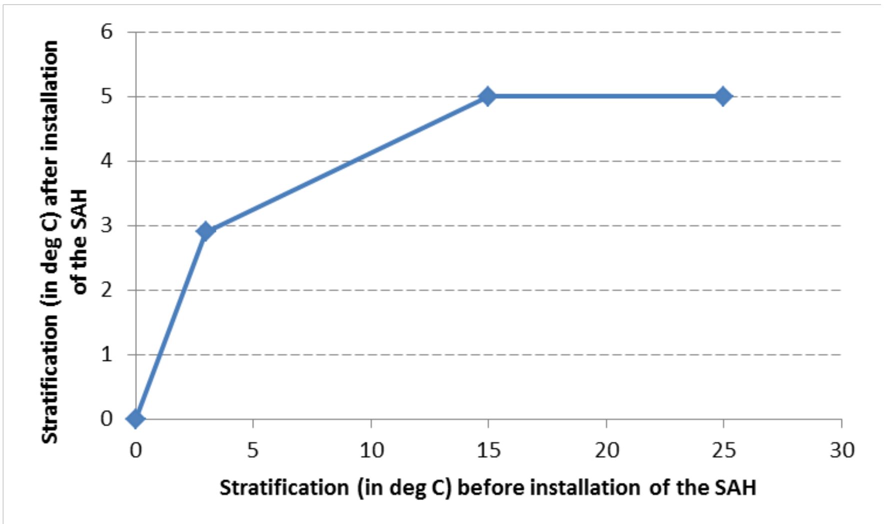

Figure 7. Effect of solar air heating installation on building air stratification

Energy Reductions for Heating Systems for Non-Industrial Buildings

In non-industrial buildings, the flow rate through the collector, $\dot{Q}_{coll}$, is assumed constant and equal to the user-specified design flow rate, $\dot{Q}_{design}$. Therefore, the calculation of energy reductions is straightforward. Collector efficiency is derived from Equation (3), setting $\dot{Q}_{coll} = \dot{Q}_{design}$, in the formula. Solar energy delivered over the year, Q_{sol}, is calculated through Equation (10). Annual building heat recapture savings, Q_{recap}, are calculated through Equation (11) except in the case of process air heaters where this quantity is assumed to be zero.

Finally the yearly increase fan energy Q_{fan}, is obtained from:

$$Q_{fan} = P_{fan} A_{coll} \frac{d_{op}}{7} h_{op} 365 \qquad (17)$$

where P_{fan}, is the increase fan power per unit collector area. Q_{fan}, can be a positive or negative value, and contributes to the reductions accordingly. Total amount of renewable energy delivered, Q_{del}, is derived by summing the solar energy collected and the amount of heat recaptured, and subtracting the incremental fan energy:

$$Q_{del} = Q_{sol} + Q_{recap} - Q_{fan} \qquad (18)$$

The specific yield of the solar air heating system, η_{sys}, is obtained by dividing the amount of renewable energy delivered by the collector area:

$$\eta_{sys} = \frac{Q_{del}}{A_{coll}} \qquad (19)$$

Energy Reductions for Heating Systems for Industrial Buildings

The case of heating systems for industrial buildings is more complex than that of heating systems for non-industrial buildings. In residential/commercial or process heat applications, the airflow rate through the collector is constant. In heating systems for industrial buildings, a recirculation damper system incorporated into the fan area mixes warm indoor air with cooler solar collector air to maintain a constant delivered air temperature. The ratio of indoor (recirculated) air to solar air heating system (outdoor) air varies continuously with changes in the solar collector outlet air temperature. As a consequence, the flow rate of air through the collector varies, as well as the collector efficiency (Equation 3) and the temperature increase through the collector (Equation 6). Since it is impossible to derive one of the quantities without knowing the other, an algorithm becomes necessary to find the service point on the curve of Figure 6.

For simplicity, calculation needs to iterate three times. First a suitable estimate is made for the starting collector flow rate $\dot{Q}_{coll}^{(1)}$. The following equation provides the suitable estimate:

$$\dot{Q}_{coll}^{(1)} = min\left(1, \frac{7.5}{\max(0,(T_{del}-T_{amb}))}\right) \dot{Q}_{design} \tag{20}$$

where $\dot{Q}_{design}$ is the design airflow rate through the collector, T_{del} is the desired delivered air temperature for the supply air, and T_{amb} is the outdoor ambient air temperature for the given month. An initial efficiency $\eta(1)$ is then determined from Equation (3) using $\dot{Q}_{coll} = \dot{Q}_{design}$. The first iteration collector temperature rise is then calculated using Equation (6). The corresponding delivered air temperature is then calculated and limited to the specified maximum $T_{del,max}$ using Equations (7) to (9). Using the new actual temperature rise T_{act} , a second estimate of collector flow rate is calculated:

$$\dot{Q}_{coll}^{(2)} = \left(\frac{T_{recirc}-T_{del}}{T_{recirc}-T_{act}^{1}}\right) \dot{Q}_{design} \tag{21}$$

where T_{recirc} is the recirculation temperature, taken as the average of the set point temperature and the stratified ceiling air temperature. This process is reiterated until $\dot{Q}_{coll}^{(3)}$ and $\eta^{(3)}$ are obtained. The efficiency is then used in Equation (10) to return the total solar energy collected.

The rest of the calculations are similar to what is done in the non-industrial case (Equations 17 to 19), except that the total amount of renewable energy delivered, Q_{del}, also includes destratification savings. Therefore Equation (18) is replaced with:

$$Q_{del} = Q_{sol} + Q_{recap} + Q_{destrat} - Q_{fan} \tag{22}$$

where $Q_{destrat}$ is the destratification savings calculated by Equation (16).

Thermal Storage Wall Components

Glazings are critical components of most solar collection systems. The purpose of the clear translucent coverings is to trap heat from the incoming solar radiation. The heat-trapping ability of glazings arises largely from their wavelength dependent transmission. That is, they allow radiation of certain wavelengths to pass through while blocking the passage of others. A good glazing material should allow maximum transmission of solar (short wave) radiation (expressed as the percentage of incident light that passes through). And it should keep heat loss to a minimum by preventing long-wave transmission and by serving as a barrier to heat loss. Long wave radiation or heat is radiated out from surfaces that absorb light in any collector system. By preventing the escape of this longwave radiation, the collector heats up. This process is the familiar "greenhouse effect".

Additionally, an ideal solar glazing should possess resistance to ultraviolet ray deterioration, good thermal stability, a high resistance to abrasion and weather, low maintenance and purchase costs, high fracture and Impact resistance, and ease of handling.

Commonly used glazing materials fall into two broad categories: glass and plastics. Glass, in a variety of forms and compositions, is the proven performer against which other materials are usually judged.

Mass Wall

In mass wall the solar heat will be stored and transmitted to the inside of the building. The material used for a mass wall is, therefore, very important and is discussed in some detail below. Also important with a mass wall is the surface exposed to the sun. It is necessary that the surface of the mass wall absorb nearly all the light energy passing through the glazing. To do this, the surface of the mass wall should be a dark color. If using paint on the mass wall, it should be black or a very dark color and should be able to withstand the high temperatures reached in a wall collector. Darkening agents other than paints may be used, depending on the wall material.

Wood stains have been used to darken adobe and concrete block. Cement stucco can easily be darkened with added pigments. Counter to much previously published information, there is apparently very little difference in absorption between flat and glossy paints, glossy paints being, in fact, better as they tend to pick up less dirt and dust.

In selecting the material for a mass wall, two considerations should be made: cost and thermal characteristics. Given the common materials for mass walls - concrete, brick, adobe and stone - one should research the availability and cost of each before making any decision. Such information can usually be obtained from local brickyards and building supply outlets. Also take into account additional expenses such as forming costs for concrete, the expense of an experienced bricklayer, etc.

With thermal characteristics, we are interested in 1) how much heat a material can store, and 2) how rapidly that heat can be transmitted (by conduction) through the material and released to the inside air. These characteristics are determined by four physical properties of a material: density, conductivity, specific heat and heat capacity.

Density, p, is a measure of how heavy a given volume of a material is, expressed for our purposes. In general, heavier (more dense) materials tend to absorb and store more heat than lighter ones. Thermal conductivity is a measure of how rapidly and easily heat can move through a material. The movement of heat is always due to a difference in temperature; heat moves from warmer to cooler parts of any material. The British Thermal Unit (Btu) is the commonly used measure of heat. A measure of conductivity is the number of Btu's able to pass through a given thickness of a square foot of a material in an hour if there is a 1 °F difference in temperature from one side to the other. Thermal conductivity, k, is expressed in Btu ft/ft^2 hr °F.

Specific heat Cp, is a measure of the amount of heat needed to raise the temperature of a given mass of material, and is expressed in Btu/lb °F.

Volumetric heat capacity is a measure of how much heat can be stored in a cubic foot of material when being raised in temperature 1 °F. It can be found by multiplying the density (p) of a material by the specific heat (Cp) and is expressed in Btu/ft3 °F.

In addition to the massive building materials (concrete, brick, stone, adobe, etc.), there are other possibilities for a thermal storage wall. Water has been used extensively as a heat storage medium; in fact, it is in many applications superior to mass walls. Salt hydrates also have great potential in storing heat for solar applications.

Because water is a fluid, convection currents distribute heat very quickly (effective conductivity close to Infinity). This property, together with the high volumetric heat capacity, allows a water wall to provide a greater solar heating fraction than a similar sized wall of concrete or some other massive material. Though often difficult to contain, water costs very little, so it can be very attractive to the solar designer/builder.

The heat of fusion or latent heat absorbed and released with phase changes (i.e. melting or freezing) is the property of most significance. A large amount of heat is absorbed by salt hydrates as they melt (when being heated up,). This heat is then released as the solutions freeze (when cold). The melting point is low, enabling this phase change to occur at temperatures reached in thermal storage wall-type collectors. One can see the tremendous potential of salt hydrates to store a great deal of heat in a small volume. Problems of cost containing the salts, and phase separation with continued cycles of freezing and thawing, however, have to date limited the use of salt hydrates for other than experimental systems. One can expect to see much research in this area and probably viable and cost effective use of salt hydrates in the near future.

Summary

In this course, the calculation method used for solar air heating project model have been illustrated in detail. The model calculates energy savings resulting from the installation of a perforated plate solar collector. Energy savings are the sum of solar energy actively collected, building heat recapture savings, and destratification savings. Depending on the type of system considered, only some of these savings may apply: process heat systems only benefit from active gains, residential/commercial systems also benefit from building heat recapture, and heating systems for industrial buildings benefit from all three modes of savings. Active solar energy gains are calculated with the help of an empirical collector efficiency curve. Other savings are approximated from simple energy balances using monthly average values. The calculation of overall energy savings is straightforward in the case of commercial, residential and process heat systems, where the collector flow rate is set by design. The calculation is more complicated in the case of heating systems for industrial buildings because the collector flow rate depends on the mixing ratio with recirculated air, and therefore an iterative procedure has to be used.

References:

Clean Energy Project Analysis RETScreen® Engineering & Cases Textbook, Third Edition, © Minister of Natural Resources Canada 2001-2005, September 2005