PDHonline Course E505 (3 PDH)

Solar Air Heating Project Analysis

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1. 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.

2. Solar Air Heating Background

The Solar Air Heating (SAH) system is a proven system for heating or preheating air in various applications. The system is most widely used to heat ventilation air in buildings, but it has also been applied in processes such as crop drying where heated air is an important requirement.

The worldwide demand for this relatively new and unique technology has increased rapidly over the past decade. Years of research and testing have resulted in this new concept for heating air with solar energy. Solar air heating installations are beginning to be used more and more for the "cladding" of exterior walls (which face the equator) on industrial, commercial and apartment style buildings, as well as for single-family residences. Solar air heating systems have also been used for drying agricultural crops such as tealeaves, and their potential has been demonstrated for a wide variety of other cultivated products.

Typically, the most cost-effective installations of solar air heating systems on buildings occur in new construction since the solar collector cladding (or plate) allows the use of less expensive wall cladding material as a backing; and no additional ventilation fan is required. The second most cost-effective installation is generally for retrofits when there are plans to repair or upgrade an existing wall, improve indoor air quality, or add more ventilation or makeup air to balance exhaust air. Many existing process air heating systems can also be easily retrofitted to include low-cost solar air preheating. Where heating costs are high, solar air heating systems are often financially attractive, even in retrofit situations that don't meet the above criteria.

3. Description of Solar Air Heating Systems

The solar air heating system consists of two parts:

- A solar collector mounted on the side of the building facing the equator
- A fan and air distribution system installed inside the building, as depicted in Figure 1.

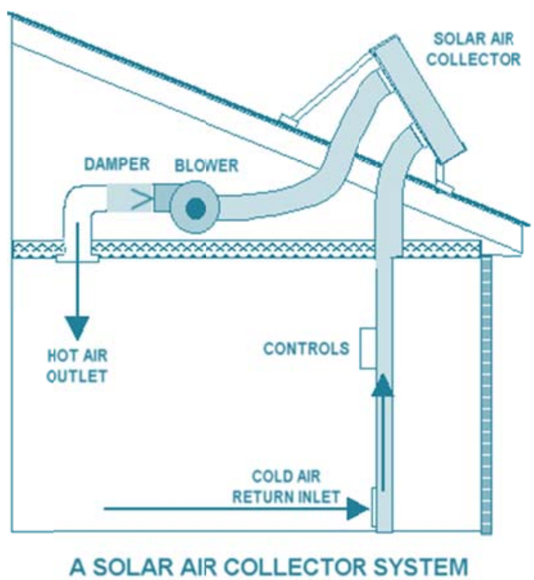

Figure 1. Typical solar air heating system

A unique feature of the solar air heating system is that it uses a perforated plate (or transpired-plate) as the solar collector eliminating the need for a glass cover, common in most other solar collectors used for heating purposes. Air is drawn through small holes in the dark coloured solar collector plate and is warmed as it passes over and through the plate. System is shown in Figure 2.

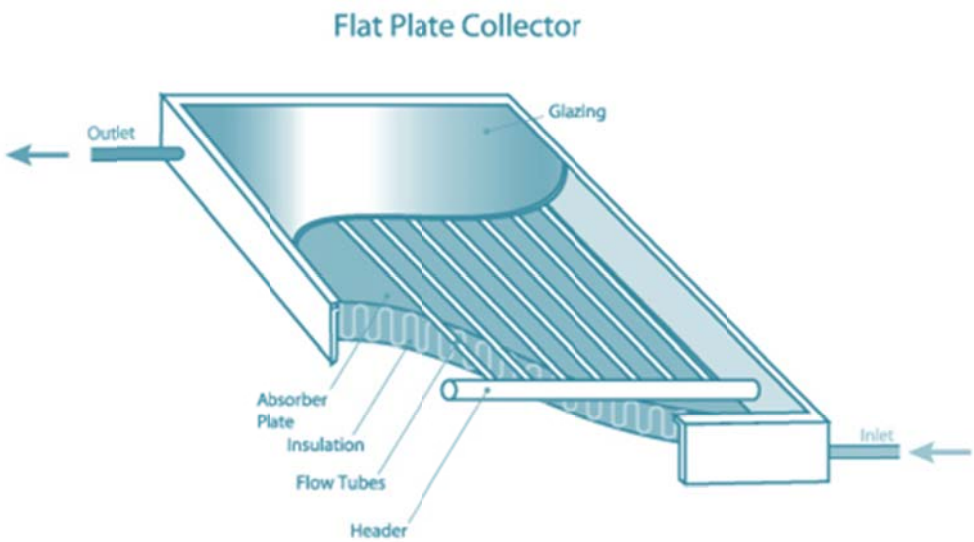

Figure 2. Plate solar collector

The air collects in a cavity between the solar collector and building wall and is ducted into the building. High-efficiencies are possible because the solar collector plate is only a few degrees warmer than the outdoor air. Therefore, there is little heat loss and most of the solar radiation is transferred to heat the air.

Bypass dampers can be located in the face of the canopy. These dampers allow ambient air to be fed directly into the building or process when no heating is required. In ventilation applications, an adjustable thermostat that senses outdoor temperature controls the two-position damper. The thermostat is typically set to open the damper when the outdoor temperature is warm enough to eliminate the need for heating (typically above 15 to 20ºC). Figure 3 presents a schematic of a typical solar air heating system.

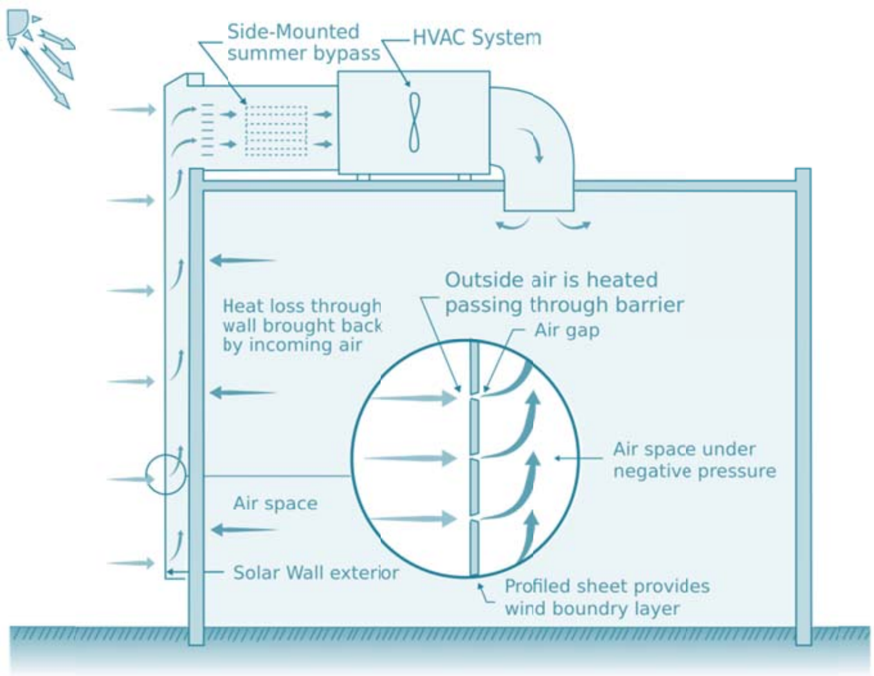

Figure 3. Solar air heating system scheme

The size of solar air heating system collectors depends on the ventilation rate and wall area available for solar collector installation. Solar air heating systems are typically sized to provide either a high temperature rise or high solar collection efficiency. A high efficiency design objective will increase the annual energy savings and possibly decrease the solar collector size. However, the average air temperature rise will be reduced.

4. Solar Air Heating System Application Markets

Applications for solar air heating systems include both building ventilation air heating and process air heating. Systems used for ventilation heating vary depending on the type of building on which the system will be installed (e.g. industrial, commercial or residential). This applies to new construction and retrofit situations. The method of solar air heating system air delivery depends on the type of building and the existing air distribution system.

5. Commercial and residential buildings

Most commercial and residential buildings need ventilation air. Solar ventilation air preheating systems preheat this air before bringing it into the building. An air-handling unit pulls ventilation air through the solar collector and delivers it throughout the building with conventional ductwork. On cold days, the solar collectors preheat the air and a heater in the air-handling unit provides the necessary remaining heat. On cool sunny days, the solar system can likely provide all the necessary air heating. In the summer, a bypass damper is opened, avoiding an unnecessary load on the air-conditioning system.

An additional advantage of making the solar collector a part of the building façade is that the collector can recapture building wall heat loss. As the heat conducts out the building wall, it reaches the collector air channel. At this point the ventilation air blowing through the channel picks up this heat and blows it back into the building. Typically the ventilation air recaptures half of the wall heat loss.

Most commercial, multi-unit residential and institutional buildings have existing air handling systems. In some cases (e.g. apartment buildings, schools), the air handling system is a dedicated ventilation system. In other buildings (e.g. offices), the air handling system provides space heating, cooling and ventilation with ventilation air making up between 10 and 20% of the total airflow. In either case, the solar air heating system is connected to the outdoor air intake and the air is distributed through conventional ductwork. The solar air heating system supplies a constant flow of outdoor air preheating the ventilation air.

6. Industrial buildings

Industrial ventilation air heating applies to buildings requiring large volumes of outdoor air to replace air exhausted from painting, welding, automotive fabrication, or other manufacturing operations. Because of the wide-open plant areas and high ceilings, it is possible to design a solar heating system that can replace conventional make-up air heaters. Instead of using a conventional heater to provide the additional heat required, solar make-up air heaters combine solar preheated air with warm building ceiling air and deliver this air to the building. The solar air-handling unit is designed to vary the amount of outdoor air and recirculated air to achieve a flow of constant temperature air (typically 15 to 18°C). As depicted in Figure 4, in industrial buildings where there is no existing air distribution system, the solar air heating system interior components consist of a constant-speed fan, a recirculation damper system and a fabric distribution-duct.

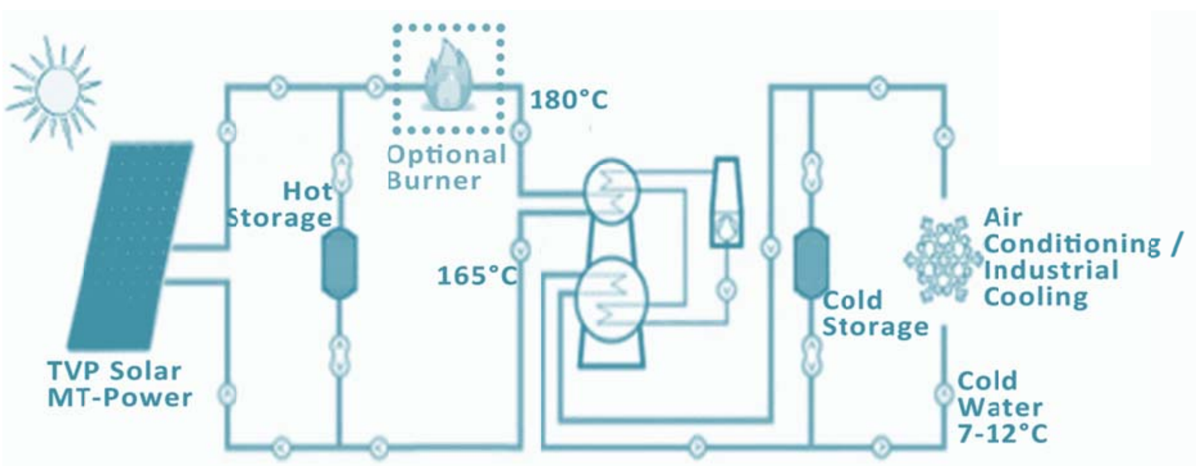

Figure 4. Industrial solar air heating/cooling system schematic

Perforated fabric ducting is a low-cost method of delivering make-up air throughout the building. A recirculation damper system incorporated into the fan compartment mixes warm indoor air with cooler solar collector air to maintain the 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, while a duct thermostat operates the damper system.

The mixture of ventilation air and recirculated air is distributed to the plant through perforated fabric ducts, which are located at ceiling level. Because the air from the ducting is cooler than air at the ceiling, the ventilation air will cool the ceiling reducing heat loss through the roof at the temperature of exhaust air (for ceiling exhausters) and the air will naturally fall, mixing and destratifying the building air.

Another advantage of the system is that it too can recapture building wall heat loss if the collectors are mounted on the building wall.

7. Process air

Large quantities of outdoor air are used for process air heating applications. Drying of agricultural products is a good application for solar energy, as the required temperature rise must be kept relatively low to prevent damaging the crops. Those crops that are harvested continuously over the year are well suited because all the available solar radiation can be used. Solar systems can also serve as a preheater to (high temperature) industrial drying systems.

Solar process air heating systems are similar to ventilation air preheating systems. The perforated plate absorber is located in any convenient location that has good exposure to the sun. Sloped roofs as well as walls are suitable mounting structures. A constant flow of air is taken through the collectors and is ducted into the air intake of the process. If necessary, additional heat can be added from auxiliary sources to deliver the desired air temperature and some or all of the process air can bypass the collectors if the air is above the desired temperature.

8. Solar Air Heating Project Modelling

Solar air heating project modelling can be used to evaluate solar air heating projects, from larger scale industrial building developments to smaller scale residential applications. It is also able to model process air heating applications, such as the drying of crops. Solar air heating systems can save conventional energy in three ways, depending upon the application:

- Collection 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 recirculated back into the building)
- Destratification of building air in buildings with high ceilings, for example, industrial manufacturing plants or warehouses.

This section describes the various algorithms used to calculate, on a month-by-month basis, the energy savings of solar air heating systems. A flowchart of the algorithms is shown in Figure 5. Sections below present the calculation of the three modes of energy savings:

- Collected solar energy savings
- Building heat recapture savings

- Destratification savings

How these three modes contribute to the overall energy savings for non-industrial buildings and industrial buildings is shown in the following sections.

The heat transfer in solar air heating systems is relatively complex. It is dependent upon the solar radiation, temperature and wind speed surrounding the system. Most solar air heating analysis tools use an hourly time step to follow the changing solar and weather conditions. Described approach evaluates the performance on a monthly basis in order to provide results quickly with a minimum of input information. This approach is deemed suitable at the pre-feasibility stage in project development.

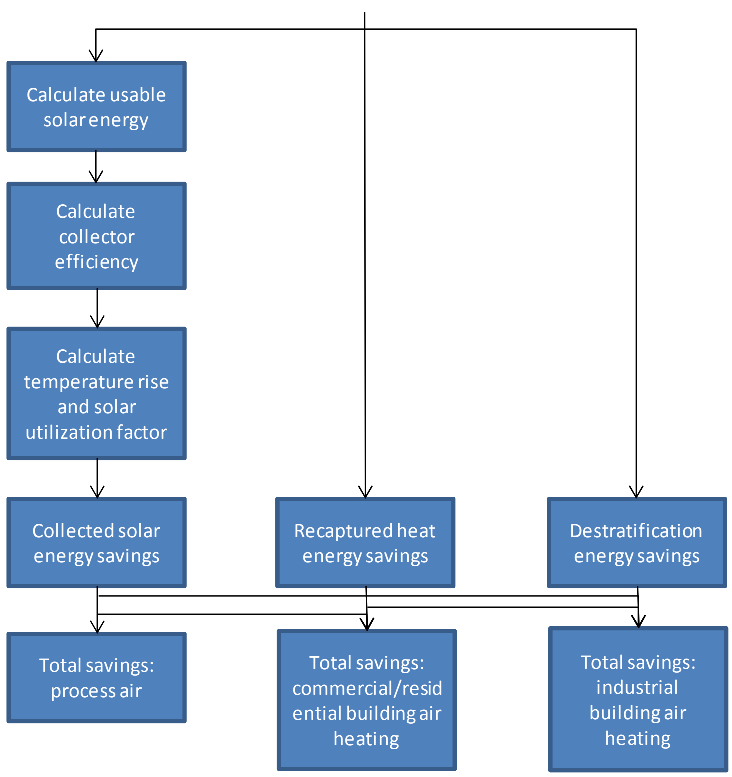

Figure 5. Solar air heating energy model calculation method

Process air heating is assumed to benefit only from collected active solar energy savings. It is assumed that the building does not require space heating and any reduction in wall or roof heat loss does not save energy. Furthermore, because the heated air goes straight from the solar collector to the drying ovens, or other process machinery, there is no potential for destratifying the building air.

Commercial/residential buildings benefit from two modes of energy savings:

- Collected active solar energy savings
- Recaptured heat savings.

Industrial buildings, due to the method of air circulation on the building and the height of the ceilings, benefit from all three methods of energy savings.

Because of introduced simplifications, described solar air heating model has a certain number of limitations:

- The ventilation model does not incorporate a detailed energy consumption and make-up system analysis for the existing building. This minimised data requirement approach makes it much easier for the user to prepare an analysis, but modelling accuracy will be partially reduced as a result.
- The model does not include advanced heat recovery technologies currently under development for the solar air heating system. Therefore, the model may understate the potential savings of a combined advanced heat recovery/solar air heating system.
- Finally, the model assumes industrial buildings have a balanced ventilation system for the calculation of destratification savings.

For the majority of applications, these limitations are without consequence.

9. Collected Solar Energy Savings

Solar radiation incident upon the tilted collector must be calculated from data input by the user, namely, daily solar radiation on a horizontal surface and operating multiplier. Energy collected by the solar collector is calculated by multiplying incident radiation by the average collector efficiency. However, only part of the energy collected will actually be usable. The concept of solar utilization is covered in the following sections.

10. Usable incident solar energy calculation

For each month, i, the total amount of solar energy usable by the collector, $G_{coll,i}$ is calculated. This value is obtained 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 $f_{op,i}$:

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

The solar radiation incident on the collector,$G_{titlt,i}$, is derived from the user-defined average daily solar radiation on the horizontal surface, $G_{horz,i}$. The value for $f_{op,i}$ demonstrates the importance of the operating schedule to the total energy savings of a solar air heating system. It is calculated using:

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

where $n_{days,i}$ is the number of days in month i, $f_{sys,i}$ is the user-entered fraction of the month used for system operation, $h_{op,daytime}$ 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 dop is the user-entered number of operating days per week. When the system is shut down, energy cannot be captured. Therefore to account for the weekly operating schedule, d_{op} is divided by 7 days a week in equation (2). To account for 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 noted, depending on the time of year and latitude, that during some months of the year the user-entered hours per day of operating time (h_{op}) may be greater than hours of daylight ($h_{sunlight,i}$). In this situation the lesser of h_{op} and $h_{sunlight,i}$ is used for $h_{op,daytime}$. This calculation also introduces an approximation since no consideration is given to the actual time of operation.

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

11. Average collector efficiency

Solar energy incident on the perforated plate collector, as given by equation (1), is used to heat or preheat air. The efficiency of a perforated plate solar collector depends on a number of variables. The more dominant of these are collector airflow and wind speed on the surface of the collector. Figure 6 shows the relationship between efficiency and collector airflow at various wind speeds.

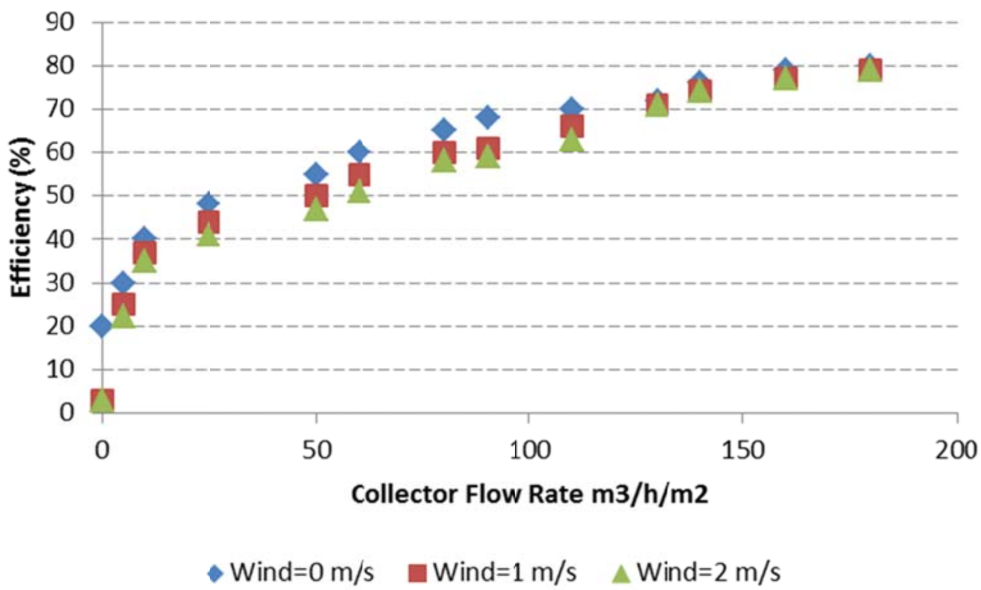

Figure 6. Solar collector efficiency vs. flow rate

A collector efficiency equation can be derived from a heat balance on the collector and can be expressed 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 given by:

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

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 the purposes of calculation, monthly average wind speed at the collector v'_{wind} is related to 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 value that does not account for sheltering or orientation of the building.

12. Solar utilization

Since solar energy in a solar air heating system is used for heating, there will likely be times when energy is collected but cannot be used to offset heating loads. Only energy that can contribute to reducing the heating load can be considered useable. Collection of non-useable solar energy is avoided in most solar air heating systems by using a bypass damper that pulls air directly from the outside instead of through the collector.

To simulate this, a utilization factor $f_{util,i}$ is introduced to determine the quantity of collected solar energy that would contribute to heating savings. In order to calculate the utilization factor, both the average actual temperature rise through the collector (ΔT_{act}) and the available temperature rise (ΔT_{avl}), are determined. The available temperature rise represents the increase in air temperature as it flows through the collector provided there is no limit on the desired outlet temperature. The actual temperature rise is the increase in temperature after the control system has limited the delivered air temperature to the prescribed maximum, $T_{del,max}$. The utilization factor $f_{util,i}$ is then given by:

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

Available temperature rise is found 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.

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

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

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

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

where $T_{del,avl}$ is the available delivered temperature and T_{amb} is the average 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 and if necessary the actual temperature rise is forced to zero.

13. Active solar energy savings

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

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

where 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).

14. Building Heat Recapture Savings

When a solar air heating collector is installed on a building, there is an added benefit due to the return of lost building heat through the collector. If the collector is not running, there is a small benefit associated with a slightly increased RSI-value (thermal resistance) of the building wall. The model estimates building heat recapture savings under three different modes: daytime operating, night-time operating, and during shutdown times. The net savings Q_{recap} are found by simply summing 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 user-defined fraction of month i used for system operation. Heat recapture for the three modes is calculated as follows:

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

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

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

where $n_{days,i}$ is the number of days in month i, $h_{op,daytime}$ is the number of hours of operation during sunlight hours, $h_{op,nighttime}$ is the number of hours of operation during night-time hours, and h_{op} is the number of hours of operation ($h_{op} = h_{op,daytime,i} + h_{op,nighttime,i}$)). R_{wall} is the user-defined insulation value for the wall, A_{coll} is the solar collector area, and R_{coll} is the added 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 monitoring suggest that heat exchanges through the building wall are attribuable to collector temperature (responsible for about two-thirds of total wall heat exchange) and ambient temperature (responsible for the remaining one-third of the wall heat exchange). Thus:

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

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

15. Destratification Savings

Destratification savings are typically only found in heating systems for industrial buildings. The high ceiling in most 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:

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

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.

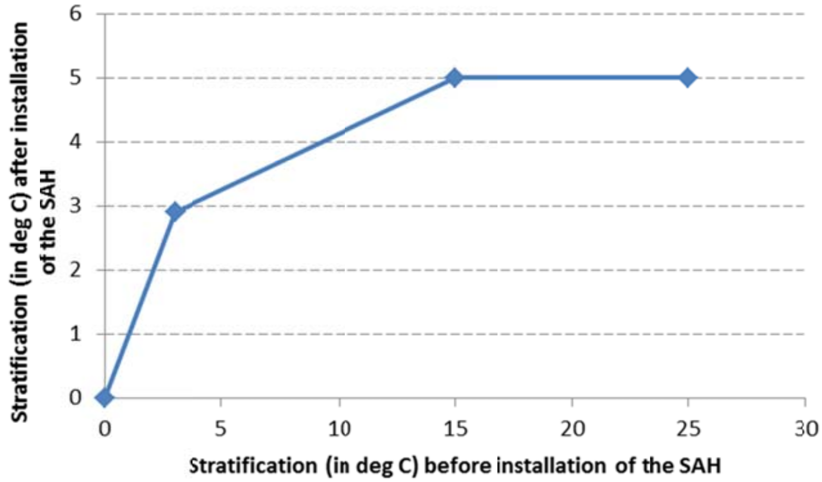

Figure 7. Effect of solar air heating installation on building air stratification

16.Energy Savings for Heating Systems for Non-Industrial Buildings

In non-industrial applications, 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 savings is straightforward. Collector efficiency is calculated from equation (3), setting $\dot{Q}_{coll} = \dot{Q}_{design}$, in the equation. Solar energy delivered over the year, Q_{sol}, is calculated through equation (10); yearly 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 incremental fan energy Q_{fan}, is calculated from:

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

where P_{fan}, is the incremental fan power per unit collector area. Q_{fan}, can be a positive or negative value, and contributes to the savings accordingly. Total amount of renewable energy delivered Q_{del}, is obtained 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:

$$\eta_{sys} = \frac{Q_{del}}{A_{coll}} \tag{19}$$

17.Energy Savings for Heating Systems for Industrial Buildings

The case of heating systems for industrial buildings is slightly more complicated 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 on the other hand, a recirculation damper system incorporated into the fan compartment 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, and so do the collector efficiency (equation 3) and the temperature rise through the collector (equation 6). Since it is impossible to calculate one of the quantities without knowing the other, an iterative algorithm becomes necessary to find the operating 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 determined using equation (6). The corresponding delivered air temperature is then determined 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 obtained:

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

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 (18) is replaced with:

$$Q_{del} = Q_{sol} + Q_{recap} + Q_{destrat} - Q_{fan} \qquad (22)$$

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

18. 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.

19.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, and in fact is in many applications superior to mass walls. Salt hydrates also have great potential in storing heat for solar applications.

Because it 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.

20.Summary

In this course calculation method used for solar air heating project model have been shown 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 collector flow rate depends on the mixing ratio with recirculated air, and an iterative procedure has to be used.

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