Solar Energy – Radiant Comfort and Efficiency

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▪ The Solar Resource

The amount of solar thermal energy available is enormous. The solar energy falling annually on just 12 square kilometers of southern Saskatchewan, Canada's sunshine capital, is equal to the total 2004 energy sales by that province's electrical utility. Even at levels considerably less than the 5.1GJ/m^2/year falling on southern Saskatchewan, the solar energy falling on a building can easily exceed the total energy used in that building. The challenge is in understanding how to use this vast but variable resource. To effectively use alternative energy, such as solar thermal, it is necessary to develop low temperature heating systems and high temperature cooling systems. That is, our buildings must be designed to effectively use energy that is of low quality.

▪ International Energy Agency, Annex 37

Fortunately, a considerable international effort has recently gone into this, under IEA Annex 37, Low Exergy Systems for Heating and Cooling of Buildings. "Exergy" refers to the quality of energy, the part that is useful in doing the work required of it. Consequent to the second law of thermodynamics, exergy diminishes as entropy increases. The Annex 37 research team found that there is an optimal combination of room air temperature and mean radiant temperature which results in achieving thermally neutral conditions with the smallest exergy loss. Radiant exergy transfer plays a more important role in low-temperature-heating or high temperature-cooling systems than in conventional air heating or cooling systems, because radiators with a temperature only slightly different from room air temperature require comparatively large surface areas.

The concept of thermal neutrality is important in raising hogs, because under those conditions the animal's performance is at its peak. There is maximum weight gain from the hog's food, because it is not spending energy on keeping cool or on keeping warm. It is a comfortable hog. The conditions required for thermal neutrality will vary widely, depending on the age and size of the hog and the air flow in the building. The conditions for human thermal neutrality happen to fall within the range of conditions for hog thermal neutrality. And the temperatures appropriate to meeting those conditions are readily achieved using low grade energy sources.

For humans, in a room that is at 50 per cent relative humidity, the optimal combination of room air temperature and mean radiant temperature to produce thermally neutral conditions is 18ºC air temperature and 25ºC mean radiant surface temperature. This suggests that for heating, radiant exergy is more effective than convective exergy.

Surface temperatures at that level can be effectively maintained with an energy source as low as 28ºC if it is delivered in a radiant slab floor. For both heating and cooling, effective delivery temperatures close to desired room temperature enables the highest efficiency as well as the use of the broadest range of potential energy sources.

▪ For Example

To illustrate that principle, I will describe the energy system in a demonstration house built in 1994 in Pilot Butte, Saskatchewan, a suburb of Regina. The floors were radiant slabs. The exterior walls were concrete, insulated both inside and outside. The same kind of pex pipe installed for the radiant floor was also installed in the concrete walls. Solar thermal collectors were installed vertically on the south wall. There was a ground source heat pump, with horizontal collection lines buried 2m deep in the yard on the south side of the home. The energy from the solar collectors was used in different ways at different times of the year. In summer, it pre-heated the domestic hot water. In the autumn months, it was directed into the ground beside the collection lines for the heat pump, boosting the soil temperature and therefore boosting the coefficient of performance of the heat pump for the early part of the heating season. In the winter months, it flowed through the pipes on the exterior walls, serving as dynamic insulation. Fresh air for the building was brought in through a corrugated pipe that was buried in the earth one meter below the building slab, and distributed through a plenum formed by the joist cavity for the upper floor. This simple air tempering system has approximately the same efficiency as a mechanical heat recovery ventilator.

> ***Ordinary glazed solar thermal collectors can be effective even during a bitterly cold prairie winter***

One thing this project demonstrated is that ordinary glazed solar thermal collectors can be effective even during a bitterly cold prairie winter. Winter brings with it a compensating factor for the shorter days and severe cold. That compensation is snow. The reflection from a snow-covered foreground can provide a 40 per cent boost to the direct solar energy delivered by the mid-winter sun. The vertical solar collectors on this project received, for four hours a day in early January, 10 per cent more solar energy than is available from direct sunshine at that location at summer solstice. With outdoor air temperatures of -35ºC, these solar thermal collectors were delivering to the concrete walls a high flow of 19ºC fluid between the hours of 10:30 am and 2:30 pm. It was the design of the wall structure that made this low quality energy useful. The entire energy system of the house was designed to match the quality of the available solar energy with its most effective use at the time.

▪ Proper Design and Construction

A well insulated and well designed building envelope is essential for optimizing comfort and energy efficiency. If there are windows, they must be installed according to passive solar design principles to allow solar heat gain in winter but block it in summer. The building should also contain high thermal mass, such as concrete floors and walls, so that it absorbs and releases energy slowly. Concrete can be a highly effective storage and delivery medium for solar energy. But its effective use requires the proper use of insulation. The insulation must be on the outside, so the thermal mass is working with the building's energy system, not against it. The Egyptian architect, Hassan Fathy, noted more than half a century ago how inappropriate bare concrete is for extreme climates, because of its fast thermal transfer properties, four times the rate of clay brick or adobe. The proper use of insulation can turn that into a positive characteristic, particularly if the concrete also has a thermal circulation system embedded in it. The earth under the floor slab, particularly near heat sources such as manure pits, can also be an important part of the building's energy system. Effective perimeter insulation can create a large thermally stable zone that can be used as a heat exchanger for makeup air. All it takes is a set of long intake pipes and parallel exhaust pipes buried about a meter under the floor. There are more than 50 such air tempering systems in use across western Canada, in homes, churches and schools. Experience in Europe more than a decade ago demonstrated a 75 per cent reduction in the energy required for tempering makeup air. Of course there are engineering details to keep in mind, such as the need, in cold climates, to remove the moisture from the exhaust stream before it reaches the freezing outdoor temperatures. For cooling purposes, you could bury an air intake pipe outside the building perimeter, perhaps in the shaded soil on the north side of the building. You might want to bury that one deeper, perhaps as deep as four meters. Studies done in Saskatchewan in the 1970s found a four month thermal lag at that depth. At the height of summer, the earth temperature at 4 metres still feels like late winter.

▪ Energy When Needed

If your goal is to provide all, or even most, of your thermal energy from solar, you are going to need massive storage. The most practical large thermal storage medium would be an aquifer. In the 1980s the University of Regina's Energy Research Unit built a mathematical model for such a thermal storage system. They assumed the energy was to come from burning the methane produced from hog manure. But the storage principle is the same, because what matters is not the energy source, but the energy retrieval. The researcher on that project was Keith Hutchence, who now works for the Saskatchewan Research Council's energy unit. He found that if you tried to retrieve energy from the aquifer in the same year you started to put the energy in, you would get only half of it back in the first year, and that rate of retrieval would rise only slowly. His model showed that it would be ten years or more of continuous operation before you started getting back anywhere near 90 per cent of the energy you pumped into the aquifer. However, if you sacrificed the first year of input, dumping in enough energy to bring the aquifer up to the temperature you require of it, you can then take out 90 per cent of what you put in, and that efficiency would grow with time, approaching total heat recovery. Imagine being able to pump an entire summer's worth of warmth into the ground, knowing you can get nearly all of it back in winter.

Earlier I discussed the value of a low temperature heat emission system in our buildings. Now you can see the value of a low temperature heat absorption system for storage. The lower the temperature of the aquifer, the more readily it will absorb available energy and the less tendency it will have to dissipate that energy.

▪ What Works for Solar….

A system designed to effectively use solar energy can also make the best use of other energy sources. Comprehensive building design tools are being made available by LowExNet, the group that is promoting the work of IEA Annex 37. These tools are fundamentally different from other design tools. Calculations for all kinds of energy utilization, including heating/cooling loads of rooms in buildings and temperature distributions are based on energy balances in reference to the first law of thermodynamics, the law of conservation of energy. The LowEx tools also incorporate the second law of thermodynamics, which acknowledges that something is inevitably lost in energy related processes. What is lost is quality, otherwise known as exergy. Serendipitously, the path to spending less exergy happens to be the path to greater comfort.

▪ References

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