Direct use of Solar Energy for Heating and Cooling

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Based on a presentation by Michael Garrison

Introduction

In his lecture Professor Garrison introduced several UTSOA programs that engaged in designing and building experiments in Sustainable Design. Professor Garrison has been involved in sustainable design studies since he started at the UTSOA in 1974. Working out of the UTSOA architecture annex in the 1970s, Professor Garrison explored ideas about energy conservation and design with climate. His goal was to integrate energy conservation strategies and the use of solar energy to achieve thermally delightful spaces.

Thermal Comfort

An understanding of human comfort is fundamental to principals of design with climate. People use energy buildings do not. Thermal comfort depends on many factors. For bioclimatic comfort, the most important of these are:

1. The level of physical activity
2. The amount of clothing worn
3. The interior temperature of the air
4. The relative humidity of the air
5. The velocity of the air movement
6. The mean radiant temperature (MRT) of the surrounding surfaces
7. The temperature of surfaces in conductive contact with the body (mainly floors and furniture)

What is “Passive solar energy”? 

Passive solar technologies provide a means for using sunlight for heating without the use of active mechanical systems. Passive solar systems can collect sunlight through south facing glazing for direct heating or store heat in the thermal mass of the building for future use. Passive solar may also be used for cooling by inducing stack ventilation in solar chimneys or cupolas. A southerly facing solarium is an example of a passive solar system that provides passive heating in winter and then with the use of an open roof cupola mounted above the solarium, can be used to provide ventilation during non-heating periods.

Hybrid passive solar technologies use a small amount of conventional energy and active solar technologies use a lot more conventional energy to power pumps, control dampers, awnings, shutters and other devices that greatly enhance the efficiency of solar systems.

Passive Solar Heating

In a passive solar home, the building itself is designed as a heating system. In the winter solar heat is collected through large south facing glazed areas, and is absorbed and stored in the thermal mass of the walls and floor of the interior. The heat is then distributed via natural convective flow within the building. Proper
sizing is critical in the design and configuration of passive solar heating systems to prevent overheating.

The design of the glazing and thermal mass are sized based on the efficiency and level of thermal comfort required. For Austin, Texas provide 0.1 square foot of south glazing per square foot of house area.

All passive systems are identified by four clearly defined elements:

1. A well insulated building envelope
2. A south facing glazing
3. A building mass which serves to absorb and store thermal energy
4. A control device

Direct Solar Gain

In a direct gain building type, solar radiation passes through glazing and into the living space before being stored in thermal mass. The direct gain building type exemplifies a live-in solar collector.

The direct gain approach is the simplest passive solar system having the advantage of allowing immediate warming of a space when the sun is shining, as well as providing natural lighting and views to the outdoors. For direct gain systems to be effective and not overheat an interior space, they require an internal air temperature swing of as much as 20°F.

The most common variations of direct passive solar gain systems are found in the location of the thermal mass. Typical location alternatives include:

1. Thick heavy external building walls
2. A high mass floor surface
3. A phase-change material

To prevent excessive heat gain, sun shading should be installed for large expanses of south facing glazing. Venting will also reduce excessive heat gain but this will also reduce the amount of heat available for storage in thermal mass.

An attached Solarium system can provide much better temperature control because the temperature of the solarium can have a large temperature swing, while the house can draw heat as required. The internal air temperature swing of a well-insulated house with an attached greenhouse is on the order of only 5°F. For Austin, Texas provide 0.25 square foot of south facing solarium per square foot of house area.

Cooling

Natural cooling has four primary components:

1. Keeping unwanted heat out of the house
2. Providing ventilation
3. Using a thermal mass heat sink
4. Using evaporative cooling

In order to exclude heat, the architect can rely on numerous strategies. First, the building should be well insulated, properly oriented and shaded from intense solar radiation. Second, the building should utilize daylighting to reduce the amount of artificial lighting. And third, the configuration of the building should be arranged to utilize effective natural ventilation when outside conditions are in the comfort zone.

Ventilation can be used to increase comfort by directly discharging heat into the incoming air as long as the air is cooler and drier than the air directly surrounding the occupant.

Mean radiant cooling involves a radiant heat transfer to surrounding surfaces, provided that these surfaces are cooler than the body temperature of the occupant.

Evaporative cooling is the process of evaporating water into the air, lowering the air temperature and raising the relative humidity of the air. The mean relative humidity of the interior air must be below 60%RH for effective evaporative cooling. Evaporative cooling can be achieved in building design through fountain courtyards, water spays, swamp coolers and cool towers.

Solar-induced ventilation or "stack effect" ventilation is primarily used to vent hot air that accumulates in the attic or near the ceiling of a room. It operates on the principle that
hot air rises and cold air sinks. Solar-induced ventilation requires only that the house outlet air vent be higher and warmer than the outside inlet vent in order to drive the airflow. The rate of solar-induced ventilation will increase if the air outlet is larger in area than the inlet air. To achieve effective solar-induced ventilation, there should be a large vertical separation between openings. Inlets should be located low in the space and outlets should be located high. The farther the air can rise, the faster it will move, increasing the cooling effect. The rapidly rising airflow also tends to draw in cooler air from shaded areas close to the ground.

Shading is the best way to block solar heat gain before it enters a building. In the summer the roof of a building followed by east and west walls receive the most radiation on the structure because the sun strikes these surfaces at a near perpendicular angle. Light colored, double roofs and walls along with horizontal overhangs above south facing windows and vertical awnings for east, west and north facing windows are all effective shading devices. Not all the solar shading has to be part of the building. Trees, shrubs and vines can be used to block the sun.

Case studies in Passive Solar Design

The following projects provide examples of ways that Professor Garrison and his students explored passive solar design.

Project One

Professor Garrison’s team built a solar green house for an exhibition in Zilker Park in 1975. This was also their first experiment with ideas about modular and mobile systems. After the exhibition they moved the solar greenhouse to the University’s Balcones Research Center (now the J.J. Pickle Center) where they attached the greenhouse to an earth tempered adobe-walled structure. This served as an opportunity to document the performance of a number of sustainable design systems. First they developed an idea of inducing ventilation. What they found was that air moved through the space faster as the exhaust opening became hotter compared to the intake. The speed of the air coming out of the exhaust was up to 10,000 cubic feet per minute, just based on convective air movement. They found that the earth-tempered walls provided effective mean radiant cooling and they developed a process for fine-tuning the performance of thermal mass to control the thermal comfort of the building.

At the research center they also developed another test structure to document what is called annual heat storage. They took all the heat from a greenhouse and stored it in a large earth storage mass under the greenhouse. In the greenhouse several tubes discharged heat into the ground inside a deep insulated grade beam. Heat went into the ground in an outer tube and returned to a greenhouse rock bed through another tube inside the outer tube. Heat was discharged into the earth mass all summer and the heat stored in the mass was then used to heat the greenhouse all winter.

Project Two

In 1979 Professor Garrison incorporated a Passive solar green house with a fan forced rock bed and a solar induced cupola in an experimental house in the Woodlands, Texas using a passive solar grant from the U.S. Department of Housing and Urban Development. The house represented the first commercial application of the passive solar design principles derived from the Balcones Research Center Project and allowed for the development of an operation protocol for the passive solar greenhouse for both summer and winter.

Project Three

In 1982 the ideas that Professor Garrison and his team had developed about passive solar, mean radiant cooling and stack ventilation were taken to the marketplace when the Texas Energy and Natural Resources Advisory Council and the Public Utility Commission asked the team to develop passive solar designs and recommendations for four climate zones in Texas: hot-humid, sub-humid, hot-arid and temperate. The sites for these were to be based on the climates found in Houston, Austin, El Paso and Wichita Falls, Texas.

They used the principles that they had developed about sizing of passive solar systems, sizes of thermal mass and levels of energy conservation and airflow. They considered how fast air had to move out of a solar greenhouse in order to prevent overheating and developed designs that employed both fan-forced rock bed thermal storage and roof cupolas. Several of these houses were built during the decade of the 1980s and their thermal performance was used to develop regional bioclimatic guidelines for passive solar design.

Figure 4: Project 1 Cupcake trombe wall, building and installing
Figure 5: Project 2: San Marcos greenhouse
Project Four

In 1985 the U.S. Department of the Interior and the Park Foundation asked Professor Garrison and his student team to design passive solar housing that would replace trailers that were being used for ranger housing at Big Bend National Park. This location was in the Chihuahuan desert, so the team developed ideas about using an exterior thermal mass envelope to take advantage of the large temperature swing between day and night. The team experimented with insulated concrete forms as a way of creating the mass walls while minimizing construction labor. They also developed shading arbors to connect clusters of houses creating courtyards. The desert flora gave the houses a place to hide. The constructed houses demonstrated the energy and resource efficient ideals of green building in a hot-arid climate.

In the late 1980s Professor Garrison became the chair of the City of Austin’s Research Management Commission where, he helped the City’s Green Building Program develop energy conservation programs, the energy star program, and the beginning of the Green Building Rating program.

Three Competitions

From the 1990s on Professor Garrison and his team have been focused on developing new ideas about both passive and active heating and cooling systems, green building materials, energy management and conservation, water harvesting, and modular construction.

2000

In 2000, a select number of universities participated in the first solar decathlon competition on the national mall in Washington D.C., sponsored by the U.S. Department of Energy. The idea was that each school would have just a few days to build a completely stand alone solar powered house. All the environmental control systems of the house had to be powered by solar to maintain interior air temperatures between 72-74˚F and relative humidity between 45-50% RH during the entire week of competition. Excess solar power was required to run a television and computer, power the lights, run the appliances and charge an electric car for getting around.

The UT Austin team used a “kit-of-parts” open framing system along with a mobile utility unit to construct the house. The house was powered by a 3.6 kW photovoltaic system and two evacuated tube solar hot water arrays. The house was conditioned using a ductless hydronic HVAC system with an ice battery. Along with the solar systems the house demonstrated state of the art ideas in green building materials, lighting and appliances.

2005

In the 2005 solar decathlon competition, the UT Austin team wanted to create a more air tight, and less labor-intensive system to construct the house. They planned a design that would “snap” together in four easy to transport chunks. The main living room/kitchen/dining room space of the house was a very open space with a bathroom and bedroom located along the north side of the house. The mechanical systems were located on the west side to support the kitchen snap and office and communication systems were located on the east side to support the living room snap. A 7.8 kW Photovoltaic system and a evacuated tube solar water-heating wall powered the house.
There were three key elements for the HVAC system. One is the Energy Recovery Ventilator that preheats and precools outside air in the airtight house design. The second is a ductless mini-split inverter heat pump and the third is a “smart” energy management system that controls all the systems of the house.

2007

In the 2007 solar decathlon competition, to reduce on site labor even more the UT Austin team designed a streamlined solar-powered trailer. They used moment frames to produce an open plan to allow for more space, daylighting, cross ventilation and to allow one end of the house to open out onto a deck. The skin of the 7.9 kW photovoltaic-powered house is clad in translucent polycarbonate panels to induce ventilation between the inner and outer layers of the skin of the building. The interior walls, floor and ceiling of the building were made using structural insulated metal panels.

New in the MEP design of the building was a radiant warm floor system, supplied by three hot water tanks. A solar heated Dutch hot tub was also integrated into the design as a dump for waste heat.

All the houses have been relocated after the competition and are currently in use. The 2007 solar decathlon house has been relocated to McDonald Observatory near Ft. Davis, Texas where it is being used for staff housing on a site near the telescopes on Mt. Locke.

Future Directions

In concluding his lecture, Professor Garrison introduced us to some of the projects that he and his team are currently working on. These included some grant work on disaster relief housing studies funded by the U.S. Department of Energy and the Florida Solar Energy Center. These designs are modeled after their work on the solar decathlon houses so that a house would be mobile and could be shipped to the Texas gulf coast during the aftermath of a hurricane to provide housing.

The team is also working with on a grant from Community Renewal International (CRI) on their new 15-story Zero Net Energy Headquarters building. CRI builds what are called friendship houses in low-income neighborhood areas that are used for adult education, healthcare, etc. The team will be working with CRI on the green building aspects of both the Headquarters building and new green prototypes for their friendship houses.
Notes


Images

Figures 1-10: from Michael Garrison, School of Architecture, The University of Texas at Austin

References


Biography

Professor Michael Garrison is a registered architect active in the design and construction of sustainable buildings. He has served as the faculty sponsor of the 2002 and 2005 Solar Decathlon competitions administered by the U.S. Department of Energy and is co-investigator for the 2007 team. Garrison’s research has received numerous grants and awards from the U.S. Environmental Protection Agency, National Renewable Energy Lab, U.S. Department of Energy, U.S. Department of Housing and Urban Development, U.S. Department of Interior, National Park Foundation, Texas Energy Advisory Council, Texas Energy and Natural Resources Advisory Council, Texas Department of Housing and Community Affairs, and Austin Energy’s Green Building Program.

Professor Garrison is the author of a number of publications including *Passive Solar Homes for Texas* (1982) and *Building Envelopes*, with Randall Stout (NCARB 2004). He is past chair of the Resource Management Commission for the City of Austin, a founding member of the Texas Solar Energy Society, and since 2004 a co-Director of the UT Center for Sustainable Development. Garrison’s current research includes principal investigator for the Building Industrialized Housing Program from DOE for 2006-08 with the Florida Energy Center.
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