A REVIEW ON THERMAL SOLAR COOLING METHODS TO REDUCE ENERGY CONSUMPTION

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Abstract: Solar thermal cooling is one of the most promised technologies to get cooling from sun. It is a very efficient way of reducing energy consumption and it has reduced green house emissions to a great extent. These systems result in big savings as it reduces the electricity consumption during the peak hours which usually occur during hot sunny days of the summer season. This paper presents a review of the solar cooling technologies that have been developed and implemented for use in residential and commercial applications.

INTRODUCTION:

In the last two decades, the demand for residential cooling has increased exponentially, creatinga significant demand on the electrical grid during the summer months. The implementation of solarcooling systems could assist in reducing this energy consumption, and consequently, reduce greenhouse gas emissions released into the atmosphere as a result of the generation of the requiredelectricity to power typical air conditioners.

Air conditioning has increased significantly and is regarded as an indispensable household appliance in modern life. Many newly constructed buildings are oriented solely towards air conditioning and neglects sustainable design. This will have a large impact on the domestic energy consumption in the near future. The main design guide lines for hot and humid climates are the reduction of heat gains through the buildings envelope and the generation of the air movement.

Air conditioning is commonly used to achieve thermal comfort in commercial buildings in the hot and humid region. Air conditioning accounts 60% of energy consumption in commercial buildings and 70% of energy consumption in households. Excessive heat is the major problem that causes human thermal discomfort. Cooling is then the basic requirements of building occupants. The presence of trees vegetation and water around the building in modifying the thermal micro climate was appreciated.

Applying passive cooling means reducing difference between outdoor and indoor temperature.Improving indoor air quality and making the building better and comfortable environment for living and working.

The tropical region is an uncomfortable climate zone that receives a large amount of solar radiation,high temperature,high level of relative humidity and long period of sunny days throughout the year.

The demand of electrical energy in a developing country depends on the economic development.The generation of electricity depends on the natural resources of the country. During hot climate or in the summer when the outside temperature is high effective passive cooling system will be an option.Building heating ventilation and air conditioning are responsible for about half of energy consumed in buildings.

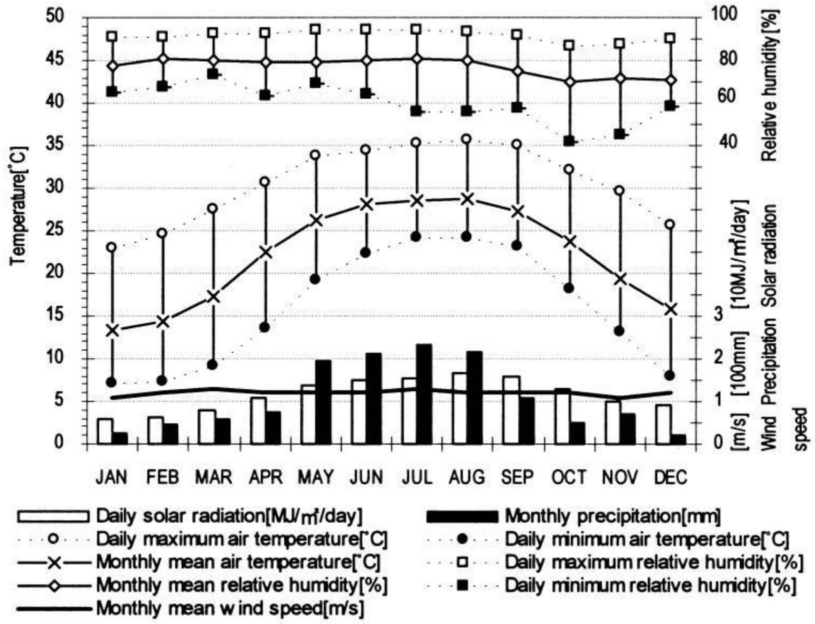
This paper reviews some techniques which can give thermal comfort in buildings and can reduce energy consumption and different types of cooling techniques are discussed

SOLAR COOLING

The term ‘solar cooling’ refers to devices and processes that use solar energy for cooling. Solar cooling systems have the advantage of using predominantly non-toxic and environmentally sound working fluids such as water or salt solution, and can be used as stand-alone systems. Solar cooling systems are in many cases able to simultaneously generate refrigeration and save conventional energy. Cooling can be provided by both active and passive systems. The capacity of solar cooling devices is generally at its peak when insolation, i.e. solar irradiation, is highest. Accordingly, solar cooling devices can ideally meet the needs of countries in sunny regions where the demand for cooling is generally high around noon.

The development of a radiant barrier system to reduce heat gainsinto the building. A layer of aluminum foil materialinstalled into the air space of a building envelope acts as a radiation barrier which blocks radiant increase the ability of natural ventilation to cool the structure, the design included a wing wall. Present study incorporated double walls so as to provide natural ventilation cooling in the exterior walls.The solar system is able to collect solar heat for space heating in winter, and cool the building in summer. The first design strategy under consideration is the prevention of heat entering the building where possible.

A triple roof design is used. Forced and passive ventilation to exhaust heat from the roof is employed. Double walls passively allow heat to vent, and exterior surfaces are finished with unglazed hollow bricks, which enables natural ventilation and evaporative cooling for the external walls. As a result, heat transfer through the walls into the building is greatly reduced. Because the local area lacks strong winds in summer, a method to enhance heat-removing ventilation was proposed. An exhaust stack was incorporated into the design. Hot air from the roof flows through the stack during a summer day, which causes the upper part of the stack to get hot, thus creating a chimney effect.



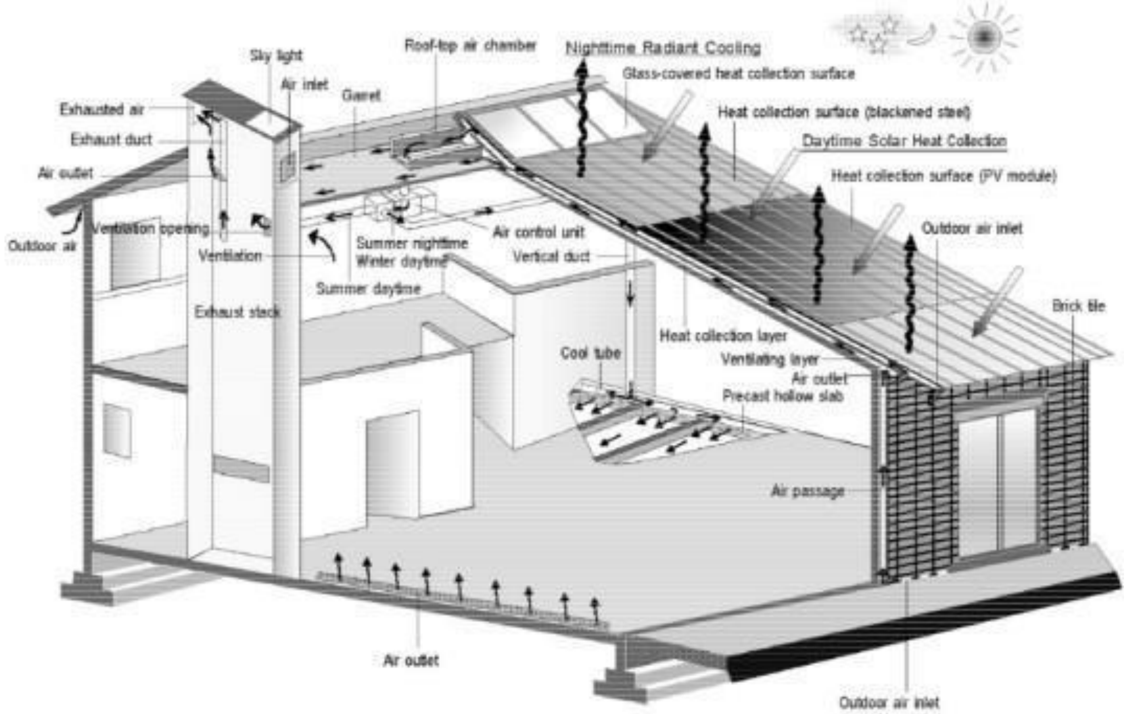
The air movement in the stack draws indoor air from the building. In addition, in order to increase the area of moisture-absorbing surfaces, the interior walls are finished with lime plaster and the floor is covered with unglazed brick tiles. The heated air in the roof is utilized for floor and space heating in winter, as well as for the hot water supply in seasons that do not require heating.

OPERATING MODES OF THE SOLAR SYSTEM:

The solar system has two seasonal modes that are adjusted manually for each season. Day and night operations differ and are changed automatically for each seasonal mode. The system specifications are given in Table 1 and details of the system operation are described below.

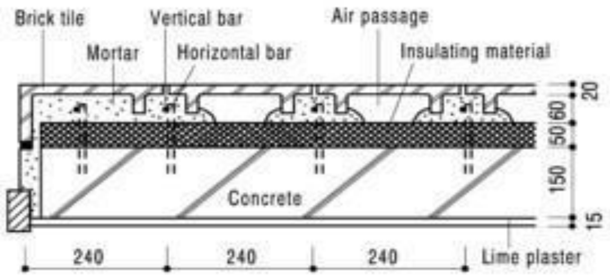
HEAT COLLECTION IN WINTER DAY TIME:

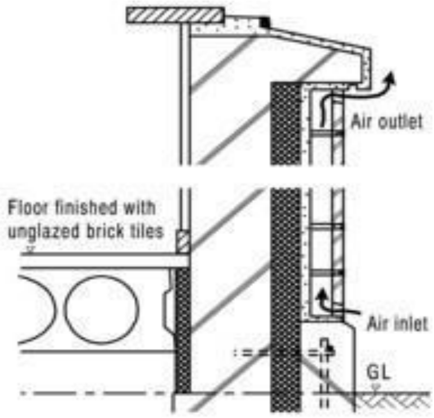
The surface of the south-facing roof is used for solar heat collection and is finished with blac-kened stainless steel. The upper part of the roof collector is made of glass under which there is a layer of air. As illustrated in Fig. 5, ambient air from inlets in eave edges is drawn by a fan installed in the air-handling box (air router) into the roof air chamber through the space under the blackened steel.



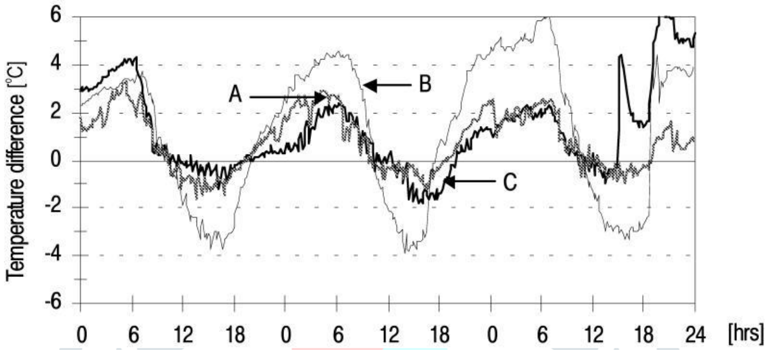
HEAT EXHAUSTIN IN SUMMER DAYTIME:

In summer daytime, the hot air that is gathered in the roof air chamber is exhausted through the exhaust duct that is connected with the exhaust stack.





COOLING IN SUMMER NIGHT TIME:



At night, outdoor air is allowed in and condensation may occur when the temperature of the metal roof becomes lower than the dew point temperature of the ambient air due to radiant cooling.

INSULATION OF THE WALL:

The surface temperature distribution of the eastern wall measured at 8:11 a.m. on a sunny summer day is shown . The graph on the left of the figure shows the exterior surface temperature of an air passage. It is noted that the higher the surface temperature, the further the heat gradient climbs up the surface of the wall.

DEHUMIDIFICATON:

A dehumidifier is generally an electrical appliance which reduces and maintains the level of humidity in the air, usually for health or comfort reasons, or to eliminate musty odour and to prevent the growth of mildew. It can be used for household, commercial, and industrial applications. Large dehumidifiers are also used in commercial buildings such as indoor ice rinks, swimming pools, as well as manufacturing plants or storage warehouses to control the humidity level.

The dehumidification effect of the house can beinvestigated by comparing indoor humidity with that outdoors. Indoor relative humidity varies only indoor a little over a day as is seen. the suggests that the house has the same tics as a wooden house. The reason for this is that the interior surfaces are finished with lime plaster.On the other hand, and brick tiles that absorb each indoor humidity is high, and when humidity is low. Even so, there should be a decrease in indoor humidity from evening to early morning.

LOW ENERGY COOLING TECHNOLOGIES:

Low energy cooling technologies provide cooling in an energy efficient manner, thus reducing energy consumption and peak electricity demand. They do so by making use of low quality sources of cooling; whether it is ambient air or ground temperatures or warmer chilled water. Those technologies may be considered passive and hybrid cooling systems. (The term passive cooling should not be confused with passive cooling building design which is focused on reducing the cooling load).These are divided intotwo groups: those including the main source of cooling and those that focus solely on delivery of cooling to the treated space (IEA 1995, Liddament 2000).The first group of systems rely on natural sources of cooling, but fans or pumps are required for most of them.

NIGHT VENTILATION EVAPORATIVE COOLING: Ground cooling

The second group of technologies focus on delivering the cooling to the treated space in an efficient manner, those technologies usually work well with lower grade sources of cooling.

RESEARCH METHODS:

For passive and low energy cooling technologies, the dynamic behavior and interactions of building, systems, occupants and environment is very important.

HISTORICAL BUILDINGS:

These buildings are usually not air-conditioned, nor mechanically ventilated. Most heavy historical buildings can be operated without air-conditioning. High thermal mass helps to maintain thermal comfort as long as passive cooling rules (low internal gains, shading) are obeyed during retrofit. The thermal mass of the building can guarantee comfort requirements. A cooling capacity of about 20 kW would be sufficient to remove both the external heat load and the internal heat gains from occupants and lights.

1950-1980 OFFICE BUILDINGS:

A very high percentage of current Czech stock of office buildings falls into this category. Retrofit of this type is an actual problem.Proper natural night or daytime ventilation can guarantee thermal comfort during almost the whole summer. If slab cooling would be applied, thermal comfort can be achieved during the whole summer.

RESIDENTIAL BUILDINGS:

In the Czech Republic almost all residential buildings are operated without air-conditioning or cooling. The reasons are the relatively small window area (usually not more than 30% of facade), the high effective thermal mass (no suspended ceilings)and the relatively low internal gains. However for some houses, especially modern ones with a lot glazing, shading or advanced glazing is highly recommended.

RADIANT COOLING:

Radiant cooling is an alternative option since it has energy and peak power saving potentials. When radiant cooling is used with displacement ventilation, where ventilation air is introduced at low level and flows by natural means to replace ventilation air, such system has been suggested to offer quiet comfort and energy efficiency superior to those of conven-tional air-conditioning systems. To employ radiant cooling in hot and humid climate, it is considered a challenge. To avoid condensation of moisture from air on the panel, the temperature of cooling water must not be lower than dew-point temperature of air. To achieve thermal comfort, the temperature of air in the space should not reach 30 1C.

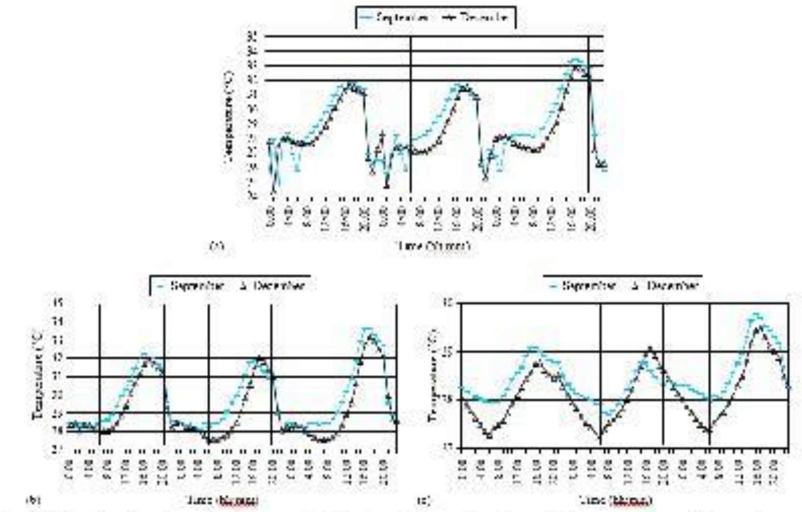


Fig. 1. Profiles of hourly air temperatures in the room with application of radiant cooling system and with conventional air-conditioning system. (a) Conventional air conditioning; (b) radiant panel; (c) Active wall

THERMAL COMFORT:

On the issue of thermal comfort, active wall seems to perform best, but all systems perform reasonably well. The capability to store heat or coolness of the active wall reduces the tendency of temperature swings.

ENERGY SAVINGS:

On the issue of energy saving, Table 6 shows that the cumulative thermal load for the case of application of active wall is 38.4% less than the case of conventional air-conditioning.

SOLAR CHIMNEY:

The utilizations of solar chimney as a natural ventilation of buildings are widely investigated in the last few years. An appropriate design of a solar chimney for cooling includes providing an air gap in a south facade or in the roof of the building that causes stack effect exists between the solar chimney and the inlet of the building. The stack effect operates between the high temperature and high pressure developed in the solar chimney and the low pressure and low temperature at the inlet. If the openings are provided at the inlet of the building and at the outlet other solar chimney, air will enter into the building due to the difference of air densities and pressure gradient and move through the building before exit from the outlet of the solar chimney.

Another passive cooling technique is a pond roof or water spraying on roof. A well-known pond roof, called Sky herm system, was patented by Hay in 1969 [9].

The Sky herm system is a concrete or steel roof covered with water filled plastic bags equipped with movable insulation. During the night times, the insulation is removed and the water in plastic bags radiates stored heat during the daytime to the sky and the obtained cooled water is using to absorb heat during the next daytime. The combination of both the solar chimney and the roof pond or wetted roof is the utilization of the advantages of natural ventilation together with the temperature reduction inside the building.

SOIL TEMPERATURE MEASUREMENT:

The first soil temperature investigation was carried out during the wet season when the weather is cooler. Sets of data were collected from October to November 2007 and it comprises of outdoor dry bulb temperature, ground surface temperature, and underground soil temperature at 1 m, 2 m, 3 m, 4 m and 5 m depth.

Another set of soil temperature data was collected alongside the earth pipe cooling experiment. This was carried out from April to May 2009, which is during the hot and dry season. The data measured comprises of outdoor dry bulb temperature and underground soil temperature at depths of 0.3 m, 0.5 m, 0.8 m and 1.0 m. After two months of data analysis, the soil temperature data collection was resumed, recording from August to December 2009. Only this time, the data measured comprises of outdoor dry bulb temperature and soil temperature at 0.5 m, 1.0 m and 1.5 m underground.

EARTH PIPE COOLING EXPERIMENT:

Three 3” polyethylene pipes were buried separately, at 0.5m,1.0 m and 1.5 m deep underground. All the pipes are 30m long.There is a fan blower connected to all pipe inlets, which provides air flow into the buried pipes at 5.6 m/s. The fan was switched on dailyfrom 10 am until 6 pm to allow night ventilation. The pipe inlets and outlets are sheltered by an experimental shed (Fig. 3), which has 2 m 2 m dimensions. Data of each buried pipes were recorded for 48 h at 10 min interval. The tests were carried out in sequence rather than in parallel to avoid thermal interference between the pipes.

The experimental site during construction of experimental shed that houses the outlets of the buried pipes.

PASSIVE COOLING DESIGN STRATEGIES:

LOUVERED SHADING DEVICES: A louvered shading device was positioned in the south east façade of the building in order to block sun gain in summer and to also allow wind to pass through it and cool the area. The shading is designed in such a way that it blocks the sun in summer yet allows it to enter in the winter. The louvers were horizontally placed and rotated to 45 (tilt angle) degrees. When sun is high, the louvers will ignore the heat and still allow the light needed for the area. Louvered shading devices were therefore applied to the south east elevation.

DOUBLE GLAZING: Recent studies indicate that in order to reduce energy and achieve thermal comfort in a building, there are parameters that should be considered such as humidity, noise, lighting and temperature (Noh-Pat et al., 2001). In buildings most of the heat gain or losses comes from openings such as windows. It is clear, therefore, that windows are the main element in the transfer of huge amounts of heat between abuilding and the exterior environment. The insulation of a window is determined by the space between two glass panels. The cavity created between the two panes of glasses can either be filled by gas or vacuumed. In this design, the glass is filled with argon in order to reduce the transmission of heat. All the glass uses solar control film to decrease energy by 55% compared to DGV without any solar control. The SHGC (solar heat gain coefficient) is about 17%, which can be interpreted as a good value and is also considered to be a low CO2 committer. To this end, the single glazing in the case study villa was replaced by double glazing with a 16 mm cavity containing Argon instead of air.

NATURAL VENTILATION: wind catcher and cross ventilation

Hughes explains that wind catchers are old designs which were used in the past to introduce cool air into a building (Hughes et al., 2012). Natural ventilation is an efficient way to reduce energy consumption as well as providing a healthy indoor environment. Wind towers provide a low carbon ventilation system which can deliver fresh air to the occupants without using any kind of mechanical system. It can further be assumedventilation is providing natural, freshair from outside to inside the building while pulling the exhaust air outside.

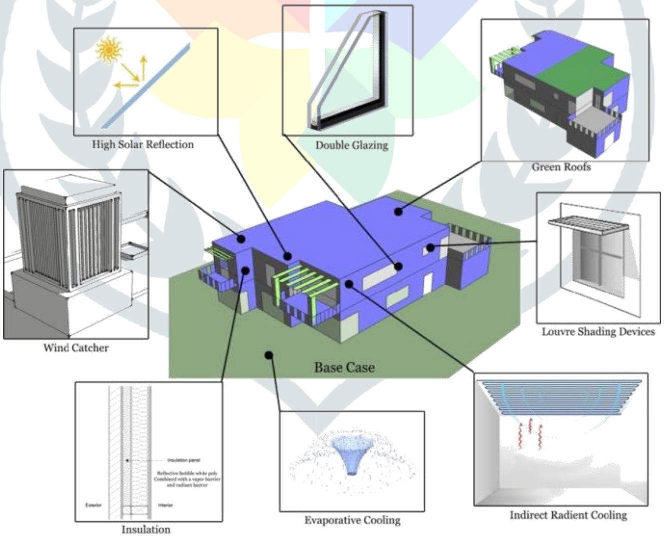
The levels of pollution or dust which come from mechanical systems will also be reduced. In the case study, cross ventilation was encouraged by opening the terraces and windows.

GREEN ROOFING:A review of the literature indicates that a green roof can be defined as a ‘building roof covered by grasses or plants which lie over a waterproof membrane’.

INSULATION:

Passive design must include insulation to reduce heat loss or gain throughout the building envelope. Insulation acts as a barrier to heat flow, reducing heat loss in winter to keep the house warm and reducing heat gain in summer to keep the house cool.

Inadequate insulation and air leakage are the main causes of heat loss in buildings. Insulation is therefore used in walls, ceiling and floors. For this case study, reflective bubble white poly insulation was used with an R-value of 15.67 m2 K/W combined with a class 1 vapour barrier and radiant barrier.



EVAPORATIVE COOLING FOUNTAIN:

A fountain can cool the air when it combines with water and evaporates leading to a reduction in air temperature.

Schematic of the adopted passive cooling design strategies.

INDIRECT RADIANT COOLING:

In a further attempt to cool the temperature of the roof, the radiant cooling method was utilised. Radiant cooling takes place through the net emission of electromagnetic waves from warm objects to cool ones. The process then continues until both objects reach the same temperature. The setup proposed for this case study is known as nocturnal cooling, which is only applicable to the second storey of the villa due to its proximity to the roof area. It involves radiant cooling of a specialised radiator that is made of a metallic plate with an air space above it (as shown in Figure 7). The air cooled by the long-wave radiation under the metallic radiator is used to cool the indoor space of the second storey (Watson and Chapman, 2002).Light colour coatings with high reflection According to Shen et al. (2001), exterior walls exposed to solar radiation can transfer a huge amount of heat to abuilding; this therefore affects the temperature of interior spaces and can also decrease the comfort level temperature.

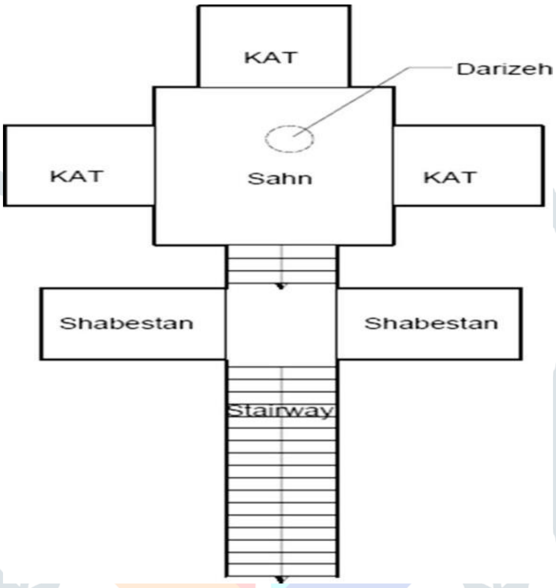
UNDERGROUND LIVING CONDITIONS:

The heritage of underground dwellings can be seen almost in each part of the world.Earth-sheltered buildings offer also other benefits, such as:

- Lower building maintenance costs (smaller surface area of exposed building envelopes),
- Better noise and vibration damping (earth dampens well the amplitude of acoustic waves),
- By definition they are less exposed to weather conditions, and often are architectonically very interesting whereby they can become a city's pride or landmark, which is an important consideration for potential investors (Staniec and Nowak, 2011).

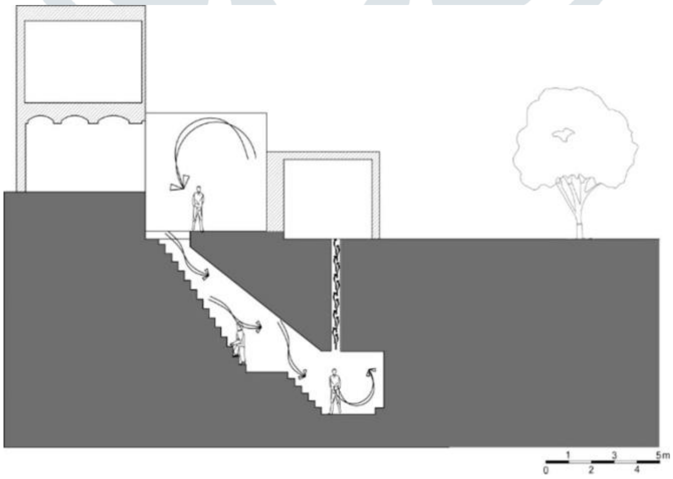
SHAVADOON:

Earth temperature in summer and winter is lower and higher than outside temperature respectively, except along the coast of the Caspian Sea and Persian Gulf and Gulf of Oman.



Most of Old Iranian houses have basements, and typically household members went to thebasement in summer (Ghobadian). Shavadoon is an underground space dug under the buildings in the old regions of cities of Dezful and Shooshtar. Its depth is from 5 to 12 m which can be reached by many different stair cases (Safaee, 2009). Sha-vadoon has been used for heating and cooling purposes when the ambient temperature is 7 C in January and 47 C in July, Shavadoon average temperature is 17 C and 23 C, respectively. The suitable Shavadoon temperature range proves the ability of this space in for saving energy. Shavadoon is one of the most innovative types.

SHAVADOON COMPONENTS:



Shavadoon's entrance corridor is continued from the entrance stairway to the Shavadoon's floor and it has more slope than today's stairways. The main part of the Shavadoon has a square plan. In large Shavadoons the difference level of floor with other parts provides an interesting character to the space. Except for the wall which is connected to the stairway, the other three walls are linked to small rooms named Kat which are separated with a maximum of one stair from the floor. In some cases, these Kats are connected to the neighboring Shavadoons by a tunnel or gate which is called a Tal (Bina, 2008).Horizontal narrow tunnels connect neighboring Shavadoons to one another. These tunnels besides having connection between Shavadoons cause the current of air.

CONCLUSIONS

This review paper has focused on the use of solar thermal cooling systems in both domestic and commercial buildings providing an alternative method to reduce the overall energy demand and increasing the carbon savings.

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