A new Thermal wall

Zahra Ghiabaklou

***Abstract*—** This paper presents an effective way of achieving building energy conservation that is through solar thermal space conditioning which uses passive solar design. The proper implementation of passive solar building design has been found to make a significant improvement in energy conservation due to the decreased demand of conventional space heating and cooling. This idea is based on a set-up using misting nozzles to generate a high rate of evaporation and to minimize moisture carry-over. The evaporative cool and heat wall system is a low cost and very simple means to provide comfort in buildings in hot–dry regions of the world which constitute about 60% of the earth's land area. The objective of this study is to develop a viable technique for natural ventilation and passive evaporative cooling and heating strategy for summer and winter; it is supposed to provide comfort conditions to the occupants of the buildings in arid regions.

***Keywords*—**Thermal Wall, Evaporative Wall, Passive Heating and Cooling, Comfort in Arid Climates.

I. Introduction

COMMERCIAL and residential buildings presently have high primary energy consumption. Approximately half of this amount is specifically used for space heating and cooling, which is mostly provided by electricity or natural gas. Obviously, the reduction of fossil fuel consumption and greenhouse gas emission can effectively be achieved through improving of energy conservation and increased use of renewable energies for space heating and cooling.

The use of solar gains is one possibility to increase energy efficiency in buildings. It consists of collecting solar radiation, preferably storing the heat produced and distributing it where and when it is needed.

Many components of a building envelope such as transmission of solar gains and light through windows, heat storage by masonry, insulation, ventilation, solar protection, etc. can have a thermal function. Employing these components appropriately allows cost reduction during the construction; aesthetic concerns also require a suitable integration of the components.

II. Effects of Dry Air on the Body

The tissue in our body are mostly composed of water, and in dry climates when the humidity level is low, moisture is extracted from our tissues and released into the environment.

Studies have shown that dry air has four main effects on the human body:

1. Breathing dry air is a potential health hazard which can cause respiratory ailments such as asthma, bronchitis, sinusitis, nosebleeds, and general dehydration since body fluids are depleted during respiration.
2. Skin moisture evaporation can cause skin irritations and eye itching.
3. Irritation effects such as static electricity build-up which causes mild shocks upon touching conductive media like metals are common when the air moisture is low.
4. The "apparent temperature" of the air is lower than what a thermometer indicates, and thus the body "feels" colder.

These problems can be mainly solved by simply increasing the indoor relative humidity. This can be done through the use of passive humidifiers, such as the proposed system in this work.

For humans, relative humidity below 25% feels uncomfortably dry. On the other hand, relative humidity above 75% feels uncomfortably wet. Human comfort requires the relative humidity to be in the range of 40-65% RH.

There are health related issues when the humidity is below 40%. The tissue in our body is composed mostly of water. In fact, when the humidity level is low, moisture is extracted from our tissues and released into the environment. This is a normal process of evaporation; however if the body loses too much water, the tissues dry up. Hence the skin elasticity decreases and therefore its function declines. Besides dry skin, the symptoms of dehydration include chronic joint and muscle pain, raspy throat, sore eyes, and lack of mental concentration. Low humidity levels can also cause or aggravate respiratory ailments.

The effects of low humidity can be especially dramatic in winter, when low moisture content induces stress upon the nasal-pharynx and trachea [1].

Regarding these problems, a passive evaporative cooling system is presented by the author for such arid regions [2-3]. The system is based on the evaporation of an exposed water film with the help of natural ventilation. Water is allowed to fall vertically over some elements such as nylon lines or other filaments to expose the maximum surface area of the water to the passing air flow.

A temperature-humidity index has been developed by the U.S. National Weather Service which gives a single numerical value in the general range of 70 to 80. This index reflects the outdoor atmospheric conditions of temperature and humidity as a measure of comfort (or discomfort) during warm weather. The temperature-humidity index, ITH, is defined as:

$$\text{ITH}=0.4\,(\text{dry-bulb temperature F} + \text{wet-bulb temperature F}) + 15 \tag{1}$$

When the index is 70, most people feel comfortable; at 75, about half the population is uncomfortable; at 80, most are uncomfortable [4].

Zahra Ghiabaklou, School of Architecture, Faculty of Fine Arts University of Tehran, Tehran, Iran, e-mail:ghiabaklou@ut.ac.ir

III. Proposed System Description

It is well known that a Trombe wall is a special type of masonry wall used for thermal storage in passive solar building design. A typical Trombe wall consists of a 20- to 40-centimeter-thick masonry wall coated with a dark, heat-absorbing material and faced with a single or double layer of glass. The glass is placed from 2 to 15 centimeters away from the masonry wall to create a small airspace. Heat from the sunlight passing through the glass is absorbed by the dark surface, stored in the wall, and conducted slowly inward through the masonry. An important disadvantage of the Trombe wall is that it covers a great part of the south facing elevation and thus prevents the provision of windows on this side.

Various possibilities exist concerning integration in space heating and cooling systems. The proposed system is composed of a brick wall that is bounded between the two layers of glazed surfaces. Thus it absorbs the sunrays and conducts the heat slowly through the wall to the inside of the building. Burned-clay bricks are the material with the best properties for the construction of the proposed wall. The basic principles of this system are simple, and yet effective.

The sun will warm some surfaces in the low-thermal-mass sunspace of this "thermal wall". It is essential that openings inside and outside allow sufficient ventilation in order to use summer natural ventilation. This system can also be integrated in the wall between the sunspace and the building as a mass wall to allow day light to go through; it can operate with and without water evaporation system too.

The oblique masonry elements offer a good view and provide interesting day lighting conditions as they diffuse light, avoid glare effects, and distribute light to the ceiling.

An initial calculation shows that total solar radiation absorbed by the oblique surfaces contacting solar beam in this system is not less than an ordinary vertical Trombe wall because of smaller incident angle on these surfaces.

This system consists of a rail parallel bar-like mass wall encapsulated between double glazings as illustrated in Fig. 1. The principles of the operation of the system are illustrated in the diagrams below for winter and summer conditions.

In winter, the external transparent cover lets the solar radiation in, but holds back the heat in winter. The horizontal oblique parallel brick bars painted black at their outer surfaces to act as absorbers will provide a good view. The water is pumped to an upper level trough by a small pump from the reservoir at the bottom of the system and then is allowed to flow down over the bricks and back to the reservoir. The sun energy heats water droplets running on the bricks to the point of evaporation. As the water evaporates, heated water vapor rises and circulates toward the room via openings on the internal glazing. Since the water evaporated into the air is removed from the system, make-up water should be supplied to the reservoir.

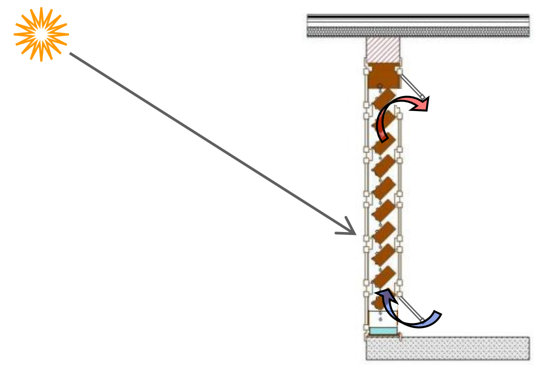

Fig. 1 Winter daytime strategy

The inner glazing saves heat and moisture during daytime. Stored heat from the day is released with a time delay to the room by opening the interior glazing during nighttime as shown in Fig. 2.

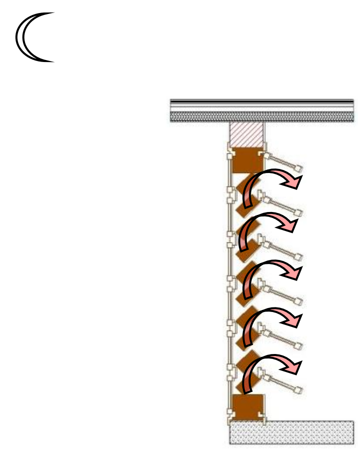

Fig. 2 Winter nighttime strategy

In summer, as shown in Fig. 3, the air is cooled by means of water misting nozzles and delivered to the building spaces. The ambient air is let into the wall from a perimeter high level external opening. The hot and dry air comes in contact with the wet brick surface and is evaporatively cooled; its density increases and causes downdraught. If the contact between the water and air is sufficient to bring the water and exit air into equilibrium, the air leaving the system will become saturated at a temperature close to the wet bulb temperature of the exiting air. The air is delivered into the room through low level openings as illustrated in Fig. 3.

Another alternative for summer cooling can be provided by fully opening outer and inner glazing to obtain cross ventilation as shown in Fig. 4.

Fig. 3 Downdraught evaporative cooling for summer

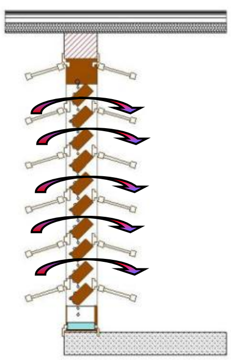

Fig. 4 Cross ventilation in summer

The basic principle of the wall structure is illustrated in Fig. 5. The wall can be simply by locating bricks on the angled beams which are horizontally arranged between two vertical columns.

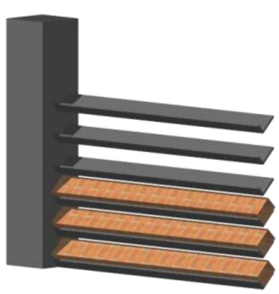

Fig. 5 Wall structure

A water store at the bottom of the wall can be integrated in the pump assisted water loop and also offers more flexibility in the design because water can easily be transported to a desired place in a controlled manner. However, this technology requires more expertise and skill than the construction of conventional thermal walls.

If designed and installed properly, this can increase the collection efficiency of the system. The interior must properly be designed to allow free circulation of the heated air throughout the space and thereby minimizing temperature variations within the structure.

IV. Modeling

In order to examine the internal environmental conditions with the proposed wall system, the environmental conditions of the building were modeled using TAS dynamic thermal building simulation software [5]. TAS has been used to simulate the dynamic thermal performance of new or existing buildings and their systems. The main module is Tas Building Designer, which performs dynamic building simulation with integrated natural and forced airflow it is a complete solution to the thermal simulation of buildings, allowing designing and comparing alternative heating/cooling strategies and facade designs in terms of comfort, equipment sizing, and energy demand.

The latent heat gains of the proposed system based on the hourly recorded climatic data are computed by Microsoft EXCEL program.

Latent heat from the evaporation of water surfaces according to the Engineering Toolbox [6] can be calculated as:

$$q_m = A\,(x_1 - x_2)\,a_e \tag{2}$$

Where,
q_m = evaporated water (kg/s)
A = surface area (m^2)
x_1 = water content in saturated air at water surface temperature (kg/kg)
x_2 = water content in the air (kg/kg)
a_e = evaporation constant (kg/m^2s)
The evaporation constant can be estimated by:

$$a_e = (25 + 19v)/3600 \tag{3}$$

Where,
v = air speed close to the water surface (m/s)
The temperature on the water surface will be lower than the temperature below the surface; it can be calculated by:

$$t_1 = t_2 - (t_2 - t_3) / 8 \tag{4}$$

Where,
t_1 = temperature on water surface (^oC)
t_2 = temperature below the surface (^oC)
t_3 = wet bulb temperature in the air (^oC)
The heat of evaporation can be calculated as follows:

$$H_e = q_m / (x_1 - x_2)\,(h_1 - h_2) \tag{5}$$

Where,
h_1 = enthalpy in saturated air (J/kg)
h_2 = enthalpy in air (J/kg)

With hot and dry summers, locations similar to Tehran have an ideal climate for the application of evaporative cooling. During the hot season (May to September) peak dry bulb air temperatures can reach 35^{o}C while the wet bulb temperature is as low as 19^{o}C. The dry/wet bulb temperature depression is generally greater than 15^{o}C. The greater the depression, the greater is the potential for evaporative cooling.

V. Description of the Base Case for Simulation

For simplicity a rectangular shaped room with dimensions of 6m ×4m ×2.7m is assumed. The building is a cavity wall construction with a concrete floor and conventional plaster ceiling. The new wall is located behind the south double glazed window with a surface of 7m^2 and an overhang on the south facade with 1m depth. For the northerly double glazed window an area of 20% of southern window has been selected. It should be noted that the total area of the glazing is not necessarily open, but the opening can be altered to control the amount of airflow through the building.

VI. Simulation in Winter

Fig. 6 compares the room air temperature with three different passive heating strategies: A Trombe wall, direct gain, and the new wall system.

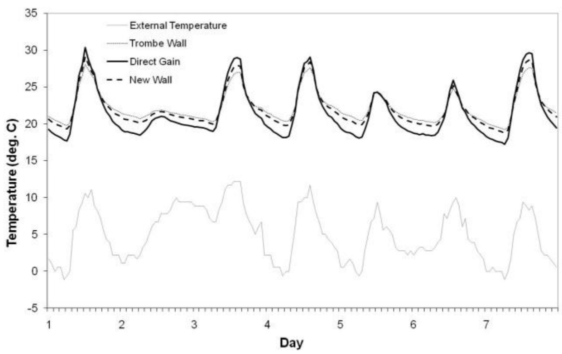

Fig. 6 The effect of various passive systems on the indoor air temperature in winter

Direct gain system resulted in the highest room air temperatures in the daytime, but the lowest at nighttime, because of smaller thermal mass and heat loss through the windows. The other types (Trombe wall and the new wall) resulted in almost the same temperatures in the daytime and at nighttime. Compared to the new wall, the Trombe wall system has a slightly lower temperature in the daytime and higher at the night because of the higher thermal mass.

Without an evaporation system, because of higher inside temperature which is caused by heating systems including passive solar systems, the inside relative humidity becomes lower than the outside (in the cases of Trombe wall and direct gain). According to Fig. 7, it can be seen that the variation of indoor relative humidity in the room with the new wall is more susceptible to the solar radiation than to the ambient temperature and relative humidity.

Evaporation from the wet surface area of the new wall during the daytime due to the solar radiation causes a higher relative humidity of the room. The average relative humidity becomes 38.6% which is more comfortable than the case of Trombe wall with 17.7% and 18.9% for the direct gain.

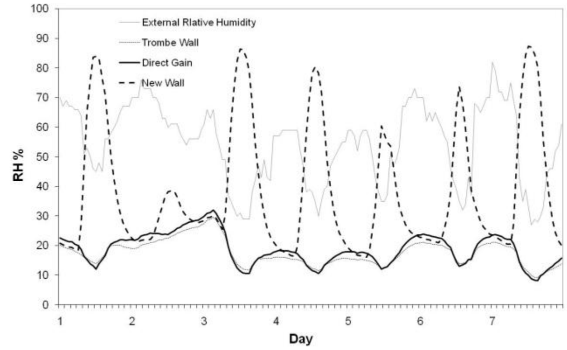

Fig. 7 The effect of various passive systems on the indoor relative humidity in winter

VII. 3.2.2. Simulation in Summer

Fig. 8 compares the room air temperature of sole cross ventilation and new wall with evaporation. The room of new wall has lower air temperature than the room of direct gain with only cross ventilation. The cooling load of the simulation period (a hot week from day 223 to 229) with the target temperature of 26 °C is the lowest in the new wall system. It is 321.5 kW which is 1130 kW (78%) lower than the load of the room without this system.

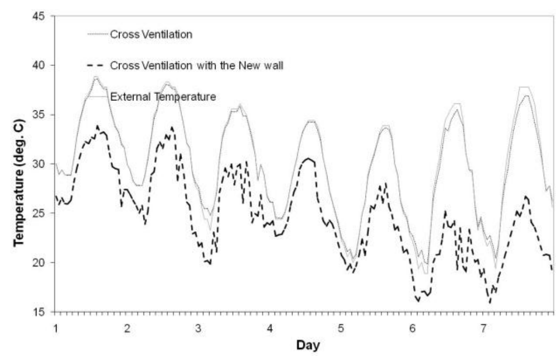

Fig. 8 The effect of new passive system on the indoor air temperature in summer

The larger air flow rate and lower humidity ratio of air cause a higher evaporation from the wall surface. When the evaporation rate becomes large, the room air temperature falls. Fig. 9 shows that the average relative humidity with the new wall is 41.3% which is twice as large as the one without this system over the average temperature.

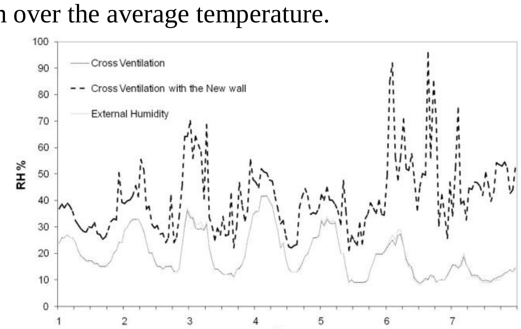

Fig. 9 The effect of new passive system on the indoor relative humidity in summer

VIII. Conclusion

This paper illustrates a proposed strategy for a passive evaporative system for the heating and cooling of buildings in arid areas.

The main conclusions drawn from this paper can be summarized as:

1- Concerning health issues, this system can provide a comfortable environment from humidity and thermal aspects of view. If the body loses too much water, the tissues dry-up and the skin elasticity drops and thereby declining its function. Besides dry skin, other symptoms of dehydration include chronic joint and muscle pain, raspy throat, sore eyes, and lack of mental concentration. Low humidity levels can also cause or aggravate respiratory ailments.

2- An evapcool and heat wall with integrated water evaporation could be designed to provide technically feasible systems suitable for arid climate conditions.

3- This application gives a good productivity, and can be particularly adapted to educational and office buildings as well as dwellings where the ventilation demands are very high.

4- Another advantage of using this method is through the use of day lighting which can reduce the need for electric lighting throughout the year. Reduced lighting also means lower air-conditioning needs during the cooling season, and thereby saving twice.

5- Moreover, this concept has an improved performance and some advantages over a conventional Trombe wall. by using oblique masonry elements offers a good view through the wall.

Since the idea is presented in the proposed stage, may raise questions in many cases that need to be more studies in this regard in the future. Further work is still required to allow the building designer to make full use of this system in designing buildings.

It is supposed that the results of this study will promote the attractiveness and utilization of passive solar design and will make it more compatible with the environment.

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