J. Appl. Environ. Biol. Sci., 3(11)96-102, 2013

ISSN: 2090-4274
Journal of Applied Environmental and Biological Sciences
www.textroad.com

Architectural Design of Passive Energy Systems, with Emphasis on Eaves

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Received: July 22 2013
Accepted: September 12 2013

ABSTRACT

This paper proposes a new method for ventilation and cooling enhancement through parts of envelope lines. Risen hot air is an important potential to increase radiant heating of spaces in summers and chimney effect which is a common method for its removing. However, air-leaking into spaces and exclusion of hot air are minimized in some regions due to unfavorable prevailing winds and high relative humidity. Thus, it is useful to design a passive energy system to ventilate and cool spaces without any inward air leaking. This is an applied research conducted analytically to design a passive energy system with cooling and ventilation functions and radiant cooling of different parts of envelop lines while emphasizing on eaves and sun shades. The system was designed considering climatic potential of northern Arasbaran (Iran) where there are dense vegetation and kinds of prevailing winds. The proposed system provides radiant cooling and ventilation using renewable energy sources, e.g. wind, risen hot air, vegetation, and parts of envelop lines relying on environmental specifications and some simple equipment.

KEYWORDS: passive energy system, radiation, eaves, air and wind flow pattern, vegetation.

1. INTRODUCTION

History of need for heating in winters and cooling in summers comes back to the beginning of human life. Man was looking for ways to provide heating and cooling with low costs as much as possible. Shadow was the earliest solution for cooling safeguarding them against sunshine [1]. Through time, new methods were offered and waste of energy source was their main disadvantage. For example, ceiling was built higher such that hot air rise [2] and leak out through under-roof windows [3], or through the some little openings on roofs in warm climate of Iran like Abyaneh village [4]. Another way is either to use channels to conduct hot air in thermal mass storage and save them [5] or vertical ducts to remove heat through chimney effect [6]. Also the hot air inside of rooms can be suctioned and removed through the Thermal run off channels [7]. The previous methods demonstrate that the common ways waste heat or save it in thermal storages [8]. Risen hot air was a threat and architects had to find some ways to remove it, so possibility of using risen hot air as a renewable energy source is challenge of research leading to following questions:

Can hot air be used as an energy source for passive cool production?

What kind of equipment can be used to convert hot air to cooling potential?

As the research hypothesis, architects may use risen hot air-as a valuable source of energy- for cooling and ventilation with emphasize on dehumidifier without any help of active energy sources. Combining airflow or wind flow patterns with vegetation, risen hot air can be converted to cooling passive energy system. Common passive energy systems, e.g. vegetation, airflow and wind flow patterns, should be initially studied and then, appropriate parts of envelope lines such as eaves required for creating a new passive energy system should be found and analyzed using common energy and physical analyses. The proposed system should use radiation specifications to keep away the air leaking and surplus humidity of regional climate from indoor spaces. As a case study, northern Arasbaran has cold winters and warm and humid summers. The article aims at using the proposed passive energy system to convert indoor air to cold and suitable air for life. Cooling and ventilation are regarded as general functions of the proposed system, but it can be used as a heating system by changing the states of some elements of proposed system that converts it to a horizontal tromb wall with daily use.

Next parts of the paper were organized as follows;

A background of passive cooling was introduced in section 2. It includes explanation of vegetation (section 2.1) and airflow pattern (section 2.2). Section 3 includes methods and materials and water supply process of the system, cooling process of water in glass pond, green channels, and humidity and ventilation application of cooling passive energy system were explained in sections 3.1, 3.2, 3.3, and 3.4, respectively. The last section, i.e. section 4 contains discussion and conclusion.

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2. Background of passive cooling

There are two major solutions of cooling functions:

1) Conducting of cold air to indoors, and 2) producing and maintaining it indoors. The solutions are achieved through:

- Cooling the air in envelope line neighborhood
- Cooling inside of envelope line
- Cooling the air in internal neighborhood of envelope line
- Cooling of indoor air

According to physical laws of nature, air temperature in neighborhood of internal part of envelope line depends on indoor and wall temperature. Inside temperature of envelope line results from the temperature of air in external parts of envelope line neighborhood [9]. Therefore, temperature control in neighborhood of exterior envelope line is very important. Proper position of windows change airflow patterns through air leaking in the spaces. If the air at a 10-cm distance of envelope line is regarded as its neighborhood air, its heating possibility will vary in different ways including direct sunlight as the most important one. Thus, architects should find ways to mitigate its effect. Application of vegetation along with envelope line of buildings is the most initial decision, however, use of vegetation and airflow patterns brings some problems explained in next subsections.

2.1. Vegetation

Plants reduce heat reflections through evaporation of water on their leaves and reflect 20-30% of sunlight. Therefore, they serve as a suitable obstacle between outdoor air and the air along with the exterior envelop line [10]. So they can be converted to a useful insulation in winter, if they are evergreen plants [11]. It is noteworthy that dehumidifier features should be considered in humid climatic regions if vegetation is applied in architectural designs.

2.2. Air flow pattern

Todays, airflow pattern is one of the best known passive energy systems. Generally, some elements such as internal panels are used to conduct air to special parts of places. They may be used as a pattern of interior wall ornament, windows position, and sunshades to make passive or negative pressure in exterior part of envelope lines, or as some equipment, e.g. fans, to flow air in indoors and prevent from more heating [12]. Hence, fans bring extra cost of energy. Fans flow indoor airs so architects should found other ways to improve cooling and ventilation qualities of indoor air.

Northern Arasbaran with cold winters and warm and humid summers is used as a case study to design a new passive energy system. As the first priority, indoors should be kept away from outdoor moisture, to directly examine effective zones, therefore, airflow pattern of indoors and outdoors should be studied individually.

Air is flowing up in closed spaces and it is heating in life height and going up. The research explains the process of converting risen hot air to cold and dry one in Arasbaran.

3. METHODS AND MATERIALS

In this section, procedure of the proposed passive energy cooling system will be discussed in four steps.

Hot air rises up indoors and is saved at upper one third of the building height. As the first step, hot air should be conducted to spaces where cooling process can be operated. To conduct hot air in eaves and overhangs, therefore, it is better to build them hollow. Eaves, sunshades, and overhangs through converting the solid masonry sunshade to a hollow U-shape space and dividing it to upper and lower parts may provide the mentioned conduction process. It can get hot air through the upper part and take it to the lower one once the cooling process is completed (Figure 1).

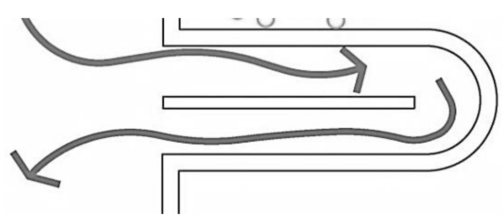

Fig 1.Pattern of getting hot air and taking cool air

In the next step, methods are designed to reduce air temperature at upper part of the hollow space. So, two water ponds are located in exterior part of the U-shape space (Figure 2).

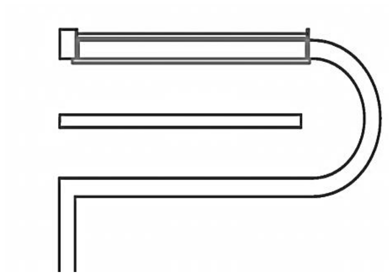

Fig 2. Ponds and their locations in U-shape eaves

The ponds have made of different materials. The upper one has made of double-layered security glass with minimum heat transfer coefficient while the lower one has made of copper with high heat transfer coefficient. To prevent water leaking, the ponds should be connected seamlessly (Figure 3).

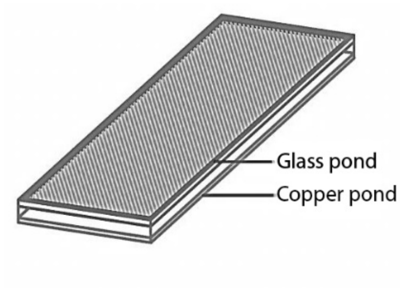

Fig 3. Ponds situation

Rainwater is poured in glass pond and, after enough heat loss, transferred to the copper pond through a gate. Copper quickly absorbs the heat and transfers it to its lower level. In U-shape seat of the copper pond is cooled to the extent that it can radiate the cold to the U-shape space. Risen hot air contacts with bottom of the copper pond at the interior part of U-shape space and loses its heat. Then, it is conducted to lower part of the U-shape space because of new risen hot air and is guided toward the indoors (figure4). Better efficiency will be obtained if a vertical panel guides cold air toward lower levels of the space.

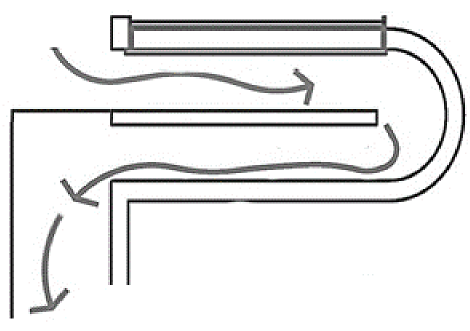

Fig 4. Process of cold air conduction to lower levels of rooms

Some problems should be solved considering application of the proposed passive energy system of U-shape spaces:

A: Water should be supplied to meet the required efficiency and return it to the glass pond

B: Cooling of water of glass pond which is major source of cooling.

3.1. Process of system water supply

Rain is the major source of water saved in a tank. In this system, hot water of copper pond returns to the water tank through transfer pipe and is poured into the glass pond because of backpressure of new water. Initially, all parts of the designed system should be filled with water except to copper pond and pipe transferring hot water to the tank. It is considerable for pipes to have appropriate slope for natural transferring (Figure 5).

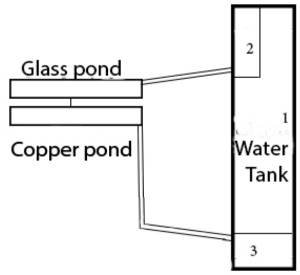

Fig 5.Water supply cycle

According to figure 5, Hot water of copper pond returns to tank No.3 through transfer pipes and new water is transferred to the glass pond from tank No.2. A floater found in No. 1& 3 tanks will manage the amount of water, a thermostat controls entering of water to the copper pond after cooling, and entering of water to transfer pipes after heating.

3.2. Cooling process of water in glass pond

Cooling of water of the glass pond is the most important problem of the designed passive energy system. Arasbaran takes benefit of strong and favorite prevailing winds so water of glass pond is cooled through passing of winds over it.

3.3. Green channels

As mentioned, one of cooling solutions for buildings is to use vegetation in exterior parts of the envelope line neighborhood trapping air there. Thus, air will be trapped through designing of wind vegetated channels known as Green Channels with a suitable distance between buildings and vegetation.

So, a green wall with vegetation should be initially made with a suitable distance from envelop line of the building in order to channelize local winds, air, and wind flow in itself. Wind channelizing is defined as conducting of air or wind flow between green wall and envelope line of building, making channelized air cooler than outdoor air temperature (figure 8). Channelized wind conducts out warm air and the vegetation cools it. According to local experiences, a distance of about 60-70cm from envelop line seems suitable for green channels.

To find temperature difference of its rooms in April, a test was conducted on a residential place with vast vegetation neighboring to south yard and North Street (figure 6).

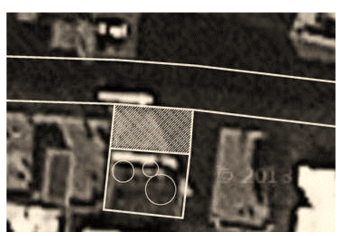

Fig 6. Position of the understudy building

Table 1. Temperature difference considering time and situation

Temperature in different time	7:00	9:00	11:00	13:00	15:00	17:00	19:00
North Street	15℃	19℃	23℃	25℃	26℃	22℃	21℃
South yard under vegetation	13℃	17℃	17℃	18℃	18℃	18℃	17℃
inside of room in neighborhood of south yard	15℃	18℃	22℃	22℃	23℃	20℃	19℃

According to Table 1, Temperature difference in vegetated areas is only 1℃ at 9:00-15:00 o'clock, i.e. sunny hours, while it is 7℃ in North Street at the same time. It is concluded that vegetation will provide a suitable balance for the designed system. Temperature difference of about 5℃ may radiate to interior spaces in southern rooms at 15:00 o'clock. Evidently, combination of wind flow and vegetation leads to cooler places.

If quick exit of airflow in channel is not important, air leaking in channels may be trapped through a 20°-45° rotation of buildings from the downwind (Figure 7).

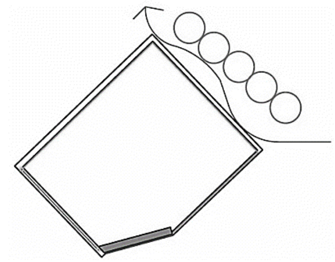

Fig 7. Wind channelizing

After building rotation, wooden fence (as a structure for green wall) will be fixed on envelope line with a distance of about 60cm and vegetation will be grown on it. If evergreen plants grow on them, the passive energy system will work with good efficiency during winters. It is possible to dislodge channelized wind from middle of the green channel, so it is important to do something for it. It is a good solution to make wooden fence with recession and dentate positions in order to trap the wind enters channels because of positive pressure (Figure 8).

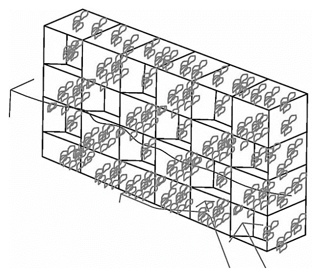

Fig 8. Green channels

Maximum stress in airflow will be achieved through changing the downwind and wooden fence angle to 90°. So if walls of wooden fence in recession parts rotate to make a 90° angle between downwind and green wall, maximum stress of air flow will be created. To achieve better performance, recession parts of green walls should be covered with dense vegetation in those regions where speed of the prevailing winds is higher than regular one (figure 9), In normal situation, however, it should be vegetated non-densely so that the wind can easily enter the recession part of the green wall.

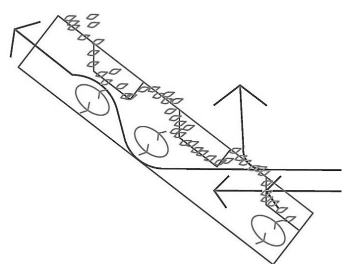

Fig 9. Patterns of air channeling in green channels

When wind collides the recession parts of the green wall, air leaks into the channel while some wind colliding the dentate parts and leaking to the channel reflects and makes positive pressure zone to prevent existing wind flow. So, wind moves in the green channel and makes it cooler where vegetation traps entered wind and air. Therefore, air of the envelope line neighborhood will be cooler than outside. Application of the designed passive energy system will be completed using the system on eaves and reducing water temperature in the glass pond through the channelized wind.

3.4. Humidity and ventilation application of cooling passive energy system.

Eliminating of moisture entered from outdoors and kitchen is the second application of the designed system. The water falling on mental-covered pots is the main concept of the system. Steam collides the metal cover, conducts heat, and converts it to cool drops of water. It is possible to dehumidify the warm and humid air of indoors through making them to contact at lower part of the copper pond. It produces drops under the copper pond and it is essential to collect them before being evaporated by hot air. Therefore, a pond with low heat conductivity and suitable slope should be put on medieval wall dividing U-shape space into two parts. A pipe placed at the end of medieval pond collects the drops in a closed space to prevent their evaporation and leaks them out of spaces (Figure 10).

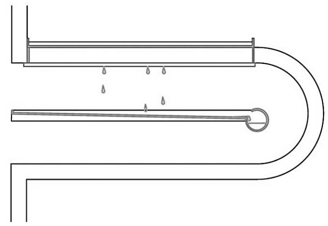

Fig 10. Dehumidifying process of system

Since the understudy region has a cold and snowy climate in winters, some kind of night insulation should be applied on eaves during nights. Therefore, the eaves should be made of materials with low heat conductivity and exterior insulations to prevent from thermal bridges.

Thermostat is the only artificial part of the proposed system that transfers water from the glass pond to copper one after measurement. Fans improve the system function and may be placed on exit of cool air to enhance the system efficiency. Figure 11 shows the general function of the system inside of a masonry sunshade.

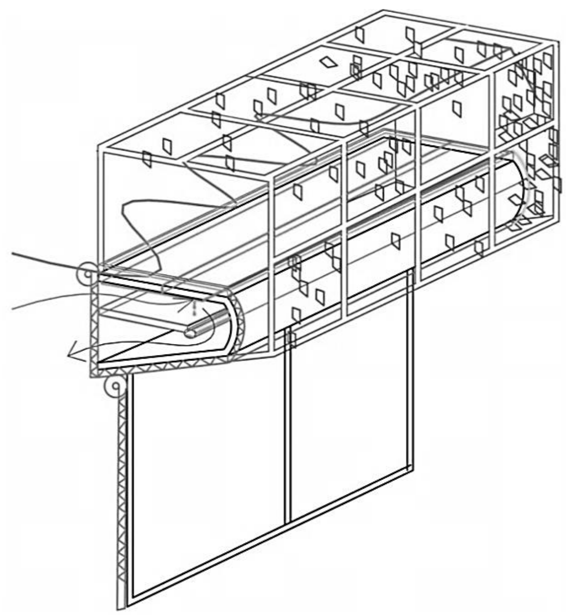

Fig 11. General function of the proposed passive energy system

If deciduous plants are used to vegetate, the ponds can be converted to a horizontal water tromb wall by closing the gate between glass and copper ponds to warm the space (you can find more information about tromb wall and how is it works on [5]). Due to conductivity of the copper pond, however, this kind of tromb wall is only useful for daily heating and it is essential to place night insulations in front of air and water gates.

4. DISCUSSION AND CONCLUSION

There are challenges considering conduction of internal airflow for energy management of buildings in summers and winters. Risen hot air is conducted outward to prevent from more heating of indoors while it is regarded as a way to waste energy and resources, in accordance with principles of sustainable architecture. To prove the research hypothesis based on possibility of using risen hot air as a renewable source of energy to cool and ventilate indoors, a new passive energy system was designed to use potential combination of airflow and wind flow patterns, vegetation, and risen hot air in buildings eaves of envelope line like a masonry sunshade.

To complete the passive energy cycle, some simple equipment were used including thermostat, wooden fence for vegetation, water transfer pipes, and ponds. The equipment get risen hot air and provide cool and dry air required by Arasbaran climate relying on vegetation, airflow, and wind flow patterns (channelized wind in vegetation) at a small space enclosed by a sunshade. The system leads to production of cool air from risen hot air without using any kind of non-renewable energies.

Acknowledgment

The authors declare that they have no conflicts of interest in the research.

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