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Full Length Research Paper

The efficiency of recyclable energies for building design: Cooling system supply for buildings using traditional wind catchers used in the dry and hot climate of Iran and its combination with solar chimney technology

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In recent years, the concept of the usage of new energies for cooling and heating in buildings has attracted the attention of engineers. In this study, the combination of solar chimneys with wind catchers has been suggested to provide natural and pleasant ventilation. It explains the increased efficiency of wind catchers for cooling through the help of solar chimneys. In addition, with the use of solar energy for moving air inside the building by a solar chimney and using the hidden heat of water evaporation, for providing cooling, which is created at the top of wind catcher, we will be able to provide a pleasant environment with suitable temperature and humidity that complies with the standards of pleasant ventilation in hot and dry climates. In continuing this research, attention had been paid to this design for Kerman City, which is located in the hot and dry climate of Iran. Wet channels and walls with radiance are placed together with water injection systems in entrances. In addition, the turbulence model had been used to calculate the buoyancy forces and the radiance model for radiance. The project considers the system performance in a constant manner and the effect of certain parameters, including entrance air temperature, rate of injected water and rate of heat flow field, and temperature and relative humidity.

Key words: Renewable energies, solar building, wind catcher, solar chimney, natural ventilation, economies in fuel usage.

INTRODUCTION

This research which relies on library studies and field research about traditional wind catchers in Iran and also about solar chimneys, is based on the theory that using a solar chimney on the southern part of a building and a wind catcher on the favourable wind side, can increase the ventilation speed in wind catchers. Accordingly, we undertook a numerical study using the limited mass method. In addition, EES software was used for calculating solar energy and fluent software for simulating anumerical solution for theair stream inside the building. Problem geometry is employed using Gambit software with 36796, while the boundary conditions of the problem are based on the actual conditions of the summer in one of the cities of Iran called Kerman.

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Due to the desert climate of most cities in Iran, with long warm and dry summers, employing energy optimization in buildings seems necessary. The most important environmental pollutant factor in the world, and, especially in Iran is the consumption of fossil energies in residential, official, and commercial areas for cooling and heating, which has increased the significance of this subject significantly. In this sense, traditional Iranian architecture, due to the shortage of technological facilities had been adopting principles and remedies for the construction of buildings, in which their results implies that the primary cost of the implementation of optimization principles in buildings can be compensated through a reduction of cost in fuel consumption in later years. Accordingly, with a logical insight, building construction based on energy consumption optimization principles can be reasonably well evaluated.

The overbearing heat of the summer in Iran and lack of easy availability to fossil fuels and technological cooling systems in the past caused its people to think about natural and spontaneous ventilation in buildings through the use of a high narrow, four sided, six sided or eight sided, tower-like elements known as wind catchers (Bahadori, 1978; Kalantar, 2005).

The increase in knowledge concerning environmental pollution has led to the increasing attention of scientists for renewable energies and the usage thereof in buildings. Therefore, architects are interested in green features in modern buildings (Liu and Mak, 2007). Green design includes the features of building architecture that are used to decrease air pollution and also control the heat, air transfer and radiation of the sun from outside to inside.

Till date, much research concerning natural ventilation had been undertaken. Afonso and Oliveira (2000) performed some research about solar chimneys, their research showed a wide increase in ventilation speed through the use of the solar chimney (Clito and Armando, 2000). In addition, Chungloo and Limmeechokchai (2007), by spraying water on the roof and the use of a solar chimney for accelerating the internal air stream, concluded that they could make the inside space temperature cooler than the surrounding temperature by about 2 to 6.2°C. In addition, research shows the use of this solar system as an instrument of ventilation in some Italian buildings in the sixteenth-century, which employed underground passages and water for cooling (Chena et al., 2003). Macias et al. (2009) studied cheap cooling systems in buildings in hot and dry climates, in which ventilation was facilitated by a solar chimney and fresh air which was cooled by circulation. This system has been applied and evaluated for living rooms of residential buildings, the results for which show that the use of solar chimneys is favourable as long as the rate of ventilation is not dependent on the outside air speed. In addition, this system is very suitable for places that have significant solar radiance and low wind speed.

Maerefat and Haghighi (2010) studied the natural cooling of a house using asolar chimney and evaporative cooling system. Their results showed that, this system can easily provide good thermal conditions for environmental air with a relative humidity of less than 50% even in environments with high temperatures. Hirunlabh et al. (1999) presented a design, which consist of natural ventilation with a metal solar wall. This wall consisted of a glassy cover, air gap, dark metal board and a layer of fibre and multi-layer boards. The rays of the sun after passing through the glass cover are absorbed by the dark metal board, which causes the internal air in the air gap to become very hot causing acceleration of the air speed. Thus, the speed of ventilation in the room was increased by the increase in the movement of the hot air and its exiting from the top of the glassy gap (Hirunlabh et al., 1999) (Figure 1).

Traditional wind catcher (Baudgeer) introduction

The wind catcher has been a part of traditional buildings in some parts of Iran and has provided good efficiency in spontaneous cooling. This structure is one of the architectural elements that is based on a dry and hot climate and in the humid and hot climate of Iran with attention to the continental condition of the native architecture. Traditional architects, in consideration of the conditions and poor facilities at that time, incorporated this structure into the architecture, thereby creating spontaneous cooling in buildings in hot areas, particularly in the hot and dry desert areas in Iran. Such a feature provided the buildings a special beauty.

In a manner, it can be said that this soil-oriented element blends with the dusty nature of the region in such a way that these wind catchers have come out of the earth naturally. However, nowadays, this critical component of traditional architecture has been forgotten, and has been substituted with mechanical devices that work with fossil fuels. One of the most important reasons for the current situation is due to the construction of buildings with more than one floor, since wind catchers cannot supply cooling to all floors. Another reason is that, most of the time; the air flow speed in the wind catcher is low and results in its very low efficiency on some days of the year. Thus, some arrangements and strategies need tobe applied in order to make use of them again.

Studying the different sections of wind catcher (baudgeer)

A wind catcher is a vertical channel that can be observed in plain form as a square, rectangle, octagon or circle. Wind catchers consist of two main sections: one is the inner section of the channel, which starts from the ceiling and continues towards the underground, and the other is the outer part located on the roof, including the openings through which the wind enters (Figures 2, 3, 4, and 5). They

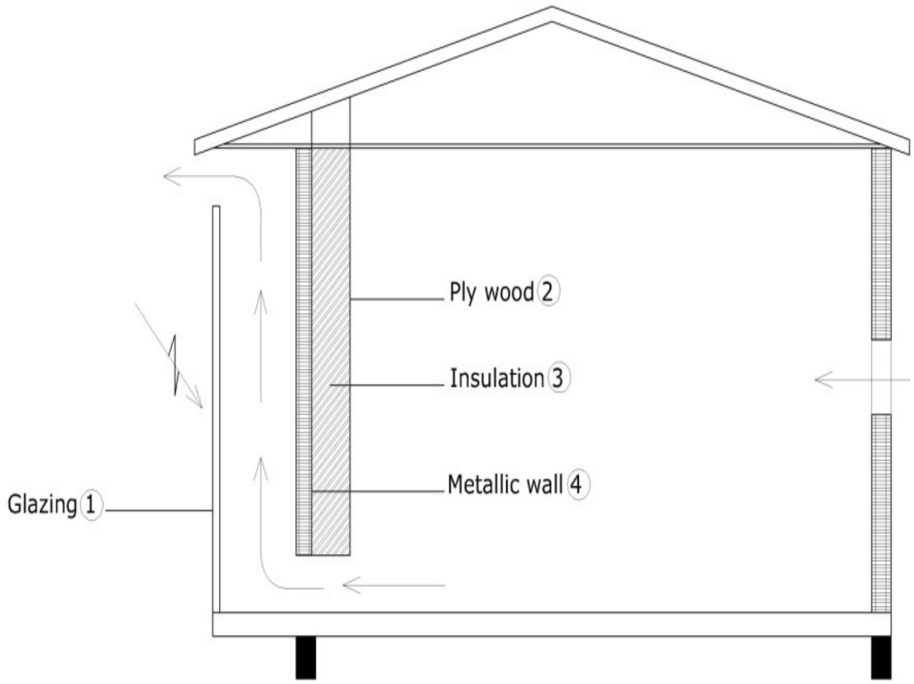

Figure 1. Natural ventilation using metal solar wall. 1, glassy cover; 2, multi-layer boards; 3, insulator; 4, metal wall.

Figure 2. An instance of wind catchers in the warm and dry regions of Iran.

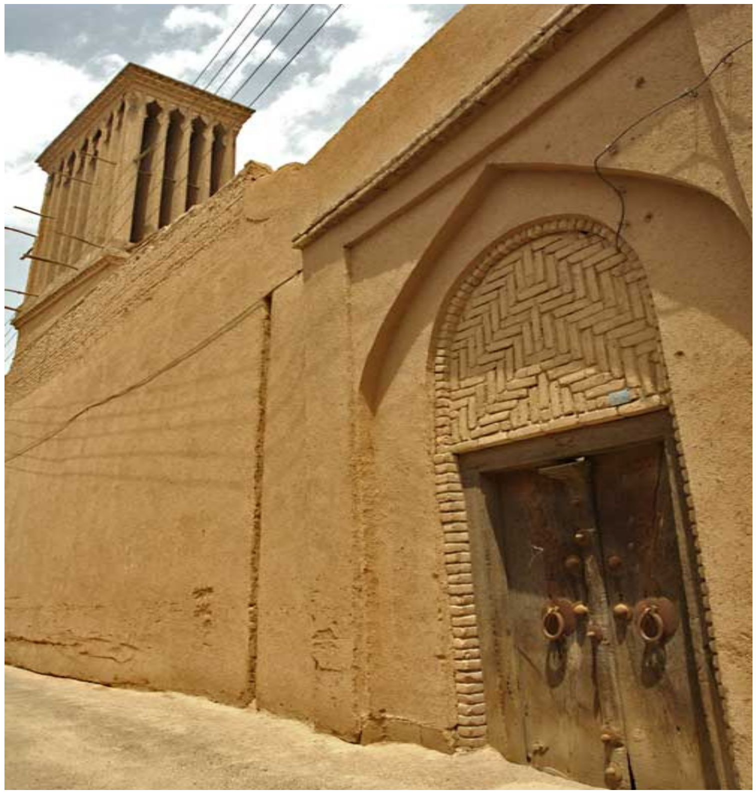

Figure 3. An instance of wind catchers in warm and dry regions of Iran.

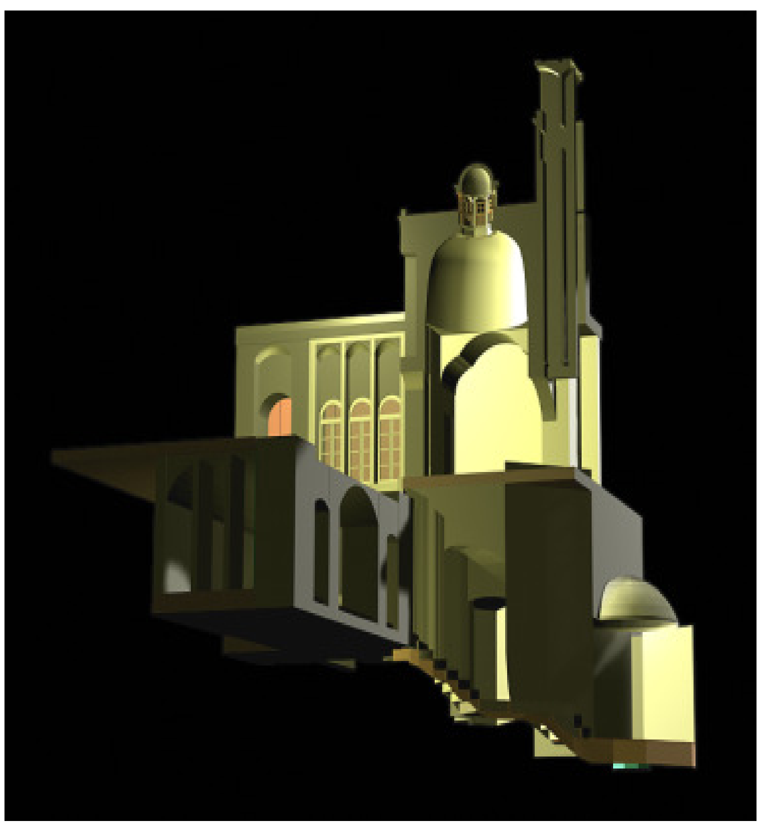

Figure 4. Section-perspective of a traditional house in Iran (Yazdcity).

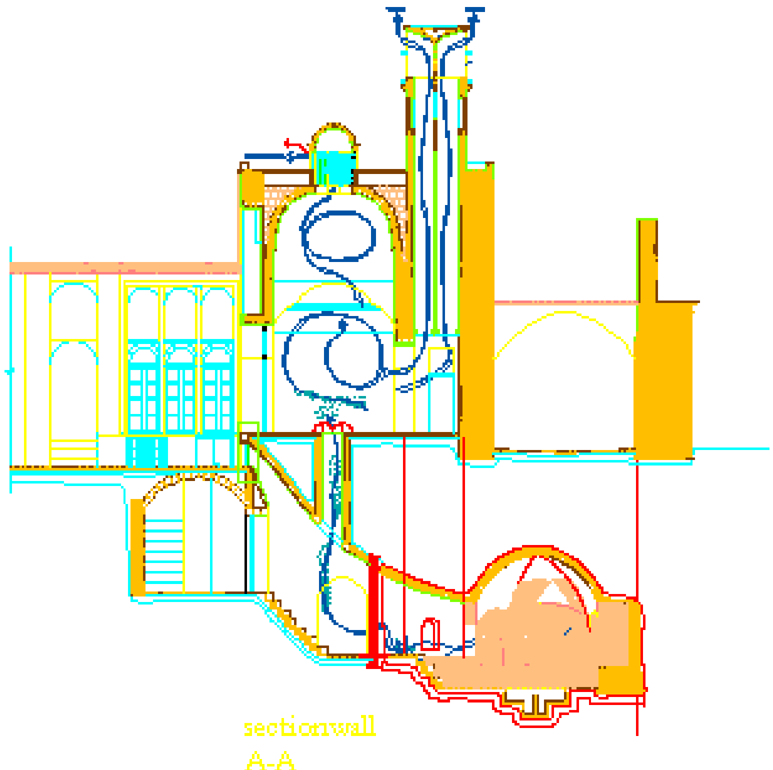

Figure 5. Section- air circulation by air entrance and suction through the wind catcher and roof hatch in the previous figure.

facilitate natural cooling operation in two ways; first, by driving the air, and, second, by cooling through water evaporation. This traditional structure consists of different components that have been considered by the architects not only due to their operational role, but also from the aesthetic point of view.

The main components of the wind catcher are the shelf, body, partitions (including main and minor partitions) and the openings between the partitions of the wind shield. The shelf refers to the upper section of the wind catcher in which the air passage channel is located. The body refers to the section beneath the shelf, which is the separating distance between the shelf and the roof. The partitions are the walls, which divide the air entrance channel to some smaller parts (main partitions extend up to the centre of the tower while minor partitions just go up to the width of the outer walls).

Solar chimney

Some researchers suggest the use of a solar chimney on the other side of the building in order to increase the efficiency of automatic air-conditioning and cooling. Applying this method indicates the completion of the idea for making maximum use of natural energies. A solar chimney is a tool designed for making use of the natural energy of the sun, which operates by increasing the pressure power of the air mass as the result of driving air flow along the chimney channel due to transformation of the heat energy to kinetic energy of air movement. Its structure usually consists of an absorbing wall, air divider, and a glass cover with high sun radiation-conducting power. Solar chimneys are mainly of two types: first are the chimneys installed on the roof, which are inclined, and, second are the chimneys connected to the southern wall of the building.

Applying solar chimneys in order to speed the air movement in the cooling operation of wind catchers

Thus, as was mentioned, by combining the solar chimney system and wind catcher, that is, using a solar chimney on the southern side of the building and applying a wind catcher in an appropriate wind-face direction, the air-conditioning in the wind catcher can be quickened. In this research, it has been done by a numerical study using the limited volume method. A 4-storey building has been considered in which the height of each of its floors is 2.5 m (Figure 6). As can be observed, the inside of the solar chimney grows warm as the result of the sun's radiation and the passage of sunlight through the glass. This warm air moves upwards and forms an air flow by the suction it

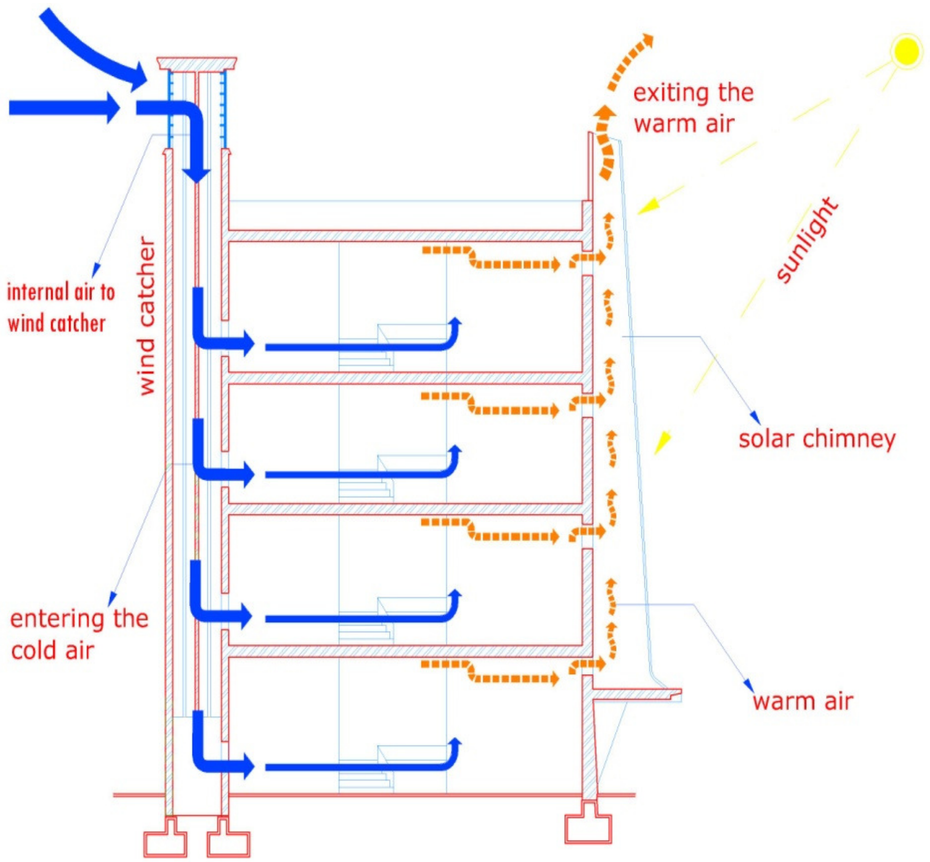

Figure 6. Geometry of input air to wind catcher and output air from solar chimney.

creates in the building. In fact it undertakes the role of a fan.

Equations governing the flow

The equations governing the flow inside the building as control volume or accounting region are as follows:

$$\frac{\partial \rho u_i}{\partial x} = s_m \quad (1)$$

This is the source phrase, which can be added to or omitted from the main flow; it is related to the water evaporation or condensation phenomena. In the above equation, ρ is the mass density of the air, which is at its lowest at the time of entrance and increased by sprinkling water into it making it heavy. This desired phenomenon creates a sort of negative floatation, which results in the downward movement of heavy air. The total mass density or mass density of the water steam or dry air components can be calculated by calculating the pure moisture and also the total and minor pressure of the water steam and dry air for any node (Kalantar, 2009; Ashare, 1981).

Momentum equations

The averaged equation of Navir Stocks, which governs the flow, is as follows:

$$\frac{\partial}{\partial x_i}(\rho u_i u_j) = \frac{\sigma p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] + \frac{\partial}{\partial x_j}\left(-\rho\overline{\acute{u}_i \acute{u}_j}\right) + f_i \quad (2)$$

The phrase introduces the Reynolds stresses, which have been created in relation to the speed fluctuations around the average amount by using the Boussinesq's hypothesis; and f_i introduces the fluid weight power in the given direction (User's Guide, 2000).

Energy equation

In order to calculate the temperature distribution inside the building, an energy equation is required, which is as follows:

$$\frac{\partial}{\partial x_j}[u_i(\rho E + p)] = \frac{\partial}{\partial x_j}[(\lambda + \frac{c_p \mu_t}{pr_t})\frac{\partial T}{\partial x_j} - \sum_i h_i j_i] + s_h$$

In this equation E is:

$$E = \sum h_i y_i + \frac{U^2}{2} \quad (3)$$

λ is fluid heat conduction coefficient

is the penetrating flux of component j; and is related to any energy source.

Transfer equation

The transfer equation for water steam and sprinkling it into the air is as follows:

$$\frac{\partial}{\partial x_i}\left(\rho Y_{H_2O} U_i\right) = \frac{\partial}{\partial x_i}[\left(\rho D_{H_2O} + \frac{\mu_t}{sc_t}\right)\frac{\rho Y_{H_2O}}{\partial x_i} + s_{H_2O} \quad (4)$$

Radiation equations

Total daily radiation is the sum of scattered daily radiation and direct daily radiation; thesolar radiation data are usually available as total daily radiation. In order to obtain the rate of energy received by the collector, the instantaneous amount of direct and scattered radiation should be calculated. To do this, first the daily scattered radiation is separated from the total radiation, and then the instantaneous amounts of the scattered and direct radiation are determined. In this research, the Miguel method is used for obtaining the daily scattered radiation which is one the most recent methods presented in this are (Miguel et al., 2001; Tsilingiris, 1993).

$$\begin{cases} f_d = 0.952 & k_t < 1.3 \\ f_d = 0.868 + 1.335K_t - 5.782k_t^2 + 3.721k_t^3 & 1.3 < k_t < 0.8 \\ f_d = 0.141 & k_t > 0.8 \end{cases} \quad (5)$$

K_t is air clearness coefficient, which is equal to the ratio of the total radiation on the earth's surface to the ultra-atmosphere radiation.

f_d is the daily scattered radiation fraction, which is equal to the ratio of the scattered radiation to the total daily radiation on the horizon.

After determination of f_d based on the air clearness coefficient and by having the total daily radiation, the daily scattered radiation can be calculated. After obtaining the daily scattered radiation, the direct radiation can be calculated as the difference in the total and scattered radiations. In order to obtain the instantaneous amounts of the direct and scattered radiation, the Jain et al. (1988) method is used, which has the best conformity with reality.

$$g(t, \alpha, \beta) = \frac{\Gamma(\alpha + \beta)}{\Gamma(\alpha)\Gamma(\beta)N^{\alpha+\beta-1}} \quad (6)$$

$$\left[\frac{N}{2} + (t - 12)\right]^{\alpha-1} \quad [\frac{N}{2} + (t - 12)^{\alpha-1}]^{\beta-1} \quad (7)$$

For total radiation: $\alpha = \beta = 2.061 + 0.0385N$
For diffused radiation: $\alpha = \beta = 1.969 + 0.0153N$

$$\Gamma(a) = (a-1)\ (a-2)K(b!)\ 0 \le b \le 1 \quad (8)$$

The Jin relation g (t,α, β) determines the amounts of r_G, that is, the ratio of total instantaneous radiation to the total daily radiation, and r_D, that is, the ratio of instantaneous scattered radiation to daily scattered radiation. In addition, the instantaneous amounts of direct radiation can be calculated as the difference of these two amounts. The r_G and r_D amounts are calculated for hourly amounts. In this research, in order to study the received energy amount more precisely, the instantaneous radiation amounts were calculated in time intervals of 6 min. In order to calculate these amounts in time intervals of 6 min, these ratios are multiplied by 0/1.

Determining the amount of absorbed radiation

By having the instantaneous data of direct and scattered radiation, the amount of the radiation absorbed by the collector can be determined using Equation 6. This equation calculates the absorbed radiation, which consists of three types of radiation: direct radiation, scattered radiation, and reradiated scattered radiation, hour by hour (Sukhatme, 1984; Duffie and Beckman, 1980).

$$S = I_b R_b (\tau\alpha)_b + I_d (\tau\alpha)_d \left(\frac{1+cos\beta}{2}\right) + \rho_g (I_b + I_d)(\tau\alpha)_g \left(\frac{1-cos\beta}{2}\right) \quad (9)$$

Rb is the ratio of the intensity of direct sun radiation on an inclined slab to the intensity of direct sun radiation to the same slab when it is horizontal.
is the vision coefficient of the collector to the sky and is the vision coefficient of the collector to the earth. In this research, heat fluxes and radiation equations were calculated by EES program at different hours, and, finally, the temperature of 305°C and heat flux of 1000(w/m^2) were obtained.

Introducing the selected numerical method and determining the material for the absorbents and walls

As was mentioned before, the Fluent Software was used for numerical calculation of the air flow inside the building, and marginal conditions of the related issue were considered based on the real summer conditions in one of

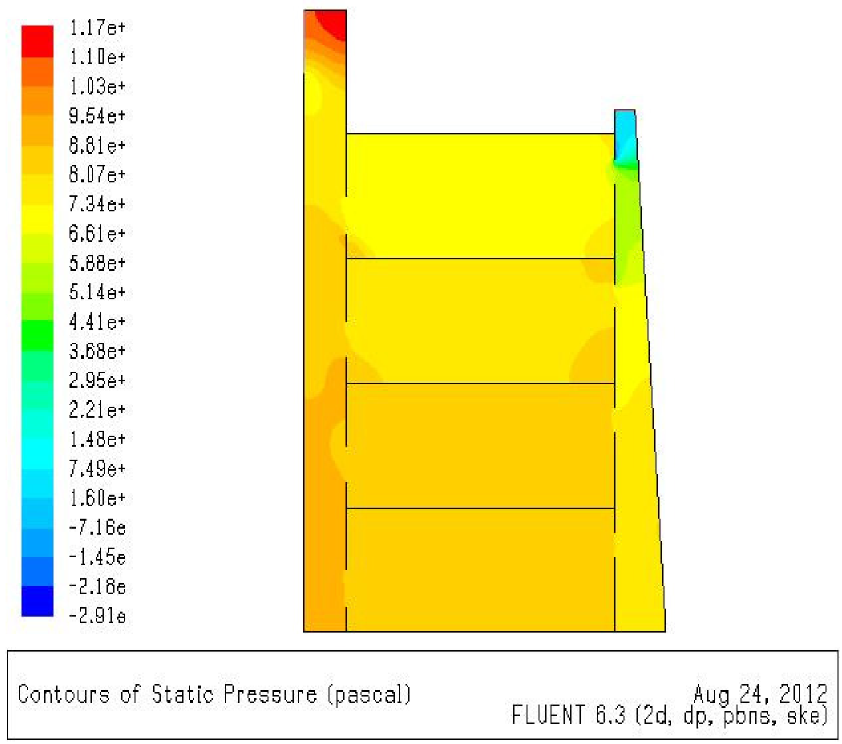

Figure 7. Calculating network.

the cities of Iran, named Kerman. Copper was considered for the material for the absorbents so that itcan operate the best for natural air-conditioning, and the walls were considered to be of brick type. The flow was obtained in the control volume and based on the k-ε model, and the pressure base was solved using simple algorithm. The temperature difference between the radiation absorbance and the air inside the chimney results in a difference in air density, which creates the natural flow movement in the chimney, and, in turn, contributes to the gas exiting.

Model simulation in the fluent software

Figure 7 shows the accounting network of the building and wind catcher in Gambit software. Studying the fine mesh and mesh-free cases results in the following geometry; by applying this geometry in fluent, the effects of the solar chimney on the air-conditioning of the building can be observed. In Figure 8, one can see the pressure counters, and, as can be observed, the pressure is high at the entrance and reduces gradually towards the outlet. These factors drive the air towards the outlet. In addition, an approximate high pressure difference can be observed in the upper and lower parts of the chimney, which is due to the dropping density as a result of the solar heating in the chimney. Figure 9 indicates the pattern of flow lines. The vortexes created in each floor contribute to the better air-conditioning in the building. The direction of these vortexes is counter-clockwise, which contributes to air circulation. The height difference between the air entrance and outlet in each floor is also a factor, which creates these vortexes.

Conclusion

Clean energies or so-called natural energies, are completely compatible with nature and do not harm the environment, which in as much as fossil energies are limited, expensive, and unrenewable, has encouraged people to move towards sustainable development. One of the important branches of sustainable development is sustainable architecture. This sustainability can be observed clearly in Iran's traditional architecture and also that of some other countries. In addition, such architecture can be revived by implementing certain changes in its use through logical insight and new technologies. Wind catchers are among the sustainable factors in Iran's traditional architecture; the integration of which with solar chimneys provides the possibility of their employment in multi-storey buildings. Accordingly, the integration of solar chimneys and wind catchers in buildings was investigated in this research.The results showed that employing traditional air conditioning systems in modern systems, demonstrates a decrease in the consumption of fossil fuels of about 50 to 60%, which

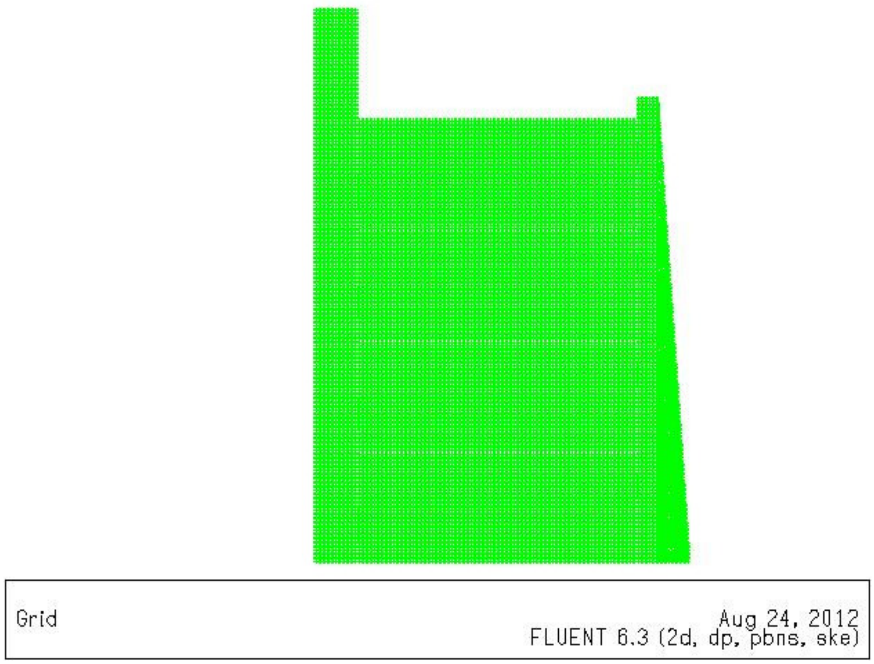

Figure 8. Pressure counter.

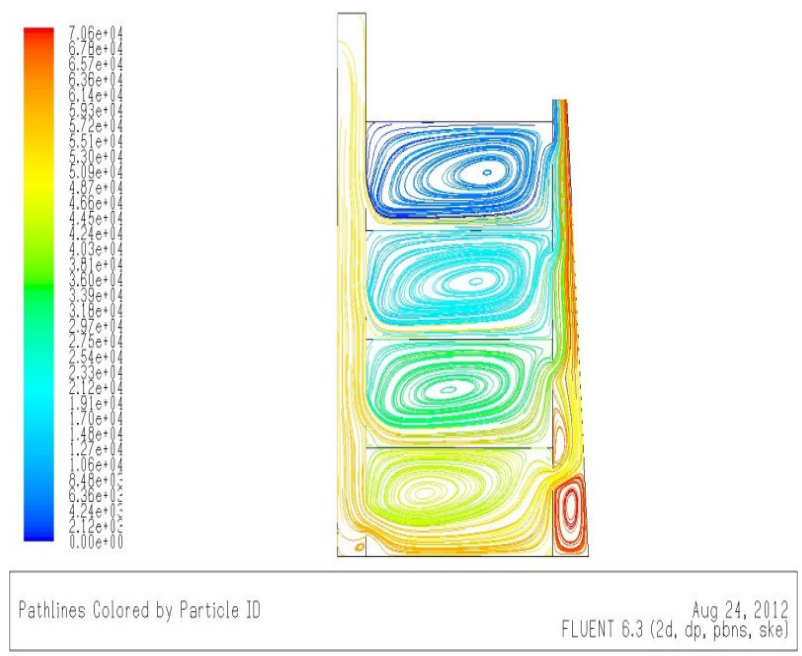

Figure 9. Flow route line.

is an important and effective contribution to a clean environment. Employing a solar chimney on the south side, in order to increase the upward movement of the air through it, causes an increase in the wind catcher's efficiency for cooling and conditioning the air.

The results of this simulation demonstrate that inside the solar chimney, due to the radiation of sun and passing the light through the glass, the air is warmed and moves upward. Accordingly, by means of the suction produced in the building, a flow is formed, which simulates the action of a fan.Therefore, by increasing the internal channel temperature, the density of this part is reduced, and, since the internal room temperature is lower than the internal channel temperature, the density of this part rises above the internal channel density, which results in a difference of densities between the two regions (channel and room space) causing the flow. As this temperature difference increases, the flow speed and the magnitude of air conditioning also increases.

Furthermore, according to the results obtained from running the program for different cases, it was observed that by employing water sprayers near the entrance of the air to the wind catcher (inside the blades) and other points along the route, had a crucial effect on various parameters, such as temperature, relative humidity, flow speed, mass density etc. The temperature is decreased significantly, while the relative humidity and mass density increased. It was observed that as the amount of injected water increases, the water temperature decreased until the saturation state was achieved. In this case, the water is not vaporized anymore and the addition of water had no effect and is just gathered as liquid at the bottom of the wind catcher.

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