Using Solar Chimney to Suck Air through a Wet Pad

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Abstract

A solar chimney is used to suck the air from the dwelling that in role will suck it through an evaporation pad that is used to decrease the temperature of outdoor air by considering low humidity ratio. The study is presented on a Baghdad climate where hot and dry ambient is common.

The results for a typical room indicate that the temperature could be lowered for more than 10 degrees; also the optimum thickness of the chimney was studied and noted that the best heat dissipation would be at the ratio of (¼) for surface area to volume of dwelling.

الخلاصة

تم استخدام برج شمسي لسحب الهواء الحار من الحيز الذي يقوم بدوره بسحب الهواء الخارجي عبر طبقة مبخرة تستخدم لتقليل درجة حرارة الهواء الخارجي والذي يفترض أن يكون ذا رطوبة نسبية واطئة. الدراسة تقدم على أساس مناخ مدينة بغداد, حيث الهواء الحار الجاف صيفا هو المعتاد.

النتائج لغرفة نموذجية أظهرت أنه بالإمكان تقليل درجات الحرارة لأكثر من 10 درجات عن المعتاد في داخل الغرفة, كما أنه تم دراسة السمك الأمثل للوسادة الخازنة للحرارة ضمن البرج الحراري وتأثيرها على عمل البرج ولوحظ بأن أقصى تبديد للحرارة سيكون بنسبة (1\4) من المساحة السطحية إلى حجم الوسادة.

Nomenclature

A	Area
A_O	Area of the orifice
A_S	Absorptivey of the outer equivalent wall surface
C_d	Coefficient of drag
C_P	Specific heat of air
D	Width of the dwelling
E_{AG}	Energy absorbed by the glass
E_{AW}	Energy absorbed by wall
E_{dH}	Diffusive solar radiation on a horizontal surface
E_{TH}	Total diffusive solar radiation on a horizontal surface
E_{Ti}	Total flux density of solar radiation on surface I
E_{Ts}	Total flux density of solar radiation on west facing surface
F	Shape factor between the glazing and the wall of chimney
G	Gravity
H	Coefficient of convection
K	Coefficient of conduction
M	Mass flow rate
Q	Heat exchanged
R	Surface area / V (for dwelling)
T	Temperature
t	Time
V	Volume of dwelling
W	Width of solar chimney
W_d	Width of dwelling wall
α	Diffusivity
ε	Emissivity of the glass
ρ	Density
σ	Sefan-Boltzman constant

Subscripts

1	Properties at glazing
2	Properties at wall surface of chimney
a	Ambient
D	Duct spacing
E	Properties at external side of glazing
ee	Equivalent exterior
ei	Equivalent inside
eq	Equivalent (area, . . .)
f	Fluid properties in the chimney
g	Ground
i	Entrance
Ip	Properties of entering air at the orifice and beyond the pad
o	Exit
s	Sky
w	Wall of chimney

Introduction

During summer months climate in Iraq becomes very hot and dry (50°C, 10-20RH); The buildings style normally consist of clay brick and concrete beams where this structure absorbs heat during the sunlight hours and reradiates it to the zones inside. On the other hand there is a dry weather that helps cooling process when evaporative cooling has been used. At nights, clear sky causes irradiation from the earth, which in role causes the temperature of ambient, be lowered as much as 20°C, so it becomes more comfortable. A new suggestion was the using of the western wall as thermal heat collector with other glass wall in front of it, to prevent convection heat transfer from this side. The eastern wall is supplied by an orifice with wet evaporation pad covering it (fig.1).

The glass wall allows sun radiation to heat the thermal collector and store it during the day times and ventilate after wards air will be suck in form the wet evaporation pad. This study uses single zone dwelling for analysis of the problem. On the other hand Gontikaki et al. (2010)[1] built a prototype for multistory building to study the benefits of solar chimney and they concluded that the length of solar chimney was the most influence parameter up on the heat dissipation. Another interesting study done by Kaneko et al. (2009)[2] where they tried to get use of adding a phase change material to the solar chimney itself, this modification stabilized the air flow in the dwelling between daytime hours and night hours and hence the efficiency of the dwelling lowered about 12% while the fluctuate in flow was only 10% all around the day.

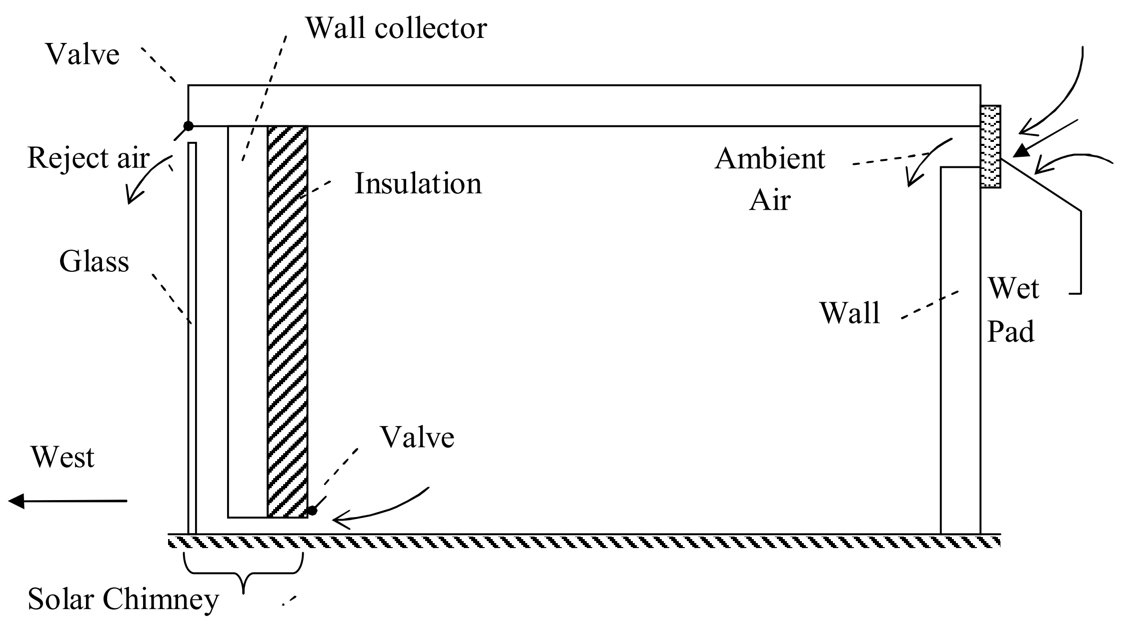

Fig.1 Schematic diagram of a typical dwelling with a solar chimney

Model description

As the model under consideration is in Baghdad where it lays on the north of Cancer tropic then the north wall wouldn't receive any percent of sunlight, while the eastern wall will receive the radiation in morning and the western wall will receive it afternoon. Western wall was selected to be collection wall since it gets most of heat late and more close to night hours.

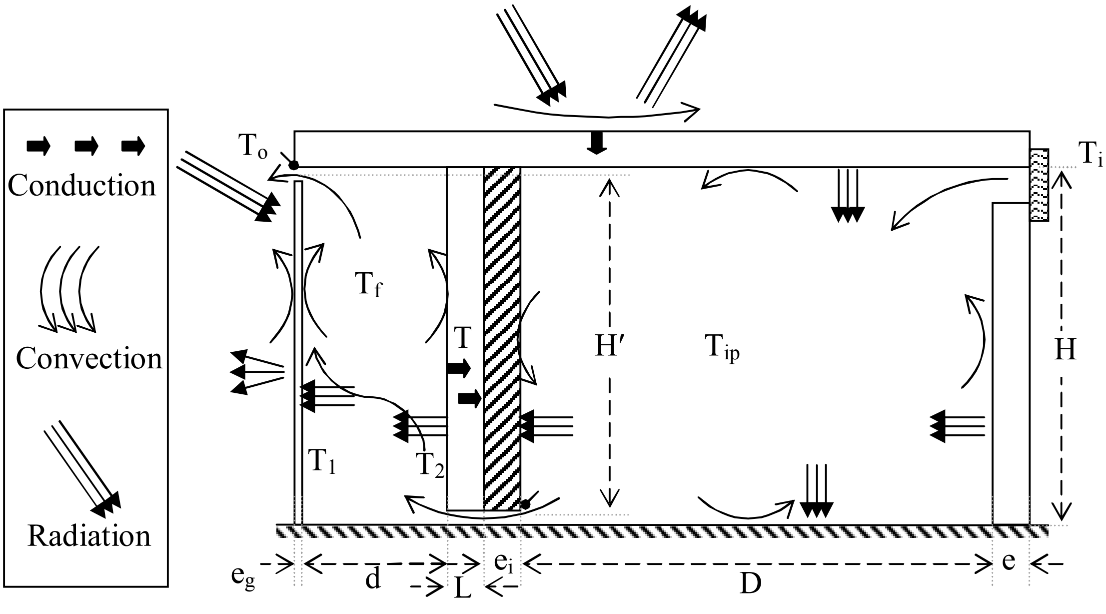

Fig.2 Definition of heat transfer modes and parameters

The system consists of single zone dwelling (fig.1). The western wall consists of glass wall and orifice at the upper end controlled by a damper. The second layer would be air passage zone, then the concrete wall with suitable thickness. At last there is ordinary western wall (assumed to be completely insulated from the collector side). The collector and the wall have an orifice from the bottom controlled by a damper.

Theoretical Analysis

Assumption

For analyzing this problem several assumptions were considered:

i) There is a radiation in each element.
ii) Transparency of glass is unity.
iii) Heat transfer is one-dimensional.
iv) Physical properties are temperature independent.
v) The analyses were evaluated for transient assumption except that for glass.
vi) There was no infiltration air.
vii) There was perfect humidification for the inlet air through the wet pad.

Analysis of calculations

The radiative energy upon the eastern vertical surface(i) is E_{Ti} (E_{Ti}: can be calculated from E_{TH} & E_{dH}) [3]. The system is divided into elements, each one has it's own thermal Equilibrium Equation:

i) Glazing :

$$E_{AG} + h_1(T_f - T_1) + \sigma F(T_2^4 - T_1^4) = h_E(T_1 - T_E) - 0.5\sigma\varepsilon(T_s^4 + T_g^4 - 2T_1^4) \quad (1)$$

ii) Wall :

$$\partial T / \partial t = \alpha \partial^2 T / \partial x^2 \quad (2)$$

$$-k\frac{\partial T}{\partial x}\Big|_{x=0} = E_{AW} - h_2(T_2 - T_f) - \sigma F(T_2^4 - T_1^4) \quad (3)$$

$$Nu_l = \frac{2}{In(1 + 2/C_l Ra^{1/4})} \quad (3a) \qquad Nu_t = \frac{C_t^V Ra^{1/3}}{(1 + 1.4*10^9 \Pr/ Ra)} \quad (3b)$$

$$C_l = \frac{0.671}{(1 + (0.492/\Pr)^{9/16})^{4/9}} \quad (3c) \qquad C_t = \frac{0.13\Pr^{0.22}}{(1 + 0.61\Pr^{0.81})^{0.42}} \quad (3d)$$

$$Nu = ((Nu_l)^6 + (Nu_t)^6)^{1/6} \quad (3e)$$

$$\frac{\partial T}{\partial x}\Big|_{x=L} = 0 \quad (4)$$

Air of chimney:

Three cases will be presented; one with damper closed, damper opened but without wet pad and the last is a dwelling, opened damper with wet pad.

- air damper closed $\qquad m = 0$

$$T_f = (T_1 + T_2)/2 \quad (5)$$

- air damper open without wet pad

$$m = C_d A_{Orfice} \rho \sqrt{gH' \frac{T_o - T_i}{T_o + T_i}} \quad (6)$$

$$T_f = (T_o + T_i)/2 \quad (7)$$

Where: C_d=0.4 [5] & H′: Shown in the figure

- air damper open with wet pad (Equations (6) & (7) can treat this case too)

Where the T_o can be calculated from:

$$mC_p(T_o - T_i) = A_w[h_1(T_1 - T_f) + h_2(T_2 - T_f)] \quad (8)$$

- air in the dwelling :

The air admitted by the orifice will exchange heat by the equivalent wall mass. The air admitted by the orifice will gain humidity and lose a little bit of it's temperature as it passes through wet pad and then exchanges heat with equivalent wall.

$$A_{eq} = \sum_{i=1}^{4} A_i E_{Ti} / E_{Ts} \quad (9)$$

$$\rho C_P V (dT_i / dt) = m C_P (T_a - T_i) + A_{eq} h_i (T_{ei} - T_i) \quad (10)$$

Where h_i (film convection coefficient) calculated from [6]

- Equivalent wall :

$$\partial T_e / \partial t = \alpha \, \partial^2 T_e / \partial x^2 \quad (11)$$

$$-k \frac{\partial T_e}{\partial x}\Big|_{x=0} = \alpha_s E_{is} - h_w (T_{ee} - T_a) + 0.5 \sigma \alpha_s (T_s^4 + T_g^4 - 2T_{ee}^4) \quad (12)$$

$$-k \frac{\partial T_e}{\partial x}\Big|_{x=0} = h_i (T_{ei} - T_i) \quad (13)$$

- Dwelling with closed damper. Equations (9)-(13) are solved with m=0.
- Dwelling with open damper & without wet pad. Equations (9)-(13) are solved with m≠0.
- Dwelling with open damper & with wet pad. Equations (9)-(13) are solved with T_{ip} instead of T_i.

Solution Method

Crank-Nicolson method was used to solve equations (2)-(4) and (11)-(13) while Euler's method was used for equation (10). The non-liner resultant system is solved using Gauss-Siedal iterative method. For the case of dwelling without the solar chimney, equations (10)-(13) were dealt with m=0, Dwelling with a solar chimney but without wet pad at the orifice was also considered as a second case study while the third was for dwelling with a solar chimney and wet pad at the ventilation orifice.

Results and discussion

Example: the work concentrated upon the building in Baghdad (altitude =32m; latitude =33°20΄N Longitudinal =44°20΄W). The hourly diffuse components of solar radiation on horizontal surface and the outside air temperature are taken from literature [7] other parameters are taken as follows: thickness of glass = 4mm, d = 80mm, W = 100mm, Wd=200mm, V = 240m3, A = (3*10) =30m2 and Ao =0.03A.

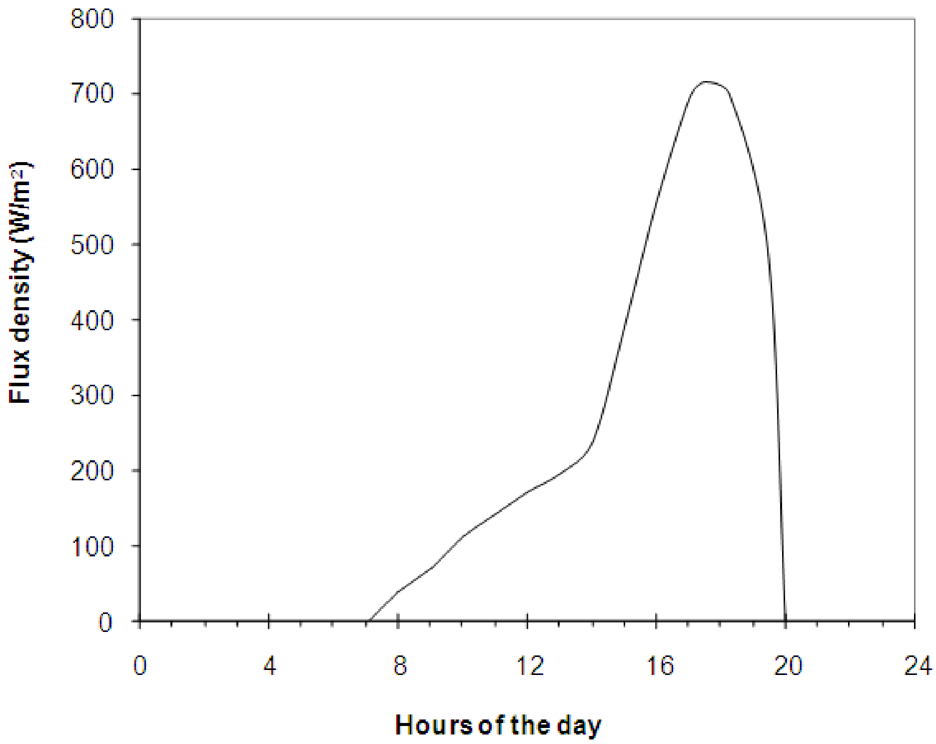

Fig. (3) : amount of received solar energy

Simulation

From 13 to 15 July was the simulation period for the study case, where heat gain by eastern wall was calculated [7] as shown in fig. (3). only the last days' results were shown in fig. (4). This figure shows the temperature change range from 50ºC in the afternoon to about 30ºC early in the morning and that the air temperature of dwelling without a chimney is higher than that of outside air from 7:00 PM to 7:00 AM. The ambient air temperature reaches 44ºC at about 8:00 PM which is completely uncomfortable temperature throughout evening night.

At 8:00 PM the orifice of chimney was opened allowing for ambient lower temperature air to pass in causing temperature drop for more than 4.5ºC making the dwelling relatively more comfortable. When the wet pad was added for the inlet orifice the temperature in the dwelling decreased for more than 10ºC compared with initial case. At about 7:00 AM the ambient temperature increases for 27ºC which is more than that of dwelling so orifice was shut down but the temperature degrees still better than the no chimney case because ventilation sucked heat from walls of dwelling too.

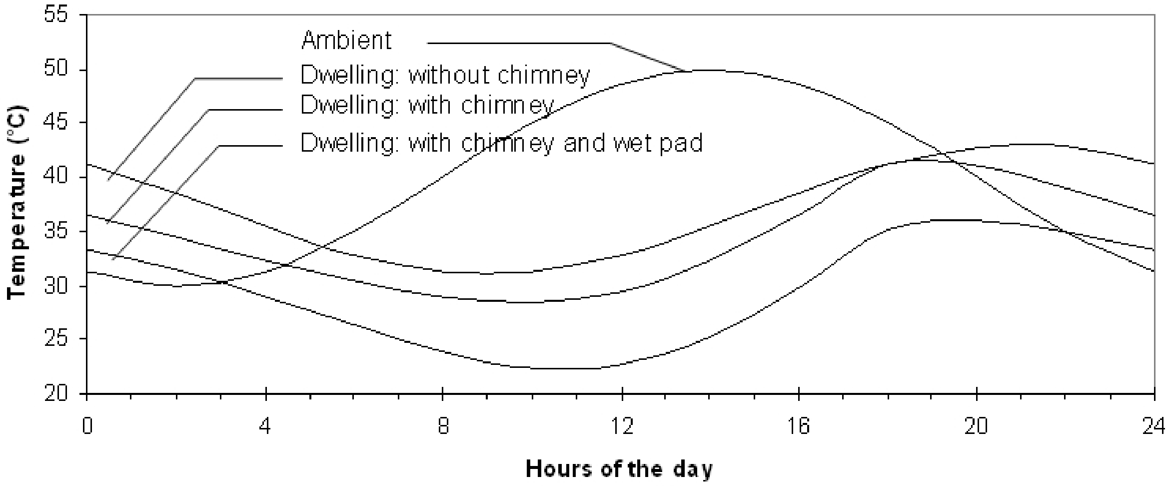

Fig. (4) : Temperatures Of Ambient And The Dwelling With Three Cases

Parametric study

A parametric study carried out by varying W from 5cm to 20cm and D from 4m to 8m (R varies from 1/8 to 1/4; since A is constant 30m^2. Figures (5&6) show the results for heat exchanged between dwelling air and outside air versus different L and for temperature difference versus time respectively. Figure 5 shows that the optimum chimney wall thickness for various R values is about 12cm and that why increasing R from 1/8 to 1/6, the ventilation energy is increasing by 34% while from 1/8 to 1/4, by as much as 63%. For L=10cm and various R values for R=1/4. Figure (6) clears that temperature difference with and without chimney can be as much as 5.6ºC. 25% increase compared to that with R= 1/8.

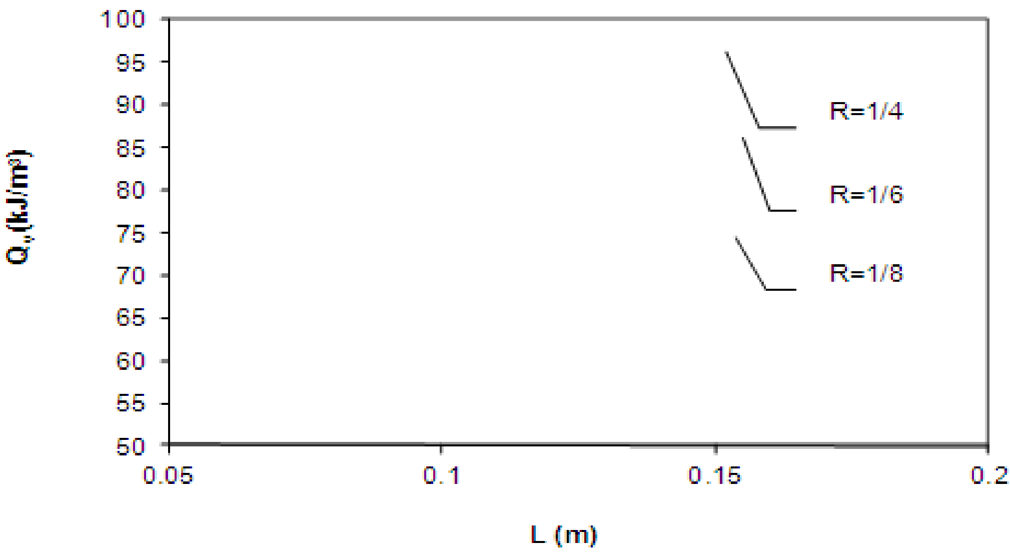

Fig. (5) : Optimum Wall Thickness For Various R Values

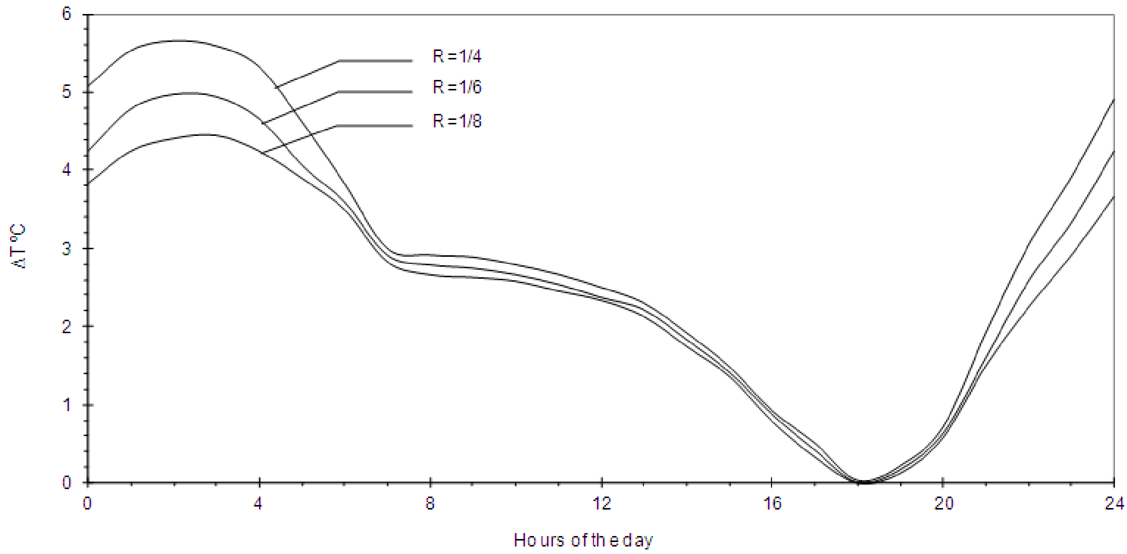

Fig. (6) : The Differencein Room Temperature For The Cases : 1 And 2 For Various (R) Ratios. (L=0.10m)

Conclusion

A model was developed to simulate performance of solar chimneys in Baghdad climatic to ventilate and cool by humidification the dwelling. The theoretical results with and without a solar chimney again with and without humidification wet pad, In typical house, have indicated: that the solar chimney on the west wall will perform quite satisfactory decrease to the ambient air temperature by about 5ºC, the solar chimney area with respect to dwelling volume could be 1/8 to 1/4 and the optimum chimney wall thickness about 10cm. while adding a wet pad could increase the temperature difference by more than 11ºC.

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