SUMMARY

A.A. Golneshan and M.A. Yaghoubi, Natural Cooling of a Residential Room with Ventilation in Hot Arid Regions. Passive cooling in hot desert area of Iran with large diuranal temperature range of the ambient air and nearly fixed wind pattern, is accomplished by several means such as the construction of wind towers (Buadgirs). In order to determine ventilation performances in those regions a transient program was simulated for a single room with glass windows. The calculations done on the climatical data of a typical city close to the central desert of Iran like Yazd. Results indicate that the incident solar radiation tothe room has a high influence on the room air temperature. For a single room constructed from bricks and which has north and south windows, an appropriate selection of ventilation during the cold period of night (12 to 30 times air-change per hour) and during the day (½ time air-change per hour), will substantially reduce the room air temperature during the hot period of the day and will keep it within an acceptable range of the thermal comfort.

RESUME

A.A. Golneshan et M.A. Ya'ghoubi, La Climatisation Naturelle d'un Logement Dans les Regions Arides. Dans les régions désertiques et arides de l'Iran qui se caractérisent par une température quotidienne de l'air ambient, à la fois trés étendue et élevée, et par le vent quasi fixe, la climatisation passive s'éffectue par les divers moyens tels que la construction d'une sorte de tour de vent (Buadgir). Pour déterminer la performance de ventilation dans une telle région, nous avons procédé à l'élaboration d'un programme transitoire destiné à une seule pièce équipée de panneaux de verre comme fenêtres. Les critères pris en considération furent les données climatiques d'une ville typique située près de Désert central de l'Iran comme Yazd. Les résultats obtenus nous montrent que l'irridation des rayons solaires exerce ,d'une façon considérable, son influence sur la température de la pièce. Ainsi pour une seule pièce faite de briques dont les fenêtres donnet sur Nord et Sud, un choix opportun de ventilation durant la période froide nocturne (entre 12 et 30 fois de changement d'air par heure) et (1/2 fois) pendant la journée ,aura comme conséquence l'abaissement de la température à l'intérieur de la pièce au cours de période chaude du jour, permettant alors de la maintenir dans un état du confort thermique acceptable.

KURZFASSUNG

A.A. Golneshan und M.A. Yaghoubi, Natürliche Kühlung der Bewohnten Räume in Heiz-trockene Gebieten Durch Lüftung. In heizen Wüstengebieten Irans, wo tagsüber eine hohe Temperatur und fast gesicherte Windarten zu betrachten sind, wurde mit Hilfe von verschiedenen Mitteln sowie Windtürme (Baudgirs) eine Passive Kühlung ausgeführt. Um die Leistung dieser Ventilations-verrichtungen festzustellen, wurde ein Pragramm für eine provisorische Nachahmung der ebengenannten Strukturen für ein einziges Zimmer mit Glas-Fenstern entwickelt. Die Berechnungen sind nach Klimatischen Angaben einer typischen Stadt, wie Yazd, nahe an das Wüstengebiet im Zentraliran gemacht worden. Ergebnisse zeigen, daß die ins Zimmer einfallenden Sonnenstrahlen einen großen Einfluß auf die Raum-temperatur ausüben. Für ein Zimmer, das mit Ziegelsteien gebaut ist und nordlich und westlich jeweils Fenster hat, wird eine angemessene Auswahl der Lüftung in den Kalten Nachtsperioden (12 bis 30 mal Luftwechsel pro Stunde) und tagsüber (1/2 mal Luftveränderung pro Stunde) die Raumtemperatur während der heizen Perioden des Tages wesentlich vermindern und sie in einem annehmbaren Umfang der Thermalbehaglichkeit erhalten.

NATURAL COOLING OF A RESIDENTIAL ROOM WITH VENTILATION IN HOT ARID REGIONS

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Introduction

With the present knowledge of air conditioning, the cooling needs of any building can be met through making available sufficient energy (mostly in the form of electrical energy). Such conditions requires high initial and operating investments and a substantial expenditure of energy. This kind of energy is not available in most rural areas like hot-arid regions of Iran, which have nearly fixed seasonal and daily patterns of wind, hot summer days with cold nights, a high degree of solar radiation and low air vapor pressure. Natural cooling in those areas is accomplished by several means, such as the construction of wind towers (Baudgirs) and underground structures (1). Therefore, for further improvements in the comfort level, thermal studies of the residential buildings in those areas with their unique meteorological patterns may yield substantial informations.

Passive cooling investigations has received considerable attention in the present years. Most of these studies are qualitative description of different procedures which have been used from the past experiences (1). Quantitative studies are few, night ventilation effect for a room with no windows is simulated by Chen and Mitchell (2). However, radiation exchange through openings which have a considerable effect on the cooling load in the arid regions was not studied.

In this paper initialy solar radiation on vertical walls with different orientations is estimated. Including radiation, the ventilating cooling effect is determined by computer simulation of the room thermal processes for various ventilation rates and different window orientations.

Methodology

A room such as shown in Fig. 1 has solar heat gain through glass surfaces, roof and exterior walls, heat flow through enterior walls, roof and ground, and ventilation primarly due to wind tower or through air vents (3). Solar radiation intensity on the surrounding walls and windows is assumed to be sum of direct beam, I, and diffuse component, D. Therefore, for any vertical wall total radiation is

$$I_i = \cos\theta_{v,i}\, I(\theta_z)(1 - CF) + \tfrac{1}{2}D(\theta_z, CF) \qquad i = 1,4 \qquad (1)$$

where $I(\theta_z)$ and $D(\theta_z, CF)$ for Iran are as follows (4)

$$I(\theta_z) = 951.55\,\{1 - \exp[-0.075(90 - \theta_z)]\} \quad W/m^2 \qquad (2)$$

$$D(\theta_z, CF) = 1.432 + 2.107(90 - \theta_z) + 121.3CF \quad W/m^2 \qquad (3)$$

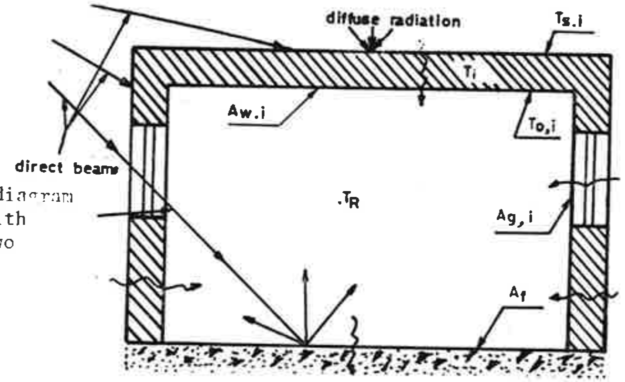


Fig. 1. Schematic diagram of a single room with glass windows on two sides.

where CF is cloud factor. Zenith angle θ_z and $\theta_{v,i}$ can be determined by

$$\cos\theta_z = \sin\delta \sin\phi + \cos\delta\cos\phi\cos\omega$$

$$\cos\theta_{v,i} = -\sin\delta\sin\phi\cos\gamma_i + \cos\delta\sin\phi\cos\gamma_i\cos\omega + \cos\delta\sin\omega\sin\gamma_i$$

where δ is declination, ϕ is latiude, ω is hour angle and δ is solar azimuth angle (5). For horizontal surface

$$I_5 = I(\theta_z)\cos\theta_z(1 - CF) + D(\theta_z, CF) \quad W/m^2 \tag{4}$$

The transmitted solar energy through the glasses is assumed to be absorbed partially by the surrounding walls and roof uniformly and the remainder by the room air. For the surrounding walls the radiation flux is

$$q''_w = \sum_{i=1}^{k} \frac{A_{g,i} I_i}{A_{w,i}} (1 - \rho_s)\tau \quad W/m^2 \tag{5}$$

and the absorbed solar energy by the room air is

$$\dot{Q}_{s,a} = \sum_{i=1}^{k} A_{g,i} I_i \rho_s \tau \tag{6}$$

where k may vary from 1 to 4. A_w is total surface area of the sidewalls and ceilling, $A_{g,i}$ is glass window area of each side, τ is solar transmissivity of the glasses, and ρ_s is solar relectivity of the walls surface. Note, it is assumed that the side walls and roof have the same thermal properties and equal surface characteristics to solar radiation.

Knowing the radiation characteristics, the room air temperature T_R can be determined by writing instantaneous energy balance for any time as follows,

$$\dot{Q}_{in} - \dot{Q}_{out} = \dot{Q}_{acc} \tag{7}$$

where

$$\dot{Q}_{in} = \sum_{i=1}^{k} A_{g,i} I_i \rho_s \tau + \sum_{i=1}^{5} A_{w,i} h_1(T_{o,i} - T_R) \tag{8-1}$$

$$\dot{Q}_{out} = \sum_{i=1}^{k} A_{g,i} U_g(T_R - T_A) + A_f U_f(T_R - T_E) + \dot{m}_v C_{p,a}(T_R - T_A) \tag{8-2}$$

$$\dot{Q}_{acc} = m_R C_{p,a} \frac{dT_R}{dt} \tag{8-3}$$

where k may vary from 1 to 4. Note $T_{o,i}$ is inside surface temperature of each wall or roof, $A_{w,i}$ is surface area of each wall or roof, A_f is floor

area and U_f is overall heat transfer coefficient between the room and the ground, $\dot{m}_v$ is ventilated air mass flow rate, $C_{p,a}$ is air specific heat, T_A is ambient air temperature, m_R is room air mass, U_g is overall heat transfer coefficient of the glasses, t is time and T_E is the ground temperature. Substituting above quantities in equation 7 results:

$$\frac{dT_R}{dt} + \beta T_R = \eta(t) \tag{9}$$

where

$$\beta = \frac{\sum_{i=1}^{k} A_{g,i} U_g + \sum_{i=1}^{5} A_{w,i} h_1 + A_f U_f + \dot{m}_v C_{p,a}}{m_R C_{p,a}}$$

$$\eta(t) = \frac{\sum_{i=1}^{k} A_{g,i} \rho_s \tau I_i + \sum_{i=1}^{5} A_{w,i} h_1 T_{o,i} + \sum_{i=1}^{k} A_{g,i} U_g T_A + \dot{m}_v C_{p,a} T_A + A_f U_f T_E}{m_R C_{p,a}}$$

$T_{o,i}$, walls' inside surface temperature could be determined by assuming one dimensional transient heat conduction in the walls. In such cases diffusion equation in unsteady state conditions reduces to

$$\frac{\partial T_i}{\partial t} = \alpha \frac{\partial^2 T_i}{\partial x^2}, \qquad i = 1,5 \tag{10}$$

where α is thermal diffusivity of the walls and roof materials, and x is distance along the depth of the wall. Corresponding boundary conditions for inside and outside of each wall or roof is

$$k \left.\frac{\partial T_i}{\partial x}\right|_{in} + f_{ii}(t) = h_1(T_{o,i} - T_R), \qquad i = 1,5 \tag{11}$$

$$k \left.\frac{\partial T_i}{\partial x}\right|_{out} + f_{o,i}(t) = h_2(T_{s,i} - T_A), \qquad i = 1,5 \tag{12}$$

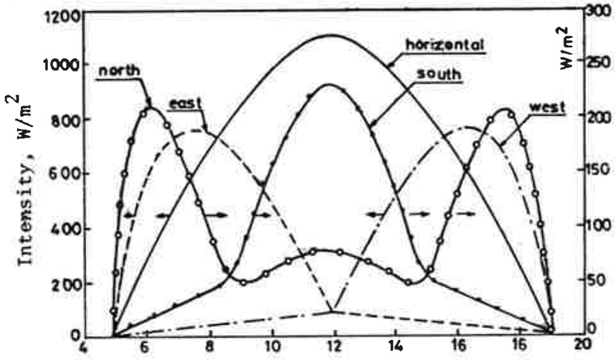
where $T_{s,i}$ is outer surface temperature of each wall or roof, h_1, and h_2 are inside and outside convection heat transfer coefficients, $f_{i,i} = q''_w$ and $f_{o,i} = (1 - \rho_s)I_i$.

Results

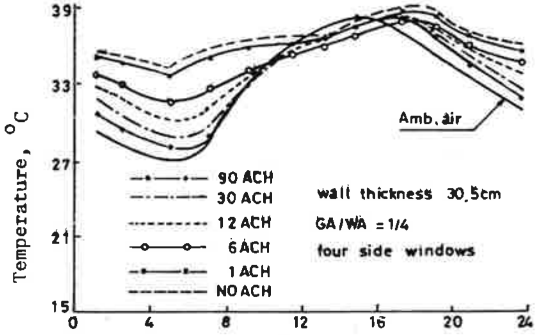
A parametric study has been carried out to determine systematically the appropriate ventilation model and window orientation for a room with dimensions 9.14m × 9.14m × 3m and with different wall thicknesses. Solar radiation components were determined by using equations 1 through 4. The room temperature T_R was determined by solving equation 9 and 10 simultaneously (6). Equation 9 was solved by Runge-Kutta method and equation 10 was solved by finite-difference method employing Crank-Nicolson technique. Solution was carried for a day with Δt = 1hr and with an assumed initial condition at t = 0. Climatical conditions used in the thermal processes are the recorded data of June 22 of the city of Yazd with 31.9 North latitude (3). The room walls and roof assumed to be from common brick with $\alpha = 0.438 \times 10^{-6}$ m²/s and $k = 0.63$ W/mK. It was also assumed that $\rho_s = 0.24$, $\tau = 0.8$, $h_1 = 11.8$ W/m²K, $h_2 = 34$ W/m²K, $U_f = 0.28$ W/m²K and $T_E = 18.3$°C(6).

Global solar radiation for different vertical orientations for the June 22 in Yazd is shown in Fig. 2. Note that solar radiation on the horizontal surface is much more than on the vertical orientations.

The effect of continuous air-change on the room air temperature (RAT) together with the out door air temperature is shown in Fig. 3. where ACH denote the room air changes per hour. Note that the room has windows on all sides with the glass area of ¼ of the corresponding wall area (GA/WA = ¼). For no ventilation the RAT is almost flat and nearly higher than the ambient air temperature, which is due to the transmitted solar radiation into the room from all sides. When ventilation permitted the RAT tends to flactuate and for 90 ACH the RAT approaches that of the outdoor air but with 1 to 2 hours lag. Similar observation is found by Chen and Mitchell (2). However, the higher the air-change the larger is the fluctuation amplitude of the RAT. When there is only north and south windows and no ventilation, the RAT has dropped significantly. However, the room with thicker walls gets higher temperature, since it's walls have higher resistance to the transmission of heat which is entered to the room by solar radiation.



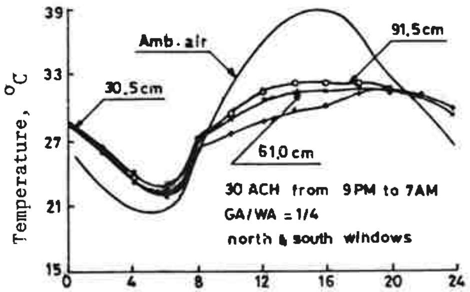
Time of Day, Hour
Fig. 2. Global irradiance on different surface at June 22 in Yazd.



Time of Day, Hour
Fig. 3. Effect of continuous ventilation rates on the RAT.

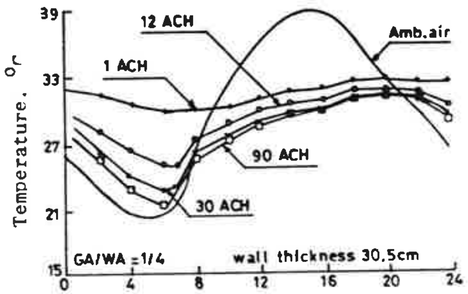
Fig. 4 shows results of only night ventilation. RAT has dropped remarkably by comparing with Fig. 3. It also indicates that the thinner wall keeps the RAT lower than thicker ones. However, the effect will be reversed if considering a room without any windows (6).

Fig. 5 illustrates the enfluence of various night ventilation rates on the RAT. High air-changes during the night improved the room air conditions during the day and kept it within an acceptable range of thermal.confort.



Time of Day, Hour
Fig. 4. Effect of night ventilation on the RAT with various wall thikcnesses.

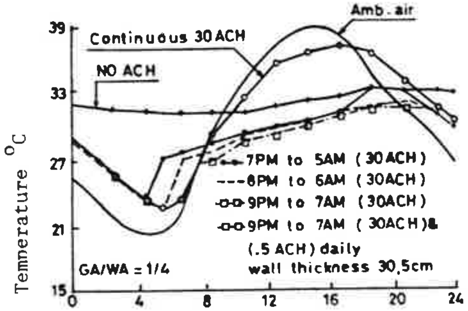
Controlling nigth ventilation period for certain hours when the ambient temperature is lower than the inside temperature, the room finds out a lower air temperature during the day as shown in Fig. 6. It indicates that for a room with north and south windows of ¼ of the corresponding wall area, the RAT at 2 PM is around 29°C while the outside air temperature is 38°C. Such as an inside condition is convenience for the dwellers in the hot arid zones of Iran.



Time of Day, Hour
Fig. 5. RAT for various night ventilation rates (9 PM to 7 AM).

Conclusions

Solar radiation arrived in the rooms in the hot arid regions of Iran has considerable influences on the room air temperature increase. In these regions natural comfort could be achieved during the hot summer days by night ventilation and appropriate selection of window sizes and their orientations. In the new housing developments, construction of east and west windows should be discouraged and north and south windows should be made as small as possible. Ventilation rates of 12 ACH to 30 ACH during the cold period of night should be incouraged and air-changes and infiltration should be avoided during the day.



Time of Day, Hour
Fig. 6. RAT with Controlled ventilation rates.

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