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# Enhancing Thermal Efficiency of Double Skin Façade Buildings in Semi-Arid Climate

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***Abstract*—**There is a great deal of interest in constructing Double Skin Facade (DSF) structures which are considered as modern movement in field of Energy Conservation, renewable energies, and Architecture design. This trend provides many conclusive alternatives which are frequently associated with sustainable building. In this paper a building with Double Skin Facade is considered in the semi-arid climate of Tehran, Iran, in order to consider the DSF's performance during hot seasons. Mathematical formulations calculate solar heat gain by the external skin. Moreover, Computational Fluid Dynamics (CFD) simulations were performed on the case study building to enhance effectiveness of the facade. The conclusion divulged difference of gained energy by the cavity and room with and without blind and louvers. Some solutions were introduced to surge the performance of natural ventilation by plunging the cooling loads in summer.

***Keywords*—**Double Skin Façade Buildings, Energy Conservation, Renewable Energy, Natural Ventilation, Semi-arid Climate.

## I. INTRODUCTION

THERE is an increasing demand to improve the efficiency of all glazed skyscrapers and office buildings. Occupants and designers endeavor to make a simulating indoor environment. DSF is considered as applicable solution for this issue [3], [4]. The DSFs are driven by:

- Decrease of energy consumption by HVAC system which helps the building designs approaches to the concept of green buildings [1], [2].
- Increasing transparency; Architects often prefer the envelope to be covered with a high percentage of relatively clear glass which also provides visual comfort within the building around the perimeter [2], [11].
- Reduction of energy consumption by relying on natural lighting; DSFs combines a number of features such as low emissivity glasses, argon-filled double-glazed units, triple-glazed units, glazing with selective coating, and V-cool glasses [1], [2], [13].
- Improving indoor environment; Sun as a source of natural lighting can materially improve the performance of the human activities that are happening inside the building. This feature also has positive financial effects as well [12].
- Enhancing acoustic insulation [11].
- In comparison to other building efficiency improvement solutions such as use of ELECTROCHROMIC, THERMOCHROMIC, PHOTOCROMIC panes, which are considered as expensive devices, Double Skin façade relies on lower construction cost. Moreover, DSFs can be available in variable climates and geographical coordinates [11].

By providing natural ventilation, airflow passes through the cavity, so the windows during the night can be opened and indoor environment can benefit the cool outdoor air. As a result the HVAC system performs in low level, however, if the DSF is not designed accurately, so the lack of natural ventilation can cause increase in cooling load during hot seasons in semi-arid conditions such as Tehran [10], [11].

## II. SOLAR HEAT GAIN BY A VERTICAL SURFACE IN TEHRAN

The Heat Transfer between external skin and air is characteristic which affects forced convection and also natural convection processes. Convection Coefficient as a crucial feature in heat transfer and natural ventilation depends on air velocity as varies by geographical conditions, building orientation and site surroundings. Moreover, heat transfer is most affected by cloud cover, atmospheric humidity, and air pollution [1], [2].

Solar Energy exists at two categories: short wavelength and long wavelength. Long wavelength heat transfer occurs among inside surfaces such as: windows, floors, ceiling, and walls [1].

Total heat gain by the external skin occurs by three components: direct radiation, sky-diffuse, ground-reflected [2]. Additionally convective heat transfer can increase the total amount of heat gain [17], [18]. Conductivity and material thickness must be applied directly in conduction calculations [1].

The amount of radiation out of the Earth's atmosphere [16]:

$$\overline{H}_0 = \frac{24 \times 3600 G_{SC}}{\pi} \times$$

$$\left(1 + 0.033 \cos\frac{360n}{365}\right)\left(\cos\phi . \cos\delta . \sin\omega_s + \frac{\pi}{180}\omega_s . \sin\phi . \sin\delta\right)$$

where $G_{sc}$ is solar constant and $G_{sc} = 1372\ w/m^2$

δ is the declination angle (the angular solar position at noon):

$$\delta = 23.45\, sin(360\ \times \frac{284 + n}{365})$$

$\omega_S$ is the hour angle at sunrise and sunset:

$$\omega_s = arc\,cos(-\,tan\,\varphi . tan\,\delta)$$

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where φ is latitude and $n$ is the number of day after the beginning of January.

Monthly average Clearness index:

$$K_T = \frac{\overline{H}}{\overline{H}_0}$$

where $\overline{H}_0$ is the extraterrestrial radiation for the location averaged over the time period on a horizontal surface.

$$\overline{K}_T = f(T, R, P, S)$$

For Tehran: $K_T = 0.8417\,S + 0.02332\,T - 0.03184\,ST$

Where T is temperature in Celsius, R is the percentage of relative humidity, P is the precipitation in mm, and S is the fraction of sunshine hours [21].

TABLE I
MONTHLY AMOUNT OF $K_T$ IN TEHRAN

| **Month** | **Jan.** | **Feb.** | **Mar.** | **Apr.** | **May** | **Jun.** |
|---|---|---|---|---|---|---|
| $K_T$ | 0.449 | 0.484 | 0.493 | 0.534 | 0.583 | 0.596 |
| **Month** | **Aug.** | **Oct.** | **Nov.** | **Sep.** | **Dec.** | **Ave.** |
| $K_T$ | 0.611 | 0.616 | 0.549 | 0.517 | 0.464 | 0.532 |

Clearness index $(\overline{K}_T)$ is a measure of solar radiation attenuation at a location due to geographic-atmospheric parameters [14].

The ratio of diffusion radiation intense to total radiation intense:

$$\frac{\overline{\mathrm{H}}_{\mathrm{d}}}{\overline{\mathrm{H}}} = \begin{cases} 1.39 - 3.560K_t + 4.189{K_t}^2 - 2.13{K_t}^3 \omega_s \leq 81.4 \\ 1.311 - 3.022K_t + 3.427{K_t}^2 - 1.82{K_t}^3 \omega_s \leq 81.4 \end{cases}$$

It is possible that after sun rising, the radiation does not receive to the related surface. So the $\omega'_s$ is calculated as it is shown:

$$\omega'_s = \min\left( \begin{matrix} \arccos(-\tan\phi \, . \tan\delta) \\ \arccos(-\tan(\phi - \beta). \tan\delta) \end{matrix} \right)$$

Total heat gain by the external skin occurs by 3 components: direct radiation, sky-diffuse, ground-reflected [2] [5].

The ratio of direct radiation on inclined to horizontal surface [16]:

$$R_b = \frac{\cos(\phi - \beta). \cos\delta . \sin\omega'_s + \frac{\pi}{180}\omega'_s . \sin(\phi - \beta). \sin\delta}{\cos\phi . \cos\delta . \sin\omega_s + \frac{\pi}{180}\omega_s . \sin\phi . \sin\delta}$$

Total amount of radiation on the associated surface [16]:

$$R = \left(1 - \frac{\overline{H}_d}{\overline{H}}\right) R_b + \frac{\overline{H}_d}{\overline{H}}\left(\frac{1 + \cos\beta}{2}\right) + \rho\left(\frac{1 - \cos\beta}{2}\right)$$

Finally, intense of bet radiation on inclined surface can be calculated from the below:

$$\overline{H}_t = R \times \overline{H}$$

The amounts of radiation per day during a year in Tehran where the surface is located vertically are indicated in the below table:

TABLE II
MONTHLY RADIATION PER DAY – VERTICALLY SURFACE - TEHRAN

| **Month** | **Jan.** | **Feb.** | **Mar.** | **Apr.** | **May** | **Jun.** |
|---|---|---|---|---|---|---|
| ***MJ/m²day*** | 12.98 | 14.20 | 13.14 | 11.75 | 11.06 | 11.24 |
| **Month** | **Jul.** | **Aug.** | **Sep.** | **Oct.** | **Nov.** | **Dec.** |
| ***MJ/m²day*** | 11.31 | 12.05 | 14.13 | 14.08 | 14.15 | 13.03 |

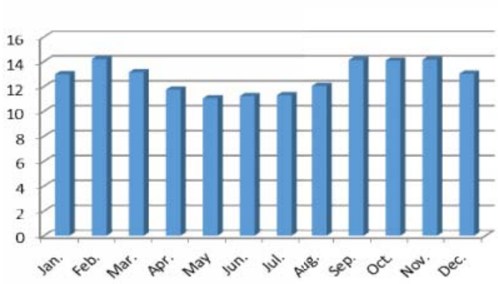

Fig. 1 Monthly Radiation per day – Vertically Surface – Tehran – MJ/$m^2$

Total annual amount of radiation = 153.11 *MJ/*$m^2$
Sum of cold months = 81.58 *MJ/* $m^2$*day*
Sum of warm months = 71.52 *MJ/* $m^2$*day*
Mean amount of radiation = 12.76 *MJ/* $m^2$*day*

As the report of NASA, Iran is known as a high radiation area and mean annual radiation in Tehran is announced 4.58 kw.hr/$m^2$.day [23]. In addition table and chart indicate radiation in Tehran because of semi-arid conditions even in cold seasons in comparison with European climates which DSFs utilize commonly, are considered as high radiation, however, the case studied has four faces that radiation during the day is various.

To simulate the air flow through the cavity, there is a continuous means heat flux during the day that impact considerably fluid analysis and natural ventilation.

TABLE III
MONTHLY RADIATION PER DAY – VERTICALLY SURFACE - TEHRAN

| **Month** | **Jan.** | **Feb.** | **Mar.** | **Apr.** | **May** | **Jun.** |
|---|---|---|---|---|---|---|
| **W/$m^2$** | 150.23 | 164.35 | 152.08 | 135.99 | 128 | 130.09 |
| **Month** | Jul. | Aug. | Sep. | Oct. | Nov. | Dec. |
| **W/ $m^2$** | 130.90 | 139.46 | 163.54 | 162.96 | 163.77 | 150.80 |

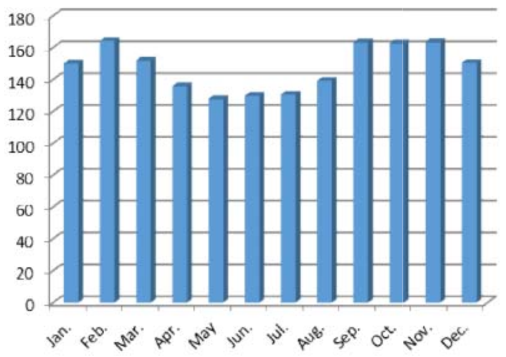

Fig. 2 Radiation – Vertically Surface – Tehran – *MJ/$m^2$*

TABLE IV
UNITS FOR SOLAR HEAT GAIN PROPERTIES

| Symbol | Quantity | SI |
|---|---|---|
| $\bar{H}_0$ | Extraterrestrial radiation for the location averaged over the time period on a horizontal surface | J/$m^2$ |
| $G_{sc}$ | Solar Constant | w/$m^2$ |
| $\delta$ | Declination angle | Degree |
| $\omega_s$ | Angular displacement of Sunrise and Sunset | Degree |
| $\varphi$ | Latitude | Degree |
| $n$ | Number of day after the beginning of January | Dimensionless |
| $K_T$ | Monthly average Clearness index | Dimensionless |
| $\bar{H}$ | Total radiation intense | J/$m^2$ |
| $\bar{H}_d$ | Diffusion radiation intense | J/$m^2$ |
| $R$ | Percentage of relative humidity | Dimensionless |
| $P$ | Precipitation | mm |
| $S$ | Fraction of sunshine hours | Dimensionless |
| $\bar{H}_t$ | Intense of bet radiation on inclined surface | J/$m^2$ |
| $T$ | Temperature | ºC |
| $\bar{K}_T$ | Clearness index | Dimensionless |

J= joule, m= meter, W= watt, C= celsius

## III. CONSTRUCTION PROPERTIES OF CASE STUDY

The building under study is the “Supreme Audit Court” in Tehran, which is located in $(35^{\circ}41'N, 51^{\circ}19'E)$ and is oriented $45^{\circ}$ towards south-east. The DSF is designed on all equal four faces from second floor up to the last one. The office rooms are on the four sides of the facade with a depth of six to seven meters. There are 17 office rooms on each floor with 20–25 persons working there [10]. Cavity width is 70cm [10] (75 cm [15]) and there are two to four windows on the inner skin that can be opened to benefit the natural ventilation and fresh air, however external skin is designed without openings. Lack of natural ventilation through the cavity can influence indoor environment. Outer façade and inner façade are 6mm and 4mm single glazing respectively. This building’s DSF is classified as corridor façade separated vertically at each two floors and this especial design cavity on north-east (NE) and south-east (SE) are connected and south-west (SW) and north-west (NW) facades are connected too [7], [10]. The ratio of the vents’ area to the facade area on each side at sixth and seventh floor is 9.3% for the upper vents, 2.8% for the lower vents and 5.75% for the middle vents. These ratios for the 10th and 11th floors are 1%, 5% and 16% respectively [10]. In CFD analysis the ratio of intake vents and outtake vents are considered important to improve the natural ventilation by stack effect.

In comparison single façade and DSF, maximum surface temperature of the external skin with DSF in summer and winter are less than single façade [10]. This reduction refers to the cavity and the air flow which passes through it.

## IV. NATURAL VENTILATION

The thermal performance of a DSF depends on the material properties and geometric configuration. Proper operation of the system is crucial to improve the energy savings. The design of the DSF involves decisions on geometric parameters, glass selection, and ventilation strategy, shading devices, day lighting, aesthetics, wind loads, and maintenance and cleaning cost expectations. Previous studies indicate the lack of natural ventilation as the prime cause to increase cooling load during the hot seasons. In summer, in comparison to single façade, the cooling load decreases during the day, however at night, it increases [10]. Most strategies to ventilate are using the idea of stack effect and in the case of the continuous DSF, the mass flow rate is higher due to trapped heat over the height of the cavity assisting the buoyancy effect as higher temperature differences between the cavity and ambient temperatures [17]. The height of the facade and the size of the openings can be adjusted to maximize the preheating and to prevent overheating in the room [19]. There are some solutions to prevent overheating:

- For air to move into and out of a building, a pressure difference between the inside and outside of the building is required. The resistance to flow of air through the building will affect the actual air flow rate. In general, controlled natural ventilation and infiltration are driven by pressure difference across the building envelope. The pressure difference is caused by: wind, difference in air density due to temperature difference between indoor and outdoor air (stack or chimney effect) [6], [8], [9], [23]. The orientation of the building and also neighboring buildings affect directly weather parameters such as wind pressure, wind direction dry bulb temperature and air pollution which influence heat gain and stack effect calculation. Consequently, natural ventilation may perform improperly. Hence, skyscrapers and highways can make a substantial impact on primary calculations.

- Shading devices: The analyzed DSF consists of an external layer made of an integrated glass-shading device system that make it possible to take advantages from DSF design in cold weather as well as the cooling load reduction derived from the shading system in summer. During heating season, the shading devices should be horizontal, therefore solar radiation can pass through the facade because the low altitude of the sun above the horizon allows a direct gain, together with an indirect contribution linked to multiple reflections of the slat surface constituting the shading system. In cooling season, to avoid overheating, the shading devices should be adjusted with a high tilt angle, to reflect part of the solar radiation [20], [21], [22].
- Optimized position of shading devices position: The lowest temperature were obtained in small simulation when the louvers are located outside and close the external skin, however according to experiments, there is a relative small temperature difference when the louvers are located in the cavity [18] which is more suitable to maintenance. It is highly important to make a continuous ventilation to avoid overheating by louvers.
- Various colors louvers: The color of the louvers influences the absorbed heat by them. In comparison of three diverse colors, White - Black – Grey, the lowest temperatures were obtained by white louvers, nevertheless, using less reflective louvers helped to reduce more efficiently the amount of heat transferred to the room. By using the black louvers because of the lower radiation reflected to the room, room temperature was lower than using the white ones. This clearly indicates that the darker the shading devices, the more efficient the stack effect inside the cavity and airflow through the cavity. Thus for cooling: the first factor to control is shading, the second is ventilation.
- Lighting and transparency: The best levels of lighting were achieved when the louvers were positioned close to the inner skin and the lowest visible light levels were obtained when the blinds were behind the external skin. The levels of luminance in average have a reduction by 30% and 50% for the black to white louvers grey to white respectively. It has demonstrated that decreasing reflectivity also contributes to a decrease in visible light reflectance, which is the key element in natural lighting.

The black surface was facing the light source thus convective heat transfer was increased, and the white surface was facing the room and consequently the luminance levels were not as low as when using fully black louvers [18].

## V. CONCLUSION

In this study, the DSF construction properties of a case building in semi-arid climate of Tehran are considered. Previous studies has demonstrated cooling load problem during the hot seasons in weather condition such as Tehran. Calculating the total amount of heat gain and regarding the other features that can make an impact on natural ventilation are crucial. As a result enhancing the performance of natural ventilation continuously and installation of the louvers with optimized color in proper position can solve the cooling load problem.

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