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Saving Energy Through Improving Performance of Double Skin Facades: A Case Study Residential Building in Yazd

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A B S T R A C T

The building envelope is one of the most influential factors in energy consumption. Therefore, optimizing the facade of the building with new technologies is one of the most effective passive solutions to provide thermal comfort. The purpose of this research is to design a composite facade, which according to the two main driving forces; the pressure difference caused by the heat flow (air flow and wind force) and the insulation of the air, for a residential building with a typical plan of Yazd in the hot and dry climate of Iran. That can be used to reduce the heating and cooling load of the building. For this purpose, firstly, the effect of two types of two-skin facades - floor-to-floor and all-over two-skin facades - compared to the model without two-skin facades in cooling and heating energy consumption throughout the year was modeled and analyzed with Design Builder version 6.1 software. The results of the constructions show the possibility of reducing about 60% of cooling energy through the creation of air conditioning and 26% of heating energy through the creation of thermal insulation in the residential building simulation model throughout the year by means of two combined shells. The findings of this research lead to the creation of more efficient energy solutions by creating innovation and combining new technologies according to climatic conditions.

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INTRODUCTION

Today, energy conservation is a critical worldwide issue, leading architects to consider sustainable approaches in designing built environments [1]. In recent decades, architectural projects, due to an improper imitation of dominant movements, consume more energy for thermal comfort [2]. The importance and necessity of this issue are the main motivation for architects to use new solutions in tune with sustainable approaches to reduce the consumption of traditional energy resources and increase the level of human comfort. On a global scale, dynamic and static architectures address the issue of energy compatibility [3]. While increasing energy efficiency and reducing energy consumption for heating and cooling, these solutions also try to provide an aesthetically pleasing appearance and support sustainable architecture. In recent years, indigenous research has followed these strategies in hot and dry climates and attempted to minimize the amount of energy consumption by using modern design strategies. Most traditional houses in Iran were designed based on climatic principles and demands. All of them were built to fulfill stakeholders' different requirements [4]. Nowadays, from the point of view of using conceptual ideas of traditional indigenous architecture, solutions such as windshields in a slender element form in high-rise buildings seem illogical. Still, its conceptual idea for the problem of natural ventilation leads the mind to what happens if the walls act like a super-windcatcher? Indeed exterior covering of building plays a fundamental role in controlling the condition of the internal environment [5]. In other word, building facades have a significant impact on the reduction of natural gas and electricity consumption because they are the boundary between the interior and exterior of the building [2].

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The idea of Double-skin Facade (DSF) technology, which is composed of an external facade, an inter-mediate space and an inner facade, as an effective solution in this field is under the category of adaptable facades and the passive wall [6]. Today, the DSF, along with the aesthetic aspects and the powerful visual connection that establishes the interior and exterior of the building, has become one of the most prevalent energy-saving design technologies in the world [7].

Double-Skin Façade (DSF)

The principle of sustainable development in the built environment makes the study and decision-making for the application of new systems for the facade of buildings necessary to achieve thermal comfort. The double-skin facade consists of two walls, usually glass, separated by an air cavity or buffer zone; The cavity uses natural ventilation to drain the heat flow through the façade elements or mechanical systems. Verification of the performance of this system largely depends on the local climatic characteristics and design conditions [8]. Various terms are used to name two-skinned views that do not evoke well-defined concepts. There are different classifications for two-shell facades, but most of them are based on the type of geometry between the two shells, such as facade partitioning, opening width, height, and depth of space between the two shells [9]. Figure 1 presents the types of double-skin facades based on the type of ventilation and the variety in the area between the two facades.

Determining the appropriate and optimal size for different parts of the components of different types of double-skin facades is related to many factors such as climate, efficiency, employment level of the building, and the building's need for natural ventilation. Proper design of this type of facade can increase the circulation of airflow in the middle and inside the building in a completely passive way.

LITERATURE REVIEW

Undoubtedly, the main part of energy consumption in the building is related to heating, cooling, and air conditioning. The external shell of the building is a very important factor that determines the quality of the indoor environment, regardless of the unstable external conditions. The building's energy demand is not closely

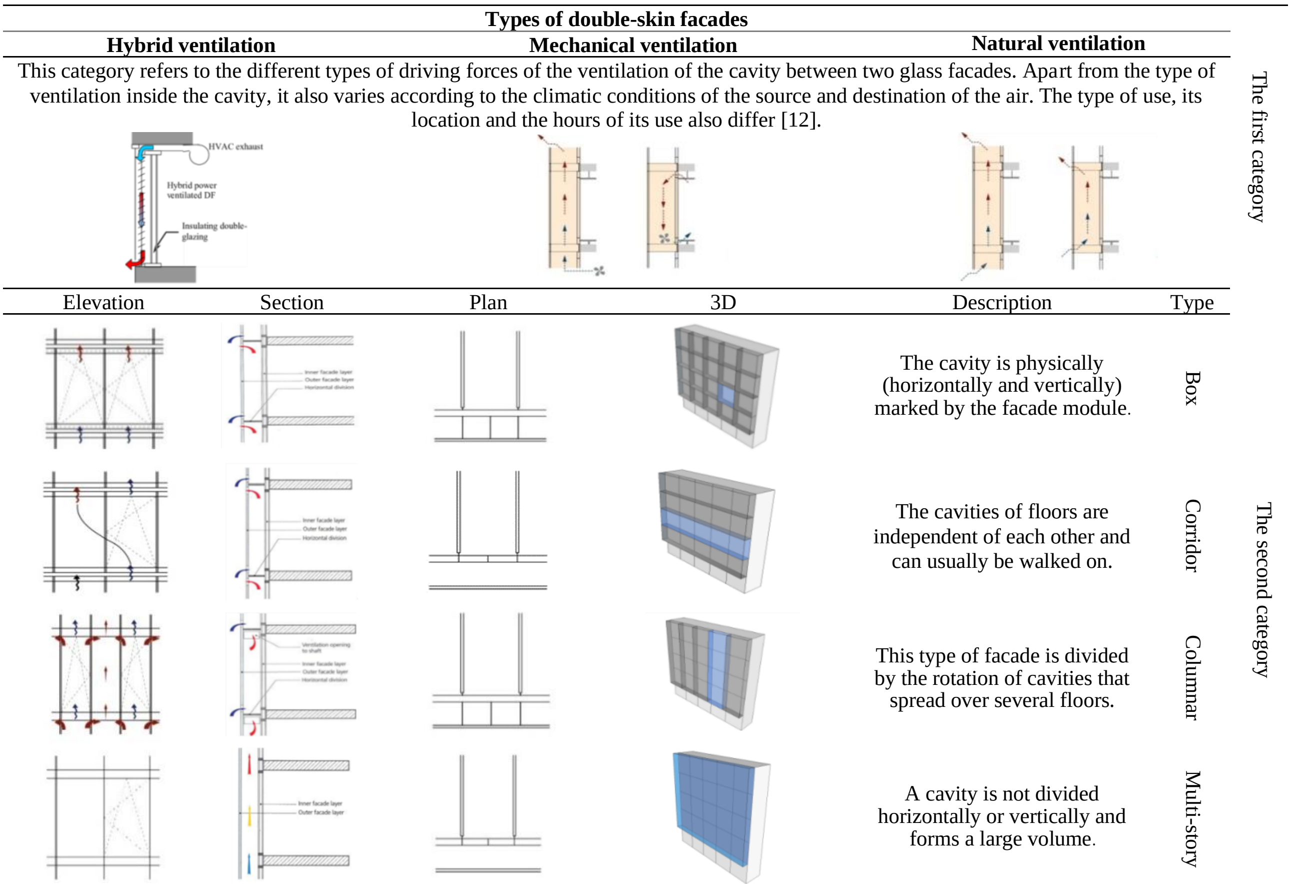

Figure 1. Classification of DSF based on the type of ventilation and variety in the area between the two facades related to the efficiency of the outer shell [10, 11].

In research conducted by Afshinmehr et al. [13] in order to take advantage of natural ventilation in summer, the number and dimensions of facade vents and their location in buildings in hot and dry regions of Iran, modeling, and results of two the peeling of facades has been investigated. The results of the software show that the two-shell facade has increased the use of natural ventilation and reduced the use of air conditioning systems, thus improving indoor air quality.

Through simulation using Fluent and Design-Builder software, it has been determined that these types of shells have a high potential in reducing consumption. Buildings have energy in the hot and dry climate of Iran. Of course, in this case, ventilation of the space between the two shells has been considered necessary to prevent flare-ups in summer [10]. In another research, it has been shown that the major results come from the natural ventilation conditions in the facade of the two shells, which are influenced by the size of the window openings. The depth of the gap and the size of the ventilation valve have the most complex effect on the ventilation rate. For example, a greater gap depth increases the counter flow at the top and an unnecessarily long valve weakens the heat transfer [14]. Also, other research results have examined the changes in energy performance among the types of two-shell facades according to the construction characteristics and the width of the air cavity. Overall, with a naturally ventilated air cavity, the double-skin facade system shows a potential reduction in annual cooling energy consumption of 22% compared to the benchmark. The use of mechanical ventilation in the air cavity can potentially reduce the annual cooling energy consumption of the building by 32%. Different typologies of two-shell facades examined in this research have shown changes in energy performance according to their design features. Meanwhile, the box type and the shaft type have the best energy performance in the demand for annual cooling, which is 22% and 17%, respectively. Also, Zomorodian and Tahsildoost [11] showed that the box and shaft models are more acceptable from the point of view of overall carbon emissions. In an article, the efficiency of this type of facade in the climate of Tehran city, in an office building in different options with and without a double-skin facade, it is modeling, and energy performance has been investigated by EQUEST simulation software, and the results show that the use of a double-skin facade in comparison with the single-skin facade leads to a 16-20% reduction in the energy consumption of the building's HVAC system [15]. Mirmohammadi and Taghizadeh [16] studied by comparing the view of two crusts in two different climates using software; it was concluded that in Moscow, the cooling load decreases by 33% and the heat load decreases by 5.9%, and in Yazd, 30 % in the cooling load and 17% in the cold load. Zomoredian and Tahsildost [11] simulated and evaluated the design process of the DSFof an office tower in Tehran. The obtained results show a 14.8% reduction in the need for heating, as well as an improvement in indoor air quality in the cold period, compared to a single-skin facade.

There are extensive research that have been done on office buildings and in the cold climate of Europe and North America [17, 18]. However, the hot and dry region is the widest climate in Iran [4]. Many regions of Iran are deserts, and Yazd (the sample studied in this research) is located in the center of the Iranian plateau. Therefore, about DSFs, this study intends to propose that, in addition to natural ventilation in summer, it causes less energy consumption in winter. For this purpose, a review of related theoretical frameworks has been accomplished and the types of DSFs' classification and their function have been studied. Residential buildings, which are known as one of the main factors of global warming due to high energy consumption [19] are often neglected. Also, Kim has investigated the thermal performance of DSFs in hot climate conditions in Saudi Arabia, proved in his paper that the proper design of a DSF system provided a better thermal performance so that the cooling energy in buildings can be reduced [20].

Aksamija [21] pointed out that DSFs perform better for insulation and trapping heat in the cold winter months than single skins in reducing annual consumption.

In research, natural ventilation conditions with DSF in an office building in a hot and dry climate (Shiraz) were investigated and simulated using Design Builder version 4.5 [5]. According to the analyzes carried out on parameters and influencing factors such as wind speed, temperature, distribution pattern, and air flow circulation, the Corridor Double Skin Façade is a favorable option for a hot and dry climate.

Hashemi his colleagues [22] investigated the effect of using two shells in the building of the Court of Accounts (located in Tehran) through experimental measurement and modeling in EnergyPlus software. While comparing the thermal performance of buildings with double-skinned facades with buildings without them, this study determines the strategies for using double-skin facades in hot and dry climates of Yazd.

Also, other research results [5, 11] have investigated the changes in energy performance among the types of double-skin facades according to the structural characteristics and the width of the air cavity. With a naturally ventilated air cavity, the two-skin facade system shows a potential annual reduction in cooling energy consumption of 22% compared to the benchmark for the hot and humid climate of Dubai [8], while by applying mechanical ventilation in the cavity air can reduce energy consumption by 32 percent. In addition, the different typologies of two-shell facades studied in this study have shown changes in energy performance according to their design features. Meanwhile, box type and shaft type have the best energy performance in demand for annual cooling, which is 22% and 17%, respectively.

Tao et al. [14] have shown that the main results are due to the natural ventilation conditions in the facade of the two shells, which are affected by the size of the window openings. The depth of the gap and the size of the ventilation valve have the most complex effect on the amount of ventilation. For example, deeper gaps increase the upstream flow at the top, and longer unnecessary valves weaken heat transfer.

In addition Zomorodian and Tahsildoost [11] demonstrated in their paper that box and shaft models are more acceptable in terms of overall carbon emissions.

Gashniani and Yazdani [23] showed that the bilayer plays an important role in the speed and pressure between the shells compared to the external environment and it is effective in regulating it for use in ventilation even in a city like Manjil, due to the high wind speed which is minimized the use of balconies and openings.

The overall behavior of the bilayer is very complex due to several physical phenomena that occur simultaneously (air movement and convection, conduction, and short and long-wave radiation). For optimal performance, two-layer facades should be used according to different climatic conditions, in the appropriate pattern or type, and with appropriate geometrical specifications and dimensions.

According to the studies, double-skin facades generally have high initial costs and high maintenance costs [24]. For this reason, researchers are trying to achieve the most optimal method by combining different technologies and solutions to reduce energy consumption in the building in the long term. For instance, Aeinehvand and his colleagues [25] proposed two different solutions to increase the amount of natural ventilation of a residential building in the humid climate of Yazd city. The first solution was the combination of a double-skin facade and a one-way wind tower, and the second solution was a two-way wind tower. According to the simulations in the Design Builder software version 4.5, increased the amount of natural ventilation during the summer by 10% and 38%, respectively.

Therefore, the development of construction techniques so is extremely important and necessary to guarantee thermal comfort and low energy consumption [26].

In order to achieve natural ventilation throughout the year in the hot and humid climate of Yazd city, in a research proposed by Mousavinejad and Monfared [27] a design that combined multi-story double-skin facade and vertical cavity double-skin facade for the southern facade of the building, which flexibility reduces the weaknesses of the double-skin facade. and keeps the building in a reasonable temperature range in different seasons.

The need to save energy, improve the quality of indoor space, and increase energy-related efficiency has encouraged researchers to study and experiment in different laboratory conditions or computer simulations in this regard. Most of the previous research has investigated the performance of a double-skin facade in commercial and office buildings without specific climate planning. In addition to calculate and compare the cooling load in the first half of the year, the current study has conducted a study on three models with the sample plan of Yazd city for residential buildings.

Ventilation in the building

Cooling by ventilation includes natural ventilation and night ventilation. Natural ventilation, as the main technique of cooling, is the natural flow of air induced by temperature and pressure differences [1]. A traditional (wind tower) wind catcher is a special a traditional wind catcher (wind tower) is an architectural solution that has been used for centuries and provides natural ventilation in buildings. The combination of buoyancy and stack effect based on temperature changes with different changes in the direction and intensity of wind flow causes changes and creates positive and negative pressure fields. These factors are emphasized in geographical locations with very different levels during day and night. This solution for passive cooling, ventilation, and air purification, in hot and dry climates was developed and used frequently by an unknown architect from ancient times [3].

Therefore, this article examines the issue of natural ventilation regarding double-skinned facades as a responsive option in providing thermal comfort conditions for buildings in hot and dry climates in the current conditions, and in this direction, studies the city of Yazd as a case study.

MATERIAL AND METHODS

Despite the many studies that have been carried out on the DSF, so far, no specific study has been done to design a suitable DSF that will reduce the heating and cooling load of the residential building throughout the year. While due to the weather conditions of this climate, it is very necessary to design a passive system that provides both thermal comforts in winter and summer.

In this research, we tried to design a new DSF for a residential building in the hot and dry climate of Yazd, considering the combination of the climatic conditions and the technology of the DSF.

Climate data

The case study, Yazd due to its geographical location on the central plateau of Iran, has a hot and dry climate. In order to collect data on thermal comfort and natural ventilation in the selected climate (Yazd, Iran), climate consultant software has been used. Figure (2) shows the psychometric chart of Yazd. The area of the blue squares marked on the right indicates the comfort zone in the summer. As shown in Figure (2), activating the natural ventilation option increases the comfort range in summer to the size of a green square (8%- 651 hours).

According to the outputs of Climate Consultant software, the average wind speed in Yazd is 2.4 m/s and the maximum wind speed occurs in the spring – the wind speed in May reaches nearly 8 m/s. Due to the low frequency of high speed winds and the spread of the average monthly speed in the range of human comfort, it is possible to use the wind potential throughout the year. Meteorological data also indicate that in the period from June to September, the prevailing wind in Yazd blows from the north and northwest. Therefore, it can be concluded that the north and northwest facades are suitable for the proper placement of the DSF to create natural ventilation in this city.

Simulation tool

In this study, ventilation rate, cooling load and indoor air distribution analysis are conducted using DesignBuilder combined EnergyPlus results to predict which type of two selected models will have better performance than the model without a DSF. Reason for choosing DesignBuilder: software is that the building energy simulation technique using DesignBuilder software (EnergyPlus simulation engine) will be used to estimate heating, cooling, and total energy requirements. In addition, this software has been used in most scientific sources to calculate Computational of Fluid Dynamics (CFD) [27, 28].

Also, in this simulation daily consumption compared better with daily measured consumption. The maximum error will be around 5% in cooling load and 3% in heating load [2].

Software validation

Baharvand and his colleagues [29] carried out a research which is evaluated the DesignBuilder validation. In present study, an experimental model which has done on airflow and temperature was selected to compare its measured data with DesignBuilder simulation and CFD results. In addition, EnergyPlus which is the main engine of simulation in DesignBuilder was used to prove the accuracy of the results.

According to Figures (3 and 4), either very little difference was seen between the experimental data and the modeling or no difference was observed at all. Hence, Baharvand and his colleagues [29] have came to the general conclusion that DesignBuilder is a suitable and reliable software in the field of cross-ventilation .

Case study

In order to evaluate the effect of DSF on the cooling load and the pattern of inlet airflow distribution and subsequently the outlet airflow distribution, models based on the optimal orientation to achieve the desired summer wind in Yazd was simulated. The simulated model in this research has three floors with packing according to the typical plans of Yazd. The glass used in this model is 3 mm double glazed with a conductivity of 0.9 W/(m-k) and

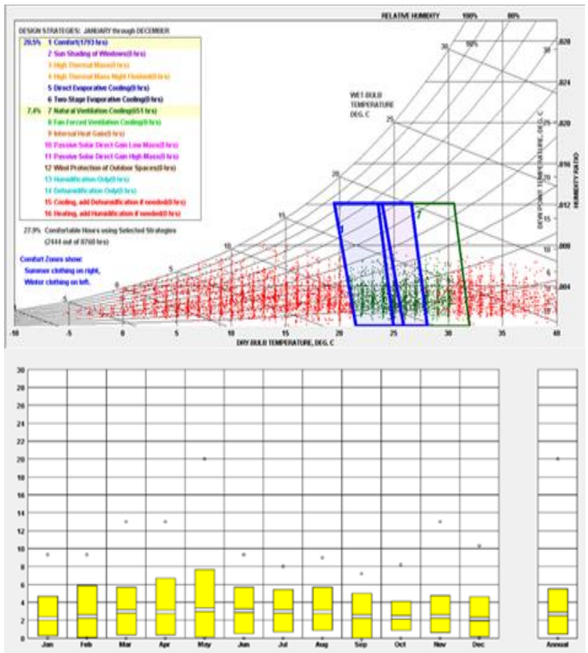

Figure 2. Down: Chart of monthly wind speed, Top: Psychometric diagram of Yazd considering natural ventilation

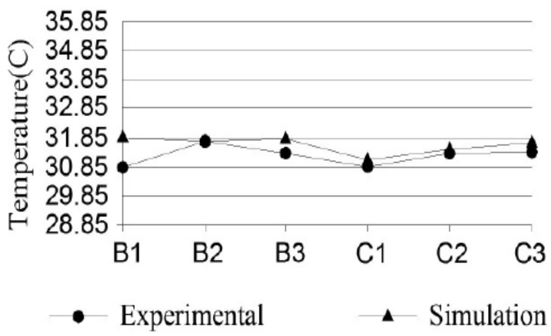

Figure 3. Experimental and simulation temperature results

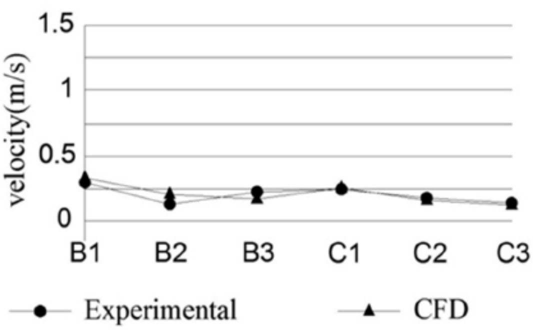

Figure 4. Experimental and simulation air velocity results

13 mm of retaining space between the two glasses is considered. Exterior wall double-glazed windows with 3 mm glass with a conductivity of 0.9 W/(m-k) are included

Table 1. Dimensions and profile of surfaces

	Number of floors	Height of each floor (m)	Area of each floor (m)	Dimensions of windows (m)	Depth of cavity (m)
Selected model	3+parking	3.5	14×7.6	1.5×1.5	0.6
Occupancy hours	Everyday/whole year (the room is intended for residential use)				
Cover level	0.5Clo Summer clothes				

Table 2. Specifications of materials used in the walls

Materials	Density (kg/m^3)	Heat capacity (kJ/kg.K)	Thermal conductivity (kJ/hr.m.K)	Thickness (cm)
Face Brick	1700	0.8	3.024	10
Polystyrene insulation	35	1.4	0.1224	8
Concrete Masonry	1400	1	1.836	10
Plasterboard	1000	1	1.44	1.3

Table 3. Specifications of materials used in the roof

Materials	Density (kg/m^3)	Heat capacity (kJ/kg.K)	Thermal conductivity (kJ/h.m.K)	Thickness (cm)
Moisture insulation	2100	1	2.56	1
Fiberglass insulation	12	0.84	0.144	14.45
Air layer	-	-	-	20
Plaster layer	2800	0.896	0.9	1.3

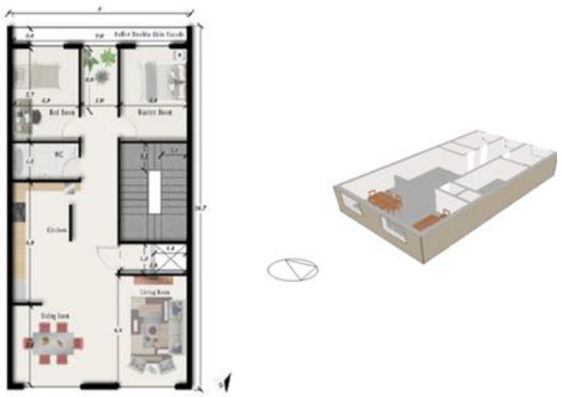

Figure 5. Proposed plan for computer simulation

Table 4. Temperature profile of surfaces

	External surface (°C)	Inner surface (°C)	Inlet air temperature (°C)
Wall surface temperature	30	25	27
Window surface temperature	25	-	27

to evaluate their compatibility and adaptability in hot and dry climate. Dimentions and temperature profile of the surfaces were tabulated in Tables 1 and 4. Also the specifications of materials used in the walls and roofs were shown in Tables 2 and 3.

RESULTS AND DISCUSSION

According to the simulations, the results obtained from modeling two selected types of DSF (multi-story and corridor) could be presented in two main parts. The first part is related to ventilation performance and its effect on energy consumption, and the second is related to how to distribute airflow in indoor spaces.

The first step in the simulation is to calculate the amount of air change per hour according to the window schedule, and the second step is to investigate the effect of DSF performance in reducing the cooling load in the absence of active cooling systems in spring and summer.

Comparison of the average air exchange rate in two models with DSF

Regarding the air change rate in two models with DSF, it could be inferred that the average amount of natural ventilation in the model with a corridor is 1.36 ac/h higher than in the model with a multi-story.

Figure 6 shows the cooling and heating load of a building without DSF in Yazd. It is observed that the maximum cooling load is 4925.67 kWh, and the maximum heating load is 739.91 kWh, which occurs in July and January, respectively.

Cooling and heating energy of two evaluation mode

Figures 7 and 8 show the energy consumption of the two simulated models –multi-story and corridor– for cooling during the warm months of the year. It could be seen the maximum cooling load of multi-story and corridor-type is 5420.28 kWh and 2509.01 kWh, respectively.

Figures 11 and 12 indicate the performance of two types of DSF compared to the model without DSF. As it is evident, the corridori type works better in hot seasons load and gas consumption in the three models that have been calculated.

Figures 9 and 10 show the effect of DSF on heating (more optimal cooling load consumption), this is the case that the multi-story type performs best in the cold moths of the year (more optimal heating load consumption). Figure 13 shows the comparison of heating energy in three models. The suggested section for DSF is illustrated in Figure 14.

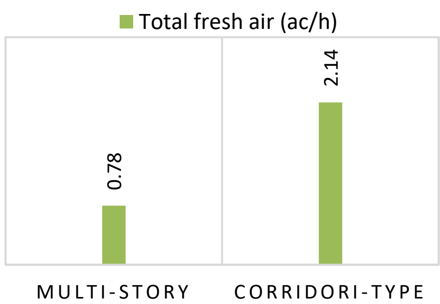

Figure 6. Comparison of total fresh air in two models

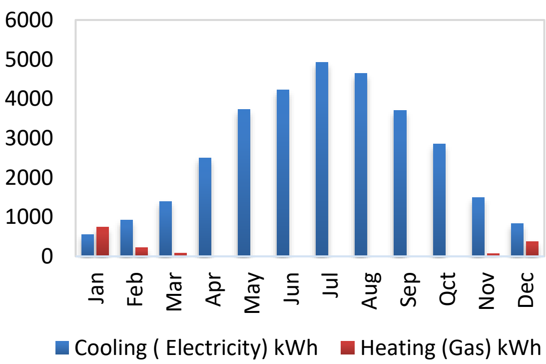

Figure 7. Cooling and heating energy of the model without a DSF

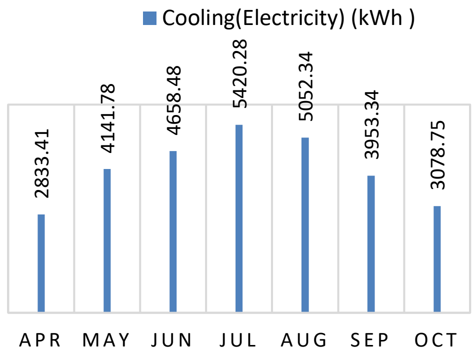

Figure 8. Cooling energy of multi-story type of DSF

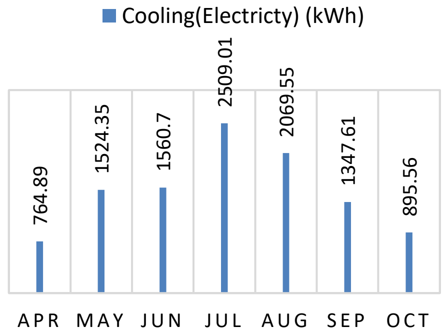

Figure 9. Cooling energy of corridori type of DSF

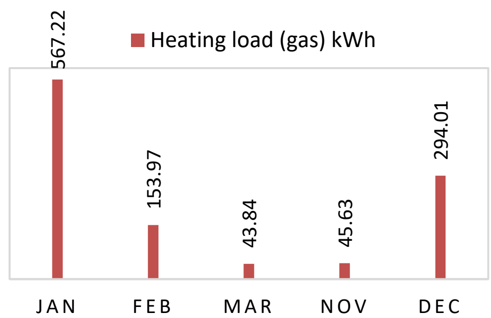

Figure 10. Heating energy of multi-story type of DSF

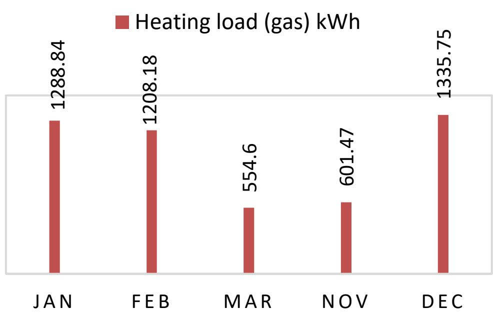

Figure 11. Heating energy of corridori type of DSF

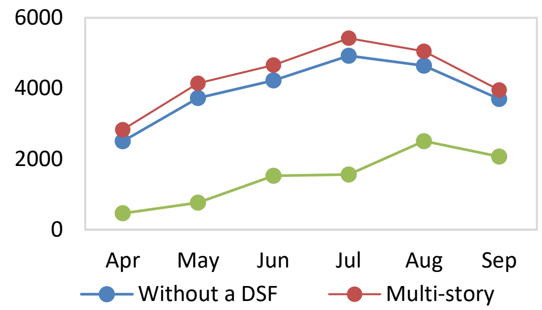

Figure 12. Comparison of cooling energy in three models

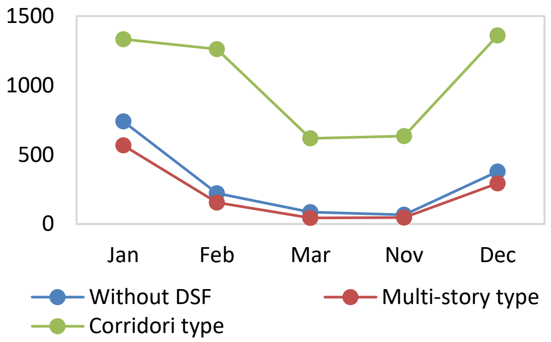

Figure 13. Comparison of heating energy in three models

INNOVATION

Proposed model

Considering that the purpose of designing this type of façade is to provide natural ventilation to the building during the warm months of the year and also help to reduce energy consumption over the year, so we need to design a façade that acts as an air conditioning system in summer to create an airflow inside the building. In addition, it should act as insulation in the winter.

According to the software simulation, it could be inferred that the model with the corridor-type of DSF is more suitable for warm months than the model without DSF and the model with multi-story type DSF. While the energy consumption of the model with a multi-story DSF is less in winter than the other two models. So to achieve optimal energy consumption in Yazd during the year by using a DSF in the building, a solution that acts as the corridor type in the summer and as the multi-story type in the winter must be offered.

How the proposed facade works?

The performance of this façade is such that in the hot months of the year, when more cooling and air exchange are needed for each floor, the entire DSF works separately (like corridor type). In cold months of the year, the existing partitions between the floors are moved away automatically. So the DSF works as a multi-story type. As

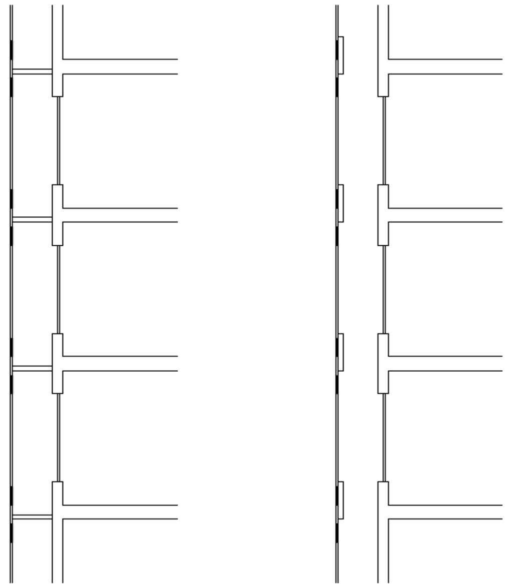

Figure 14. Suggested section for DSF

well as this, all the openings on that side of the building are considered to be closed; so the buffer part acts like insulation.

Analysis of the air flow distribution in hot months

In the second part of the research, the results of CFD analysis and the distribution of airflow both in the buffer and inside the room have been investigated. Two types of airflow could be seen in the DSF with ventilation valves; the first is a turbulent flow that has a high temperature and very low speed, and the second is a continuous flow that has a low temperature and a higher speed. Therefore, controlling the direction of air movement in DSFs and creating air movement is very important. The vertical distance between the air inlet and outlet is very effective in this regard. The closer the air inlet valve to the floor and the air outlet valve to the ceiling, the more surface of the inner shell is exposed to the blowing and cooling airflow, and the turbulent flow is more drawn towards the outer shell.

The result of this process is keeping the inner shell cool which is in direct contact with the room. According to Figure 15 the incoming airflow from the northwest side, through the DSF which is a separate horizontal corridor on each floor, causes the transfer of inlet and outlet air becomes faster and more appropriate. In multi-story DSF, because all the floors are fed from one champer, this causes the incoming airflow in each floor is significantly reduced compared to the corridor type in the summer. In addition, the possibility of a flare-up in the upper part of the buffer is more. In addition, there is a higher possibility of flare-ups in the upper part of the multi-story type.

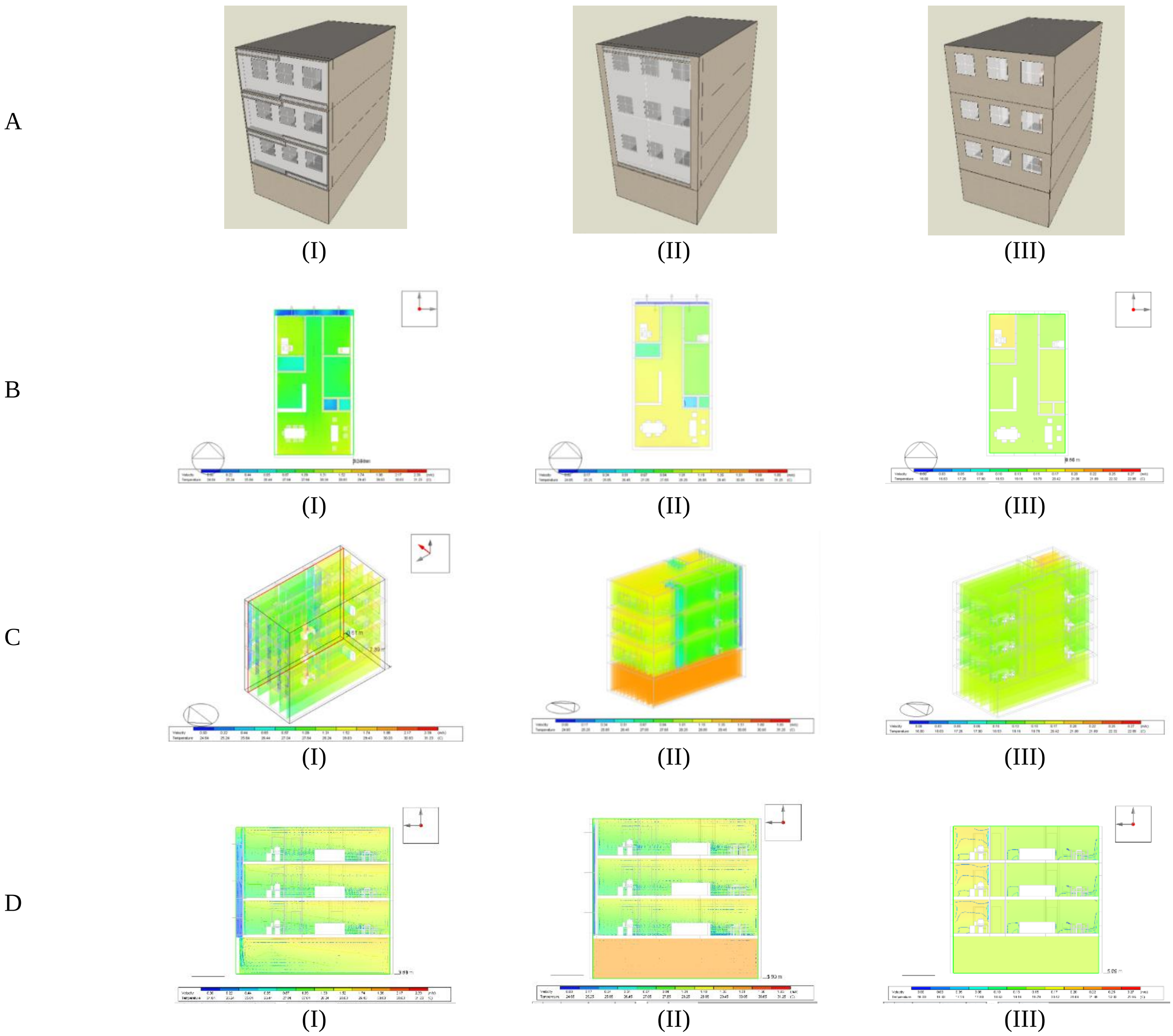

Figure 15. Classification of airflow distribution in three simulated model; (A) External renders, (B) Air flow distribution-plan, (C) Air flow distribution-section and (D) Air flow in the space between the two shells and the inner space. Signs of (I), (II) and (III) represent models with corridor DSF, with multi-story DSF and without DSF, respectively.

CONCLUSION

This study attempts to examine the potential energy savings of two kinds of DSF which are suitable for residential buildings in the hot and dry climate of Yazd, Iran. Analyzing the weather condition of Yazd using Climate Consultant software, the upcoming challenges in the process of climate design in a hot and dry climate were recognized. So, designing a DSF that could provide a suitable response to the weather conditions of Yazd was planned to ensure the comfort of the residents of the residential building during the year. Simulating different models of DSF and Single Skin Facade (SSF), a combination of multi-story types and corridor types toward the northern façade of the building was obtained. The performance of the façade could be improved both in terms of thermal and ventilation.

In the last stage, investigations were done to optimize the CFD analysis performance and distribute airflow in the buffer and inside the room. The results of energy consumption and ventilation rate charts show that the cooling load in the model with corridor type has decreased by 62.54% compared to the model without DSF during the hot months. On the other hand, the heating load of the model with a multi-story type is 26% less than the model without a DSF during cold months.

Finally, according to the obtained results, the combined DSF is designed to function as a corridor type in the summer and as an integrated structure (multi-story type) in the winter to achieve maximum energy savings throughout the year.

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Persian Abstract

چکیده

پوسته بیرونی ساختمان یک از تاثیرگذارترین عوامل در میزان مصرف انرژی است. از این رو بهینه‌سازی نمای ساختمان با تکنولوزژی‌های جدید یکی از موثرترین راه‌حل‌های غیرفعال برای تامین آسایش حرارتی است. هدف از این پژوهش طراحی نمای ترکیبی است که با توجه به دو نیروی محرکه؛ اختلاف فشار ایجاد شده بر اثر جریان گرما و عایق بودن هوا، برای یک ساختمان مسکونی با پلان تیپیکال یزد در اقلیم گرم و خشک ایران است که بتوند باعث کاهش بار گرمایش و سرمایش ساختمان بشود. به همین منظور ابتدا تاثیر دو نوع از نماهای دو پوسته – نمای دو پوسته طبقه به طبقه و سرتاسری – در مقایسه با مدل بدون نمای دو پوسته در مصرف انرژی سرمایشی و گرمایشی در طول کل سال با نرم افزار دیزاین بیلدر نسخه ۶.۱ مدلسازی و آنالیز گردید. نتایج شبیه‌سازی‌های صورت گرفته بیانگر امکان کاهش ۶۰ درصد انرژی سرمایشی از طریق ایجاد تهویه مطبوع و ۲۶ درصد انرژی گرمایشی از طریق ایجاد عایق حرارتی در مدل شبیه‌سازی شده ساختمان مسکونی در کل طول سال به وسیله نمای دو پوسته ترکیبی طراحی شده می‌باشد. یافته‌های این تحقیق با ایجاد نوآوری و ترکیب تکنولوژی‌های جدید با توجه به شرایط اقلیمی منجر به خلق راهکارهای کارآمدتر انرژی می‌گردد.