Research 1

Enhancing Natural Ventilation in Low-Rise Residential Buildings in Egypt through Solar Chimney Application

International Journal of Architectural Engineering and Urban Research

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2024

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International Journal of Architectural Engineering and Urban Research

Vol. 4, Issue 2, December, 2021

ISSN : 2785-9665

Research from PHD

بنك المعرفة المصري

International Journal of Architectural Engineering and Urban Research
PRINT-ISSN: 2785-9665
ONLINE-ISSN: 2785-9673
https://ijaeur.journals.ekb.eg/

Dear.
Dr. Henar Kalefa
Associate Professor, 6 October university

We have the pleasure to inform you that your paper entitled:

"Enhancing Natural Ventilation in Low-Rise Residential Buildings in Egypt through Solar Chimney Application"

Was reviewed by two reviewers and got positive opinion. Therefore, this paper has been accepted for publication in the International Journal of Architectural Engineering and Urban Research (**open Access Journal, issued by El Minya Higher Institute of Engineering & Technology**), to be published in Vol. (4), Issue (2), December 2021**.**

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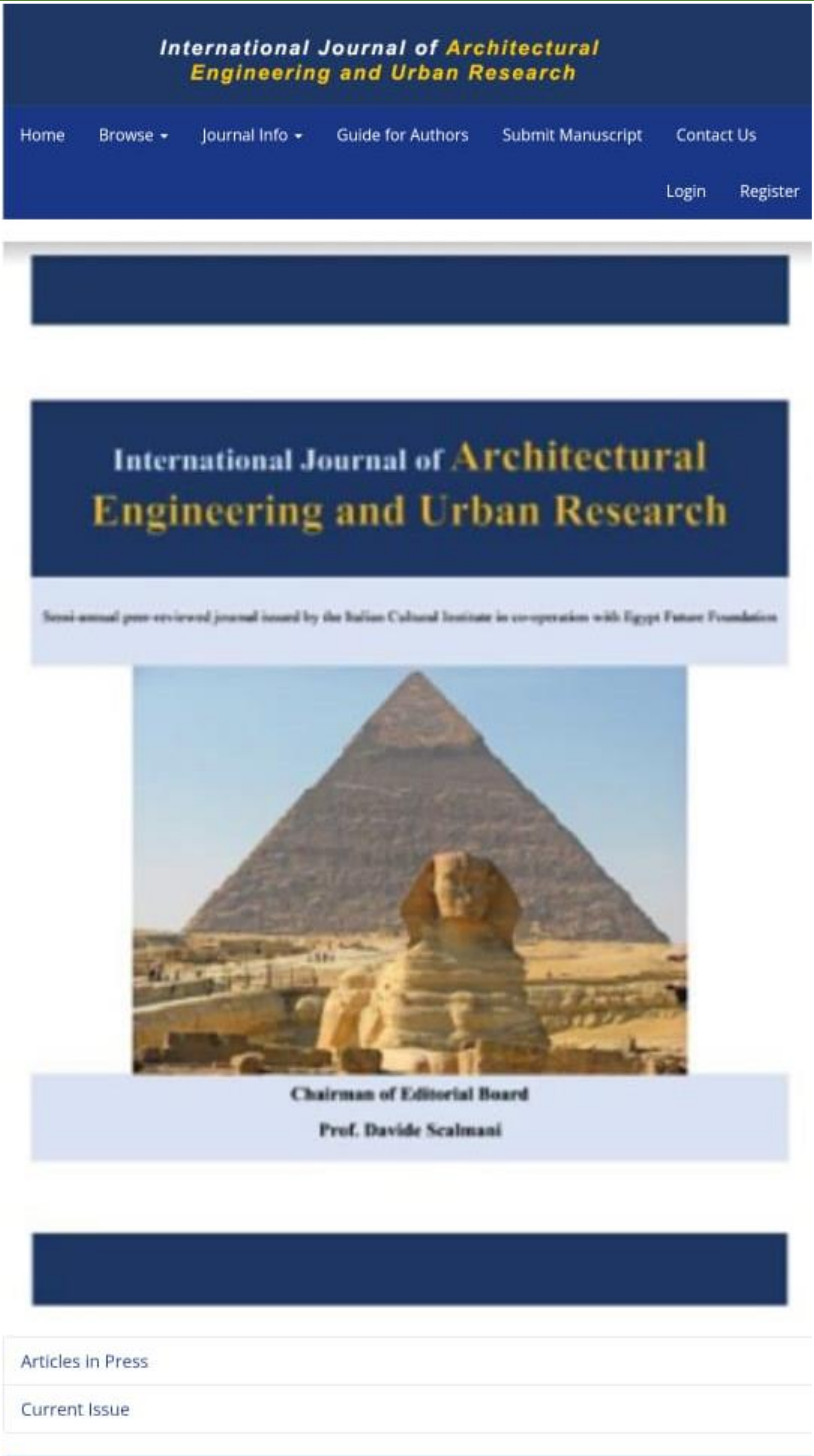
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International Journal of Architectural Engineering and Urban Research

Enhancing Natural Ventilation in Low-Rise Residential Buildings in Egypt through Solar Chimney Application

Document Type : Original Article

Authors

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10.21608/IJAEUR.2024.273518.1069

Abstract

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Ultimately, the integration of solar chimneys presents a promising approach to achieve thermal comfort in low-rise residential buildings, aligning with sustainable development goals and promoting environmentally conscious.

Keywords

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Main Subjects

Sustainable Architecture/ Environment

Volume 4, Issue 2
December 2021
Pages 138-163

International Journal of Architect
Engineering and Urban Researc

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ملخص البحث

مع ارتفاع درجات الحرارة العالمية بسبب ظاهرة الاحتباس الحراري، أصبح تحقيق الراحة الحرارية في المباني السكنية أمرًا صعبًا بشكل متزايد. وفي مصر، حيث ترتفع درجات الحرارة في الصيف، تعد معالجة الظروف البيئية الداخلية أمرًا بالغ الأهمية. تبحث هذه الدراسة في مدى فعالية المداخن الشمسية كاستراتيجية تصميم سلبية لتعزيز التهوية الطبيعية والراحة الحرارية في المباني السكنية منخفضة الارتفاع. من خلال محاكاة بالبرنامج بـ Design Builder وتحليل السلوك الحراري، تقوم الدراسة بتقييم تأثير إعادة تجهيز ساحات الخدمة الحالية إلى مداخن تعمل بالطاقة الشمسية في مبنى نموذجي منخفض الارتفاع متعدد الشقق في مدينة السادس من أكتوبر، الجيزة، مصر. أظهرت النتائج تحسنا كبيرا في درجة حرارة الهواء الداخلي وسرعة تدفق الهواء بعد تنفيذ المداخن الشمسية. ومن خلال تحويل مناور الخدمة إلى مداخن تعمل بالطاقة الشمسية، يتم تعزيز التهوية الداخلية، مما يخفف من تأثير الاحتباس الحراري الناجم عن التعرض المستمر للإشعاع الشمسي. وتعرض الدراسة جدوى وفعالية المعالجات السلبية المصممة لظروف مناخية محددة، مما يوفر نظرة ثاقبة لممارسات البناء المستدامة في المناطق الحارة والقاحلة. تساهم هذه النتائج في تطوير استراتيجيات التصميم السلبي وتقدم حلولاً عملية لتعزيز جودة البيئة الداخلية مع تقليل الاعتماد على أنظمة التهوية الميكانيكية. في السابق، وتوضح الواجهات الجنوبية التي شهدت انخفاضات كبيرة في درجات حرارة التي كانت تصل إلى 36.83 درجة مئوية ، حيث يتراوح متوسطها الآن بين 29.47 درجة مئوية إلى 30.52 درجة مئوية، بما يتماشى مع معايير الراحة الحرارية. وزاد متوسط سرعات الهواء من 0.62 إلى 1.59 م/ث، مما يعزز التهوية الطبيعية ودوران تدفق الهواء في جميع طوابق المبنى

في نهاية المطاف، يمثل تكامل المداخن الشمسية نهجا واعدا لتحقيق الراحة الحرارية في المباني السكنية منخفضة الارتفاع، بما يتماشى مع أهداف التنمية المستدامة وتعزيز الوعي البيئي.

الكلمات الدالة:

المداخن الشمسية، استراتيجية التصميم السلبي، التهوية، المباني منخفضة الارتفاع، المباني السكنية

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1 Introduction

Since the earliest phases of human settlement development, passive design strategies have been adopted to enhance their living environment. Through the use of principles known as passive design, the settlers constructed their homes to adapt to their particular climate [1]. The principles of passive design are characterized by the utilization of the sun, wind, and natural physical laws to provide cheap energy costs, little maintenance, and improved comfort. In other words, the building doesn't produce or store energy using any mechanical systems [2]. Many of the core ideas that still underpin the built world that we utilize today were developed during this time since these design methods were so important to early humans in influencing it.

As the temperature of the Earth's surface is increasing rapidly due to greenhouse effect, the summer months get hotter every year therefore achieving thermal comfort in an indoor space became a challenge that requires technological interference and an immense amount of money regardless of the impact on the environment which in return increase the greenhouse effect which results in increasing the problem further more [3] [4]

Natural ventilation serves as a crucial strategy in buildings to enhance indoor air quality, eliminate contaminants, and dissipate accumulated heat by facilitating a continuous exchange of indoor air with fresh outdoor air. While the installation of windows or openings along the exterior walls suffices to enable natural ventilation in a building, the effectiveness of this process can be significantly augmented through careful consideration of the arrangement and positioning of these openings. Thus, identifying the most optimal approach for naturally ventilating a building using basic windows and wall openings is paramount for achieving optimal indoor environmental conditions.

There are three main means of natural ventilation in a building, single sided ventilation, cross ventilation, and stack ventilation. Each type differs in its effectiveness based on the positioning of the openings as well as the wind nature of each region. Moore [5] showed that different patterns of the adjacent wall openings affect the air flow inside a room, also showed that the best positioning of an adjacent opening configuration is when one of the openings or both of them are on the furthest corner of the room to the other opening. Figure 1.

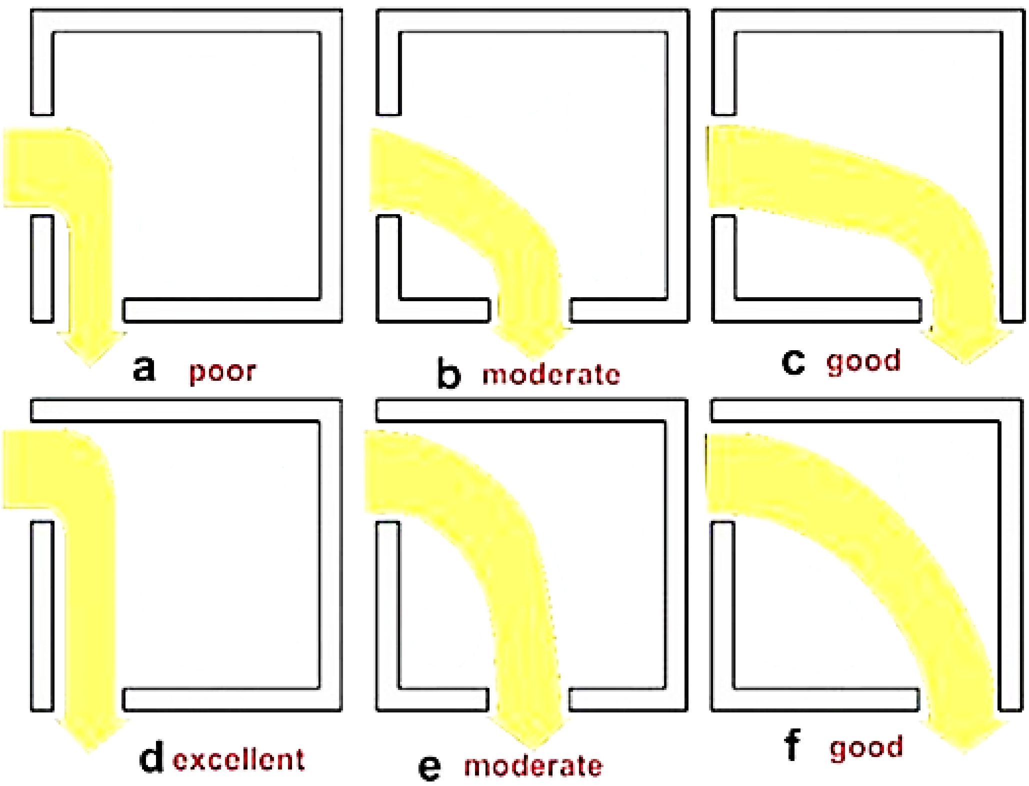


Figure 1 Adjacent openings configurations [2]

While different patterns of face-to-face openings horizontally affect the rate of air flow inside a room the relative vertical level of the face-to-face openings has a significant effect on air flow inside a room as well, a study made by Givoni, 1969 [6] and another study made by Hawaii Commercial Building

Guidelines for Energy Efficiency in 2003 [7] showed that when an inlet opening is placed on the lower part of the windward side wall and another opening with an equal size on the upper part of the leeward side wall, as shown in Figure 2, this positioning forms a staggered air flow path throughout the room passing by human activities zones, this helps achieve thermal comfort via direct passive cooling. The staggered openings can achieve an average indoor air velocity 35% of wind velocity that is less than the facing openings that can achieve average indoor air velocity 50% of wind velocity.

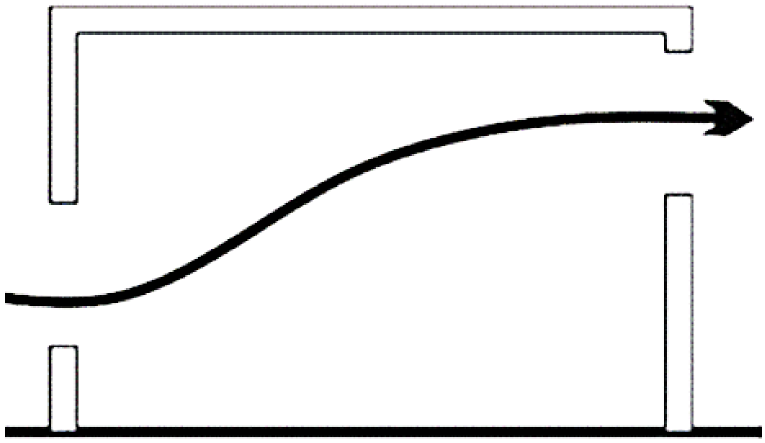


Figure 2 Staggered openings in vertical level [3]

While staggered face to face openings is more effective regarding indoor airflow, the size of the outlet opening is directly proportional to the indoor air rate of flow, whereas the outlet opening's size increases so does the indoor wind velocity. Moor, 1993 [5] studied the effect of the outlet opening size in a staggered vertical face to face cross ventilation, where he created three case studies with the same inlet and outlet opening widths but different outlet opening heights (Figure 3), in case (a) The outlet opening height was half the height the inlet opening height it was observed that the maximum and minimum indoor air flow velocities respectively was 62% and 12%, this case is recommended in regions with high velocity winds. While another case study (b) with outlet opening equals to the height of the inlet opening the maximum and the minimum indoor air velocities respectively was 110% and 25%, this case is recommended in regions with moderate wind velocities. And case (c) where the outlet opening was one and a half times bigger than the inlet opening the maximum and minimum indoor air flow velocities respectively was 127% and 30%, this case is most suitable in regions with low velocity winds.

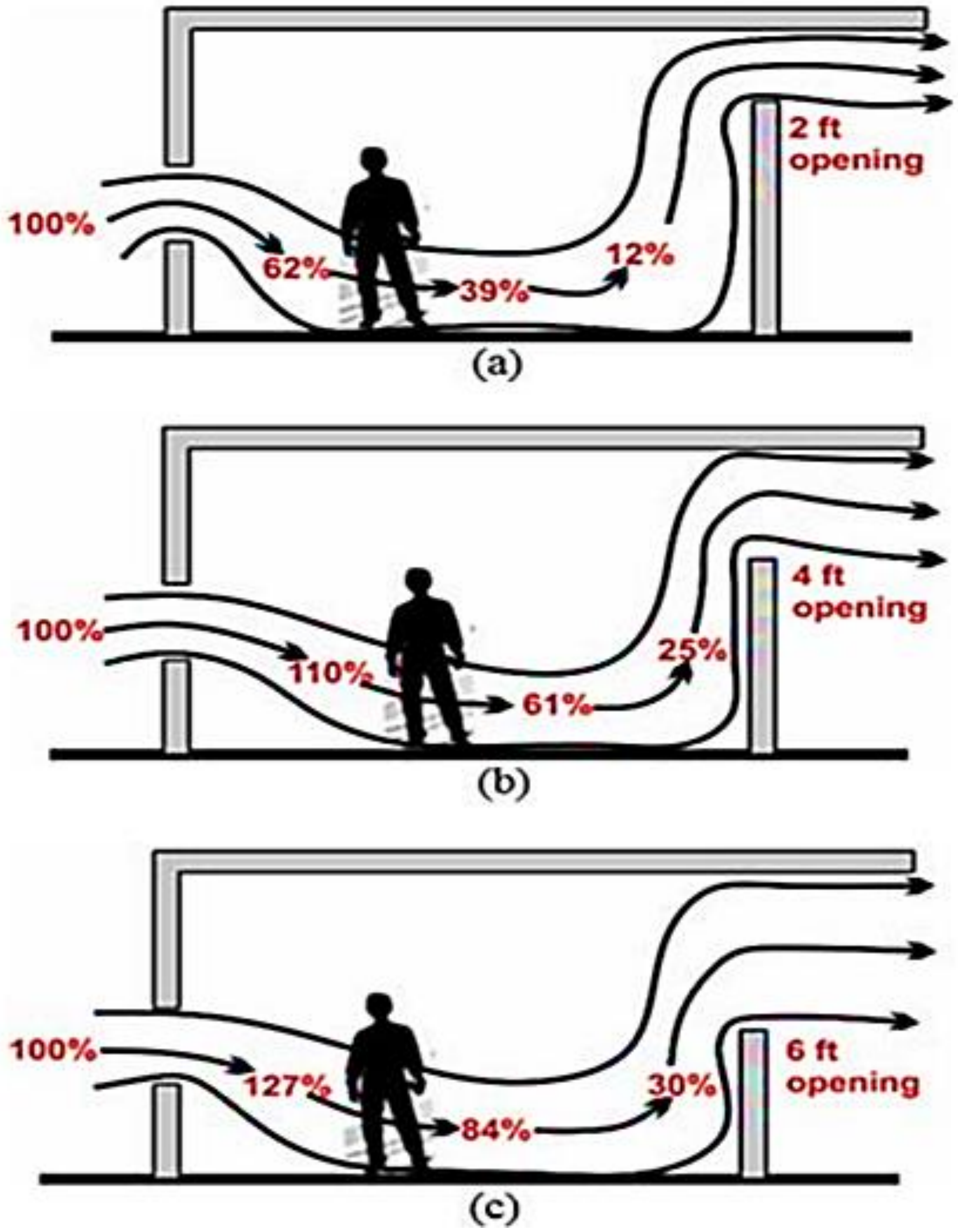


Figure 3 Wind velocity ratios between inlet to outlet openings in three different heights [2]

A solar chimney is a solar and wind-powered energy device that improves natural ventilation in buildings. It is one of the best examples of a building envelope-attached solar-assisted passive ventilation system. In specific climatic conditions, it performs remarkably well in enhancing natural ventilation and enhancing thermal comfort. Many numerical and experimental studies have been conducted to examine how solar chimneys improve ventilation.

The main principle of a solar chimney is called Stack Effect which is a process in which the difference in air density due to change in air temperature forcing the hot air to rise up as it becomes less dense which increases its buoyancy, therefor the colder air becomes denser forcing it to replace the hotter air. This effect is often used in open courts and vertical shafts to ventilate buildings and reduce the indoor temperature. Figure 4.

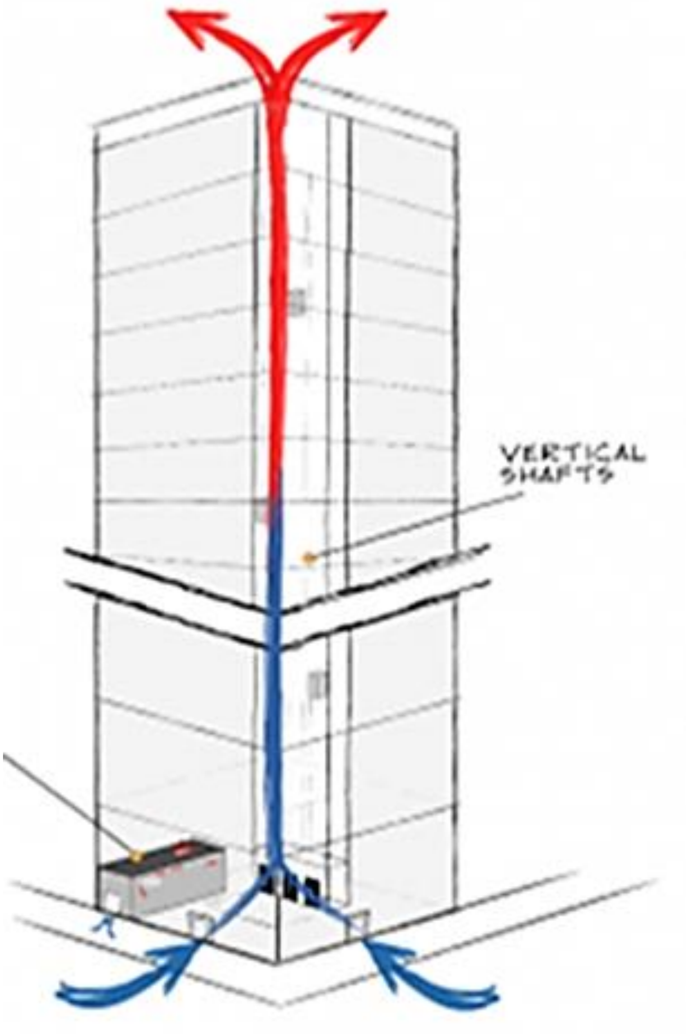


Figure 4 A Diagram illustrating Stack Effect [8]

A solar chimney in its traditional form is a trombe wall placed on the most side of a building reached by the sun where it uses buoyancy force or a stack effect to replace the air inside it, the outer layer often made by a dark thermal absorbent material or glass sheets and the inner layer is a thick masonry wall and it's preferred to added with a thermal insulator, the chimney itself contains an upper opening towards the outside of the building while the inner wall has an opening at the bottom, as the direct sunlight hits the outer thermal absorbent material a greenhouse effect is formed inside the chimney heating the air inside, as the heated air rises towards the upper exit due to the buoyancy force, colder air from inside the building replaces the air escaping the chimney via the lower opening at the masonry wall, this process creates a suction force inside the building through any natural source of ventilation (window, wind catcher, opening) providing a constant circulation of fresh air from outside the building even if there is no wind to normal air flow.

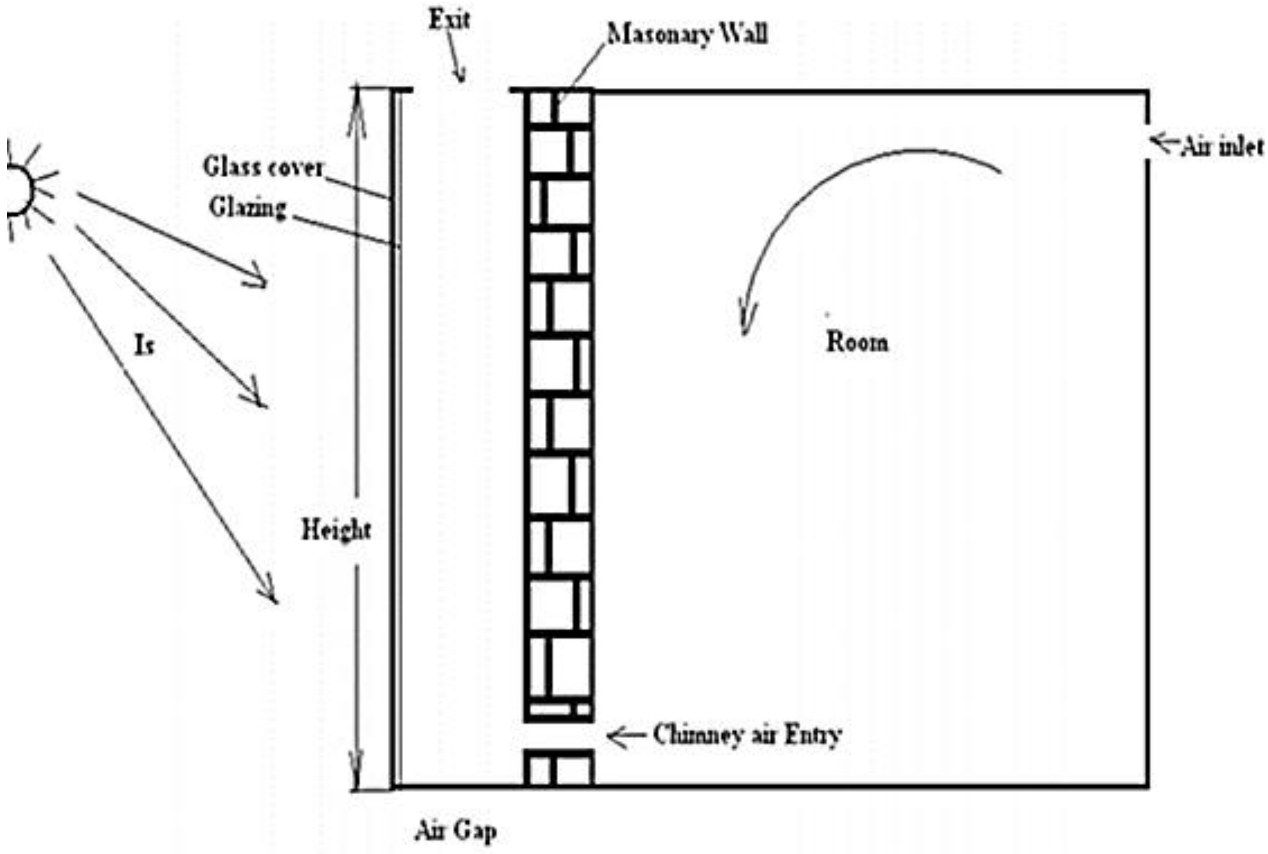


Figure 5 Solar chimney diagram [9]

This same concept could be applied on different shapes and forms to suit any design, for an example another form of a solar chimney is a roof air solar collector that takes the shape of the roof whether it's a broken hip roof or a flat roof or other geometric shapes, or even a roof wall solar chimney.

A solar chimney is most effective when it gets the maximum amount of direct sunlight, that differs from one place to another, as discussed earlier each region has its own solar behavior for an example a solar chimney at northern Europe is preferrable to be vertical or slightly vertically inclined facing south, that way it gets maximum amount of solar radiation while in Egypt or the MENA in general, a solar chimney is most effective when it's a horizontal roof solar chimney or slightly horizontally with a maximum angle on inclination of 30 degrees [10].

2 Building Description

The model selected for investigation in this study is the "Egypt Housing" project, a development initiated by the Communities Authority to address the housing needs of the middle-income population in the Arab Republic of Egypt. This project represents a prevalent form of new urban development across various cities in Egypt, aimed at providing suitable housing options for middle-income families. To date, the project has delivered approximately 100,000 housing units across ten offering stages.

Figure 6 Satellite view 4 of site location, Source: Google Maps 2024

The specific focus of this study is Building number 270, Model A, located within the Jannah October residential compound in 6th of October city, Giza, Egypt. This building typology is characterized as a low-rise multi-apartment structure, consisting of a ground floor and six typical floors. Each floor comprises four apartments, each of which is designed with specific spatial configurations. These apartments include a reception/living room with a 2m x 2.5m window, a bathroom with a 0.75m x 1m window, a kitchen with a 0.75m x 1m window, two bedrooms each with a 1.5m x 2m window, a master bedroom with a 1.5m x 2m window, and a master bathroom with a 0.75m x 1m window. The surface area of the southern apartments on the ground floor is 115m2 each, while all other apartments in the building have a surface area of 130m2 each.

Figure 7 Street View of the case study

Furthermore, the building incorporates two square service courtyards, each with a side length of 3.5m. These courtyards play a pivotal role in the building's ventilation system and are essential components of the proposed treatment involving the installation of solar chimneys.

By focusing on this specific building model within the context of the larger "Egypt Housing" project, this study aims to provide valuable insights into the feasibility and effectiveness of passive design strategies, particularly the implementation of solar chimneys, in enhancing natural ventilation and thermal comfort in low-rise residential buildings in Egypt.

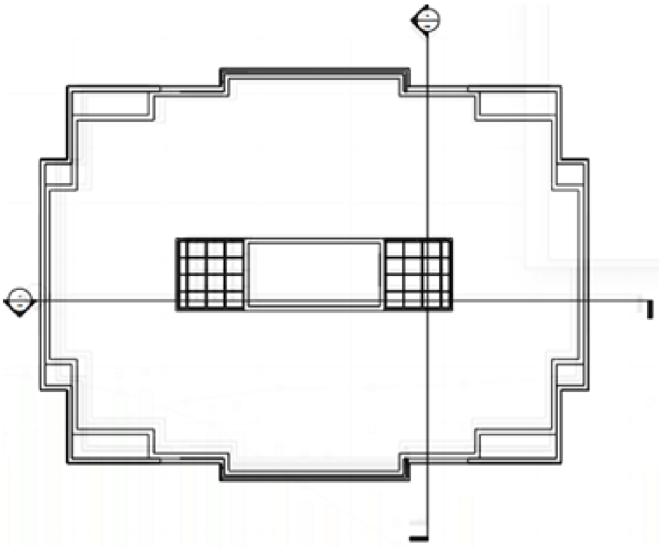
3 Methods

To systematically investigate the enhancement of thermal behavior and indoor cross-ventilation in low-rise residential buildings within Egyptian new cities, a rigorous methodology was employed. Initially, a comprehensive analysis of thermal behavior and Design builder commercial software package simulations were conducted for each floor plan of the base case model. These analyses provided a detailed understanding of the existing conditions within the building and formed the foundation for subsequent comparisons with alternative scenarios.

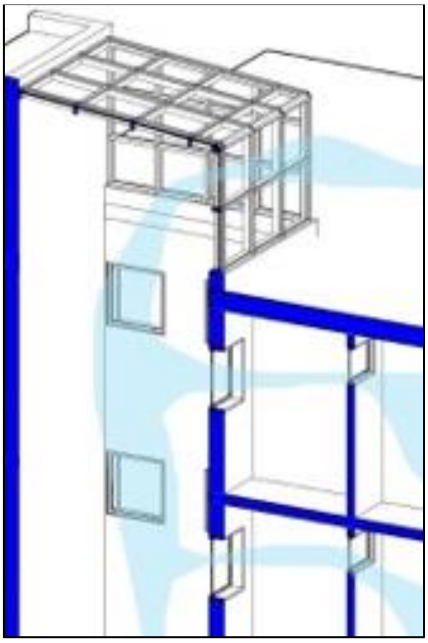
The proposed treatment centered on the conversion of existing service courts into solar chimneys. This treatment comprised two primary components. Firstly, the service courts were retrofitted with clear glass top covers, effectively transforming them into functional solar chimneys. Each cover was meticulously designed with specific dimensions (3.5m x 3.5m x 3m) and constructed using single clear glazed walls and roofs made of square clear single glazed panels. Additionally, to facilitate effective ventilation, the southern parts of each glass cover were outfitted with openable glass panels, ensuring optimal airflow. Furthermore, a designated strip measuring 0.5m x 3.5m of the southern part of the cover's roof featured openable glass panels, further contributing to the overall ventilation strategy.

These modifications were carefully implemented to maintain the surface area of the original court openings while significantly enhancing their functionality as solar chimneys as shown in Figure 8 .

Subsequently, comprehensive thermal behavior analysis and CFD simulations were conducted for the modified building configuration by using DesignBuilder software. These analyses enabled a detailed evaluation of the impact of the treatment on thermal distribution and airflow velocity within the building envelope.



A)



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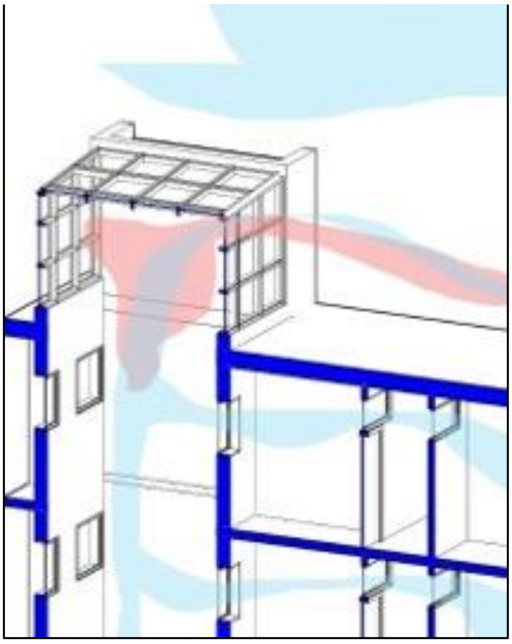


c)

Figure 8 A model created using Autodesk Revit to illustrate positions and shapes of courtyard glass covers (solar chimneys) in a) 2D top view b) and c) 3D sectional views.

The findings from the analyses were presented in a clear and organized manner, utilizing charts and diagrams to facilitate comparison between the base case and the modified scenarios. Additionally, the degree of compliance with the Code for improving energy use in buildings ECP 306-2005 [11].was assessed to ascertain the level of thermal comfort achieved through the proposed treatment.

By employing this systematic and methodical approach, the study aimed to provide valuable insights into the efficacy of solar chimneys as passive design strategies for enhancing natural ventilation and thermal comfort in low-rise residential buildings, particularly within the context of Egyptian new cities.

3.1 Simulations Conditions

Climate data for the case study was obtained using Climate Consultant, with the weather data sourced from the EPW file "Cairo. AP, QH, EGY" representing Cairo International Airport, the closest region with up-to-date weather data. During the period from May to October, temperatures in the region typically exceed 30 degrees Celsius, often reaching as high as 40 degrees Celsius. This extreme heat necessitates effective passive design strategies to ensure thermal comfort within buildings.

Utilizing Climate Consultant 6, various climate attributes were analyzed to inform the design of layout techniques suited to the specific climatic conditions of the region. This facilitated the development of the treatment hypothesis, which involved equipping the courtyards with clear glass top covers to transform them into solar chimneys. Each cover was designed with careful consideration of dimensions and materials to optimize ventilation and thermal comfort within the building envelope [12].

The integration of climate data analysis and passive design strategies formed the basis for the proposed treatment, aiming to mitigate the adverse effects of extreme temperatures and enhance indoor environmental quality within low-rise residential buildings in Egyptian new cities.

According to subject 95 of the conditions of skylights (courtyards) in the new building law 119 of 2008 [13] “It is taken into account that all skylights and courtyards are exposed from above, and in the case of putting any roof on them, the following conditions and requirements apply, If the roof is transparent or semi-transparent, side openings connected to the outside must be provided and the total area of these openings must not be less than the area of the courtyard or skylight if the roof is not transparent, side openings must be provided connected to the outside and their total area should not be less than one and a half times the area of the courtyard or skylight.”

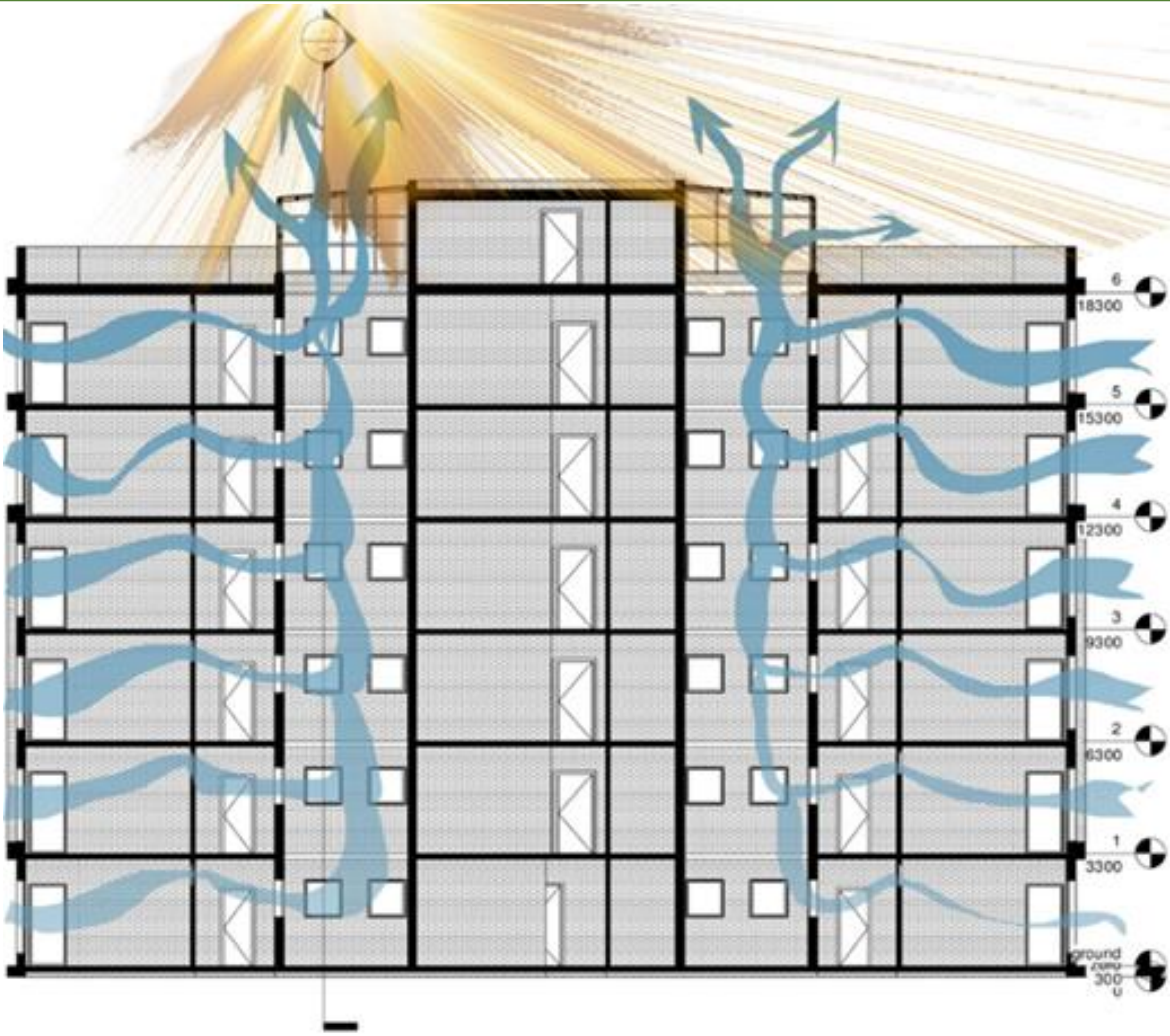
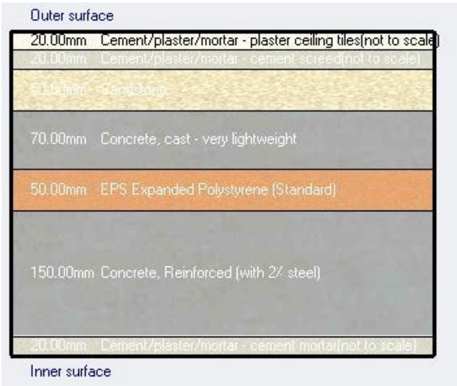


Figure 9 A model created using Autodesk Revit to illustrate air flow inside the building using courtyard glass covers (solar chimneys) in a longitudinal section.

These glass covers will trap direct solar radiation heating the air inside which then will escape as exhaust air from the openable panels placed on the southern part of each glass cover, those openable glass panels are placed on the southern part of the glass covers to provide a smooth airflow outside the courtyards where it will not conflict with the northern prevailing winds. Using this technique, a stack effect will occur inside the shaft of the courtyards due to the difference in air pressure. If strip glass openings are created along the inner walls of the southern apartments in each floor, the stack effect occurring inside the courtyards will suck outside air from southern façade openings of the building where wind doesn't often blow. Therefore, creating constant cross ventilation in the southern apartments that are more exposed to direct solar radiation.

After Finishing the site location, climate studies, creating the design builder model of the case study and after stating the main definitions, the choice of the time of the year is essential to the simulation process, so the following step is simulation outputs through the summer months to find the best time to run the rest of the simulations.

Table 1 The construction material's visual structure layers and properties for the model of study via design builder

<table>
<tr><th>Structure type</th><th>Visual structural layers</th><th>Structural layers</th><th>U-Value (w/m²-k)</th></tr>
<tr><td>External Wall
25 cm</td><td>
</td><td>• 5 mm exterior paint
• 2 cm Conch cement
• 25 cm brickwork
• 2 cm Inner clamshell</td><td>1.852</td></tr>
<tr><td>Thickness of walls and partitions
12 cm</td><td>
</td><td>• 2 cm cement clamshell
• 12 cm brickwork
• 2 cm inner clamshell</td><td>2.281</td></tr>
<tr><td>Roof</td><td>
</td><td>• 2 cm cement tiles,Cement layer, sand
• 7 cm inclined concrete
• 5 cm EPS thermal insulation layer
• 15 cm reinforced concrete slab
• 2 cm of cement whiteness</td><td>2.010</td></tr>
<tr><td>Flooring</td><td>
</td><td>• 1 cm ceramic
• 2 cm cement layer
• 7 cm of sand
• 15 cm reinforced concrete slab</td><td>3.686</td></tr>
</table>

4 Result and Desiccation

4.1 Base Case Simulation

In this phase thermal behavior analysis and CFD simulation (thermal distribution and air flow velocity) were carried out for each floor plan of the base case of the model of study and results were illustrated in the form of charts to be compared with other cases.

4.1.1 Ground Floor Plan

The results of Computational Fluid Dynamics (CFD) simulations revealed a predominant single directional airflow ventilation pattern on the ground floor. This configuration led to variations in indoor air temperatures, with the northern zones registering an average of 30.1°C, while the southern zones experienced higher temperatures averaging at 33.5°C. Additionally, the analysis indicated limited cross ventilation within the space, with average air velocities ranging from 0m/s to 0.18m/s in the northern zones and from 0m/s to 0.09m/s in the southern zones. Consequently, the absence of effective cross ventilation necessitated the reliance on open doors to facilitate airflow within the building.

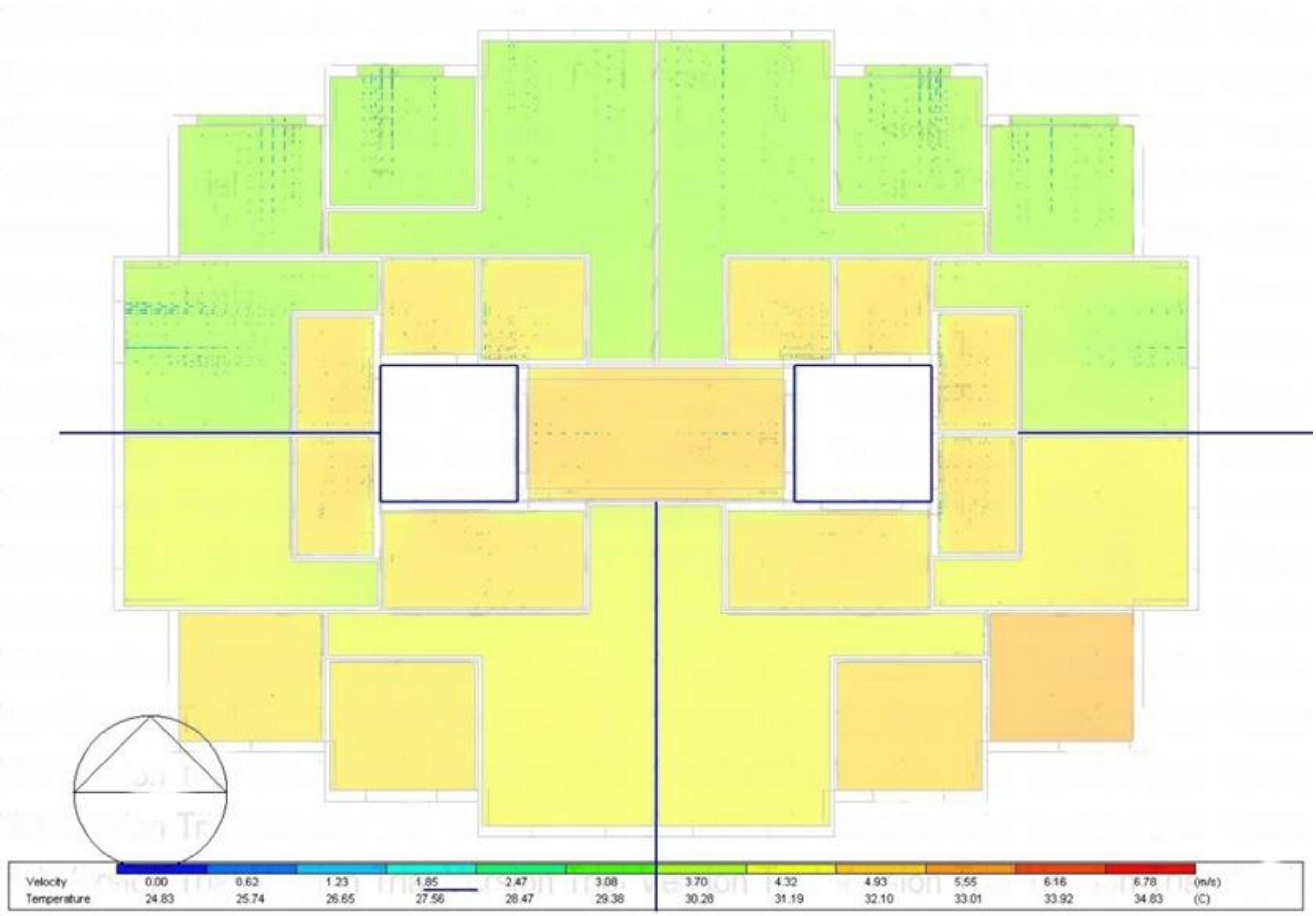


Figure 10 Simulation results for the indoor air temperature and velocity vectors for the Ground Floor Plan,

4.1.2 Typical Floor Plan (3rd floor)

CFD simulations were conducted to analyze a section of the reference case, specifically the typical floor plan of the 3rd floor. This floor plan exemplifies a single directional airflow ventilation technique, resulting in distinct indoor air temperature variations. The northern part of the zones maintained an average temperature of 29.38°C, whereas the southern part exhibited higher temperatures, averaging at 33.01°C.

Additionally, the simulations revealed notable differences in average air velocity across the zones. In the northern zones, the average air velocity measured approximately 0.18m/s, whereas in the southern zones, it ranged from 0m/s to 0.09m/s. These findings indicate limited cross ventilation within this configuration, emphasizing the necessity of opening doors to facilitate airflow between zones.

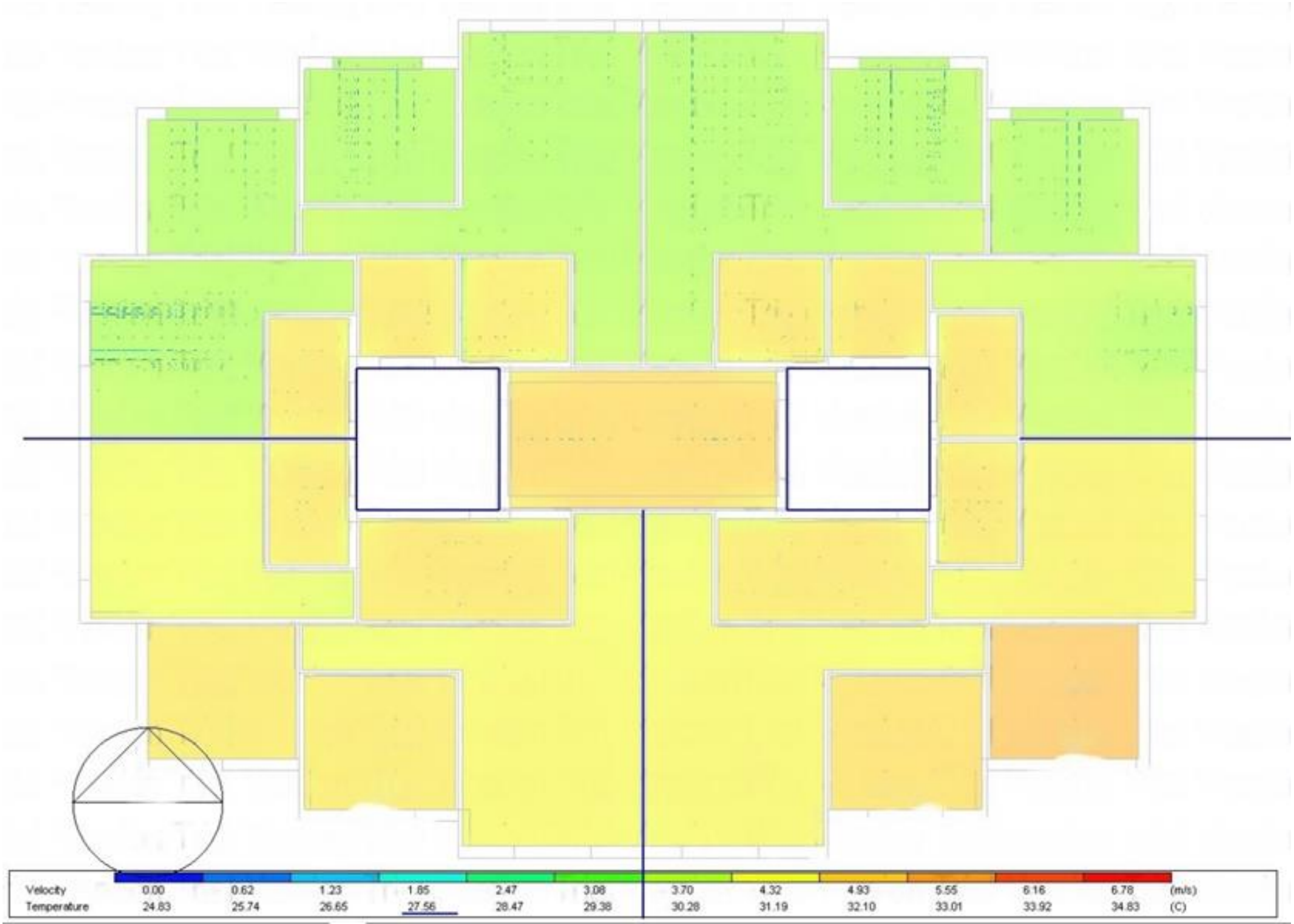


Figure 11 Simulation results for the indoor air temperature and velocity for the Typical Floor Plan (3rd floor),

4.1.3 Last Floor Plan: (5th floor)

CFD Simulations were carried out showing a plans and longitudinal sections of the reference case that has a single directional air flow ventilation technique resulting in an indoor air temperature up to 36.83 C⁰ on the southern last floor zones which are the hottest zones in the building and 30.78 C⁰ on the northern zones of ground and typical floors which are the coolest zones. The opening areas positioned in the northern and southern façades of average dimensions are (2.5m x 2 m) m² with a single clear glazing of 3mm.

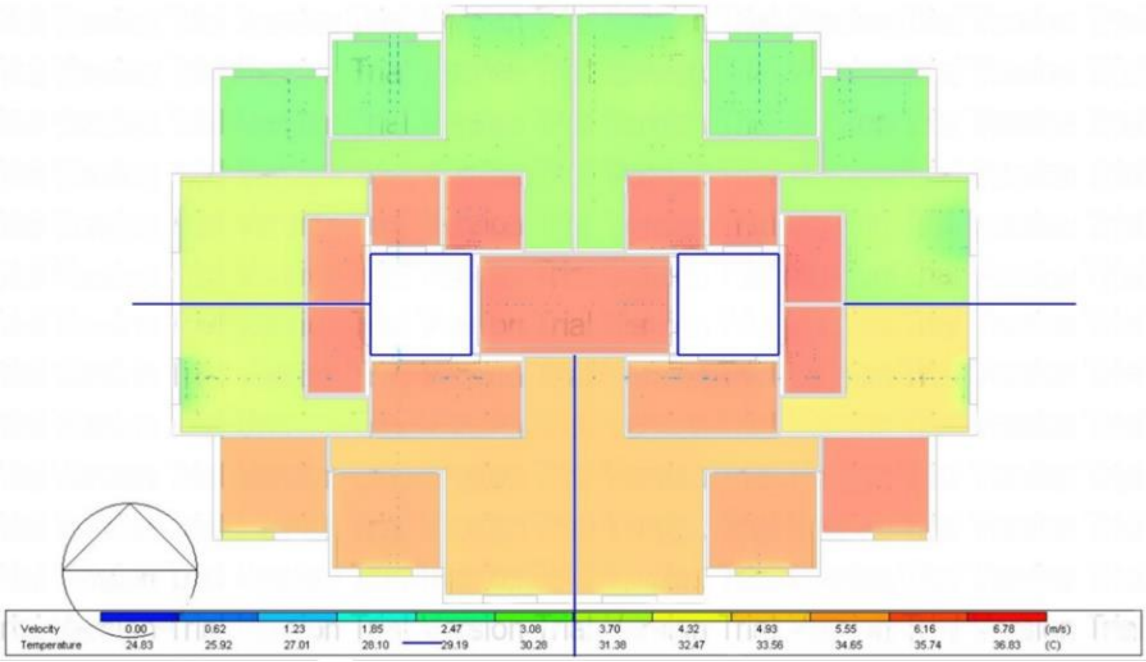


Figure 12 Simulation results for the indoor air temperature and velocity vectors for the Last Floor Plan: (5th floor

4.2 Base Case Simulation Results

The simulation results for the base case reveal significant disparities in thermal comfort between the northern and southern zones of the building. Southern zones experience heightened temperatures, attributed to the greenhouse effect induced by continuous solar radiation exposure and the absence of natural ventilation. Unlike the northern zones, which benefit from preferable orientation towards the prevailing northern wind, facilitating natural ventilation and mitigating the greenhouse effect, the southern zones are disadvantaged.

Consequently, it is imperative to implement passive treatments specifically tailored for the southern zones to ameliorate indoor air temperature and enhance indoor air quality. Such interventions are essential to ensure a conducive and comfortable living environment within the building.

4.3 Solar Chimney Treatment

Simulation target is enhancing the flow rates and comfort conditions in the master plan of the residential house by applying a solar chimney system on both court of the building which may affect positively natural ventilation rate and thermal comfort conditions within the space of the room. The vertical length of the chimney is equal to the first-floor height plus above the roof. A solar chimney (2m x 1.5m) glass is modelled at the top area of the court with a single clear glazing 3mm. The solar radiation will transmit through the clear glass that will radiate back towards the glass, heating up that air in the gap which then rises by the stack effect, which promotes the indoor natural ventilation. Indoor air velocity and operative temperature were recorded for each solar chimney's value as shown. The operative temperature combines the air and mean radiant temperatures into one numerical quantity. It is a measure of the body's response to convection and radiation energy exchange. This technique creates a continuous airflow throughout the entire floor spaces in each floor, therefore preventing the greenhouse effect created in the base case due to lack of cross ventilation, also a constant air flow is created throughout the day even when the outside wind velocity is at zero speed, this phenomena occurs when air from outside the building is sucked inside through the outer windows from which travels through a series of strip window openings places on the inner walls of the building providing a path for the air to flow through, until it reaches the solar chimney shaft (court) replacing the exhausted heated air. Using this same technique an air intake is provided even in the southern elevations where prevailing winds doesn't often blow, making the four flats of each floor equally naturally ventilated despite the orientation.

4.3.1 Ground Floor Plan

CFD Simulation shows a variation of operative temperature and the air velocity pattern through the CFD domain, with points closer to the façade showing slightly warmer temperatures. The Design builder calculated air temperature and the air velocity per zone of the solar chimney, additionally indicates an average of air temperature approximately 29.01 to 30.55 C^{o}, while the velocity ranges from 0.62 to 1.59 m/s compared to the base case without solar chimney with 30.1 C^{o} to 33.5 ^{o}C and 0 to 0.09 m/s air velocity.

It is also noticeable that staggered cross ventilation is created in the southern, eastern and western zones due to a combination between the stack effect created by the solar chimneys in the two courts and the placement of the inner wall openings.

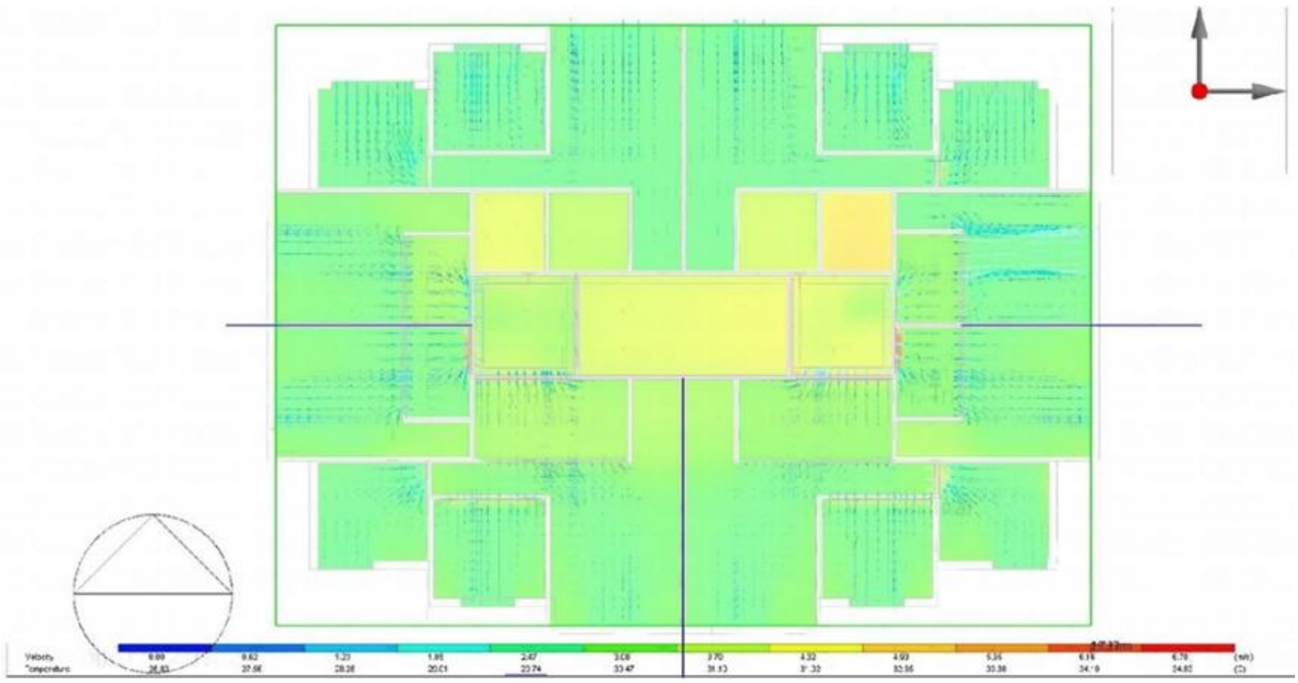


Figure 13 CFD slices showing the operative temperature and the air velocity pattern of the Ground floor plan while using the solar chimney treatment,

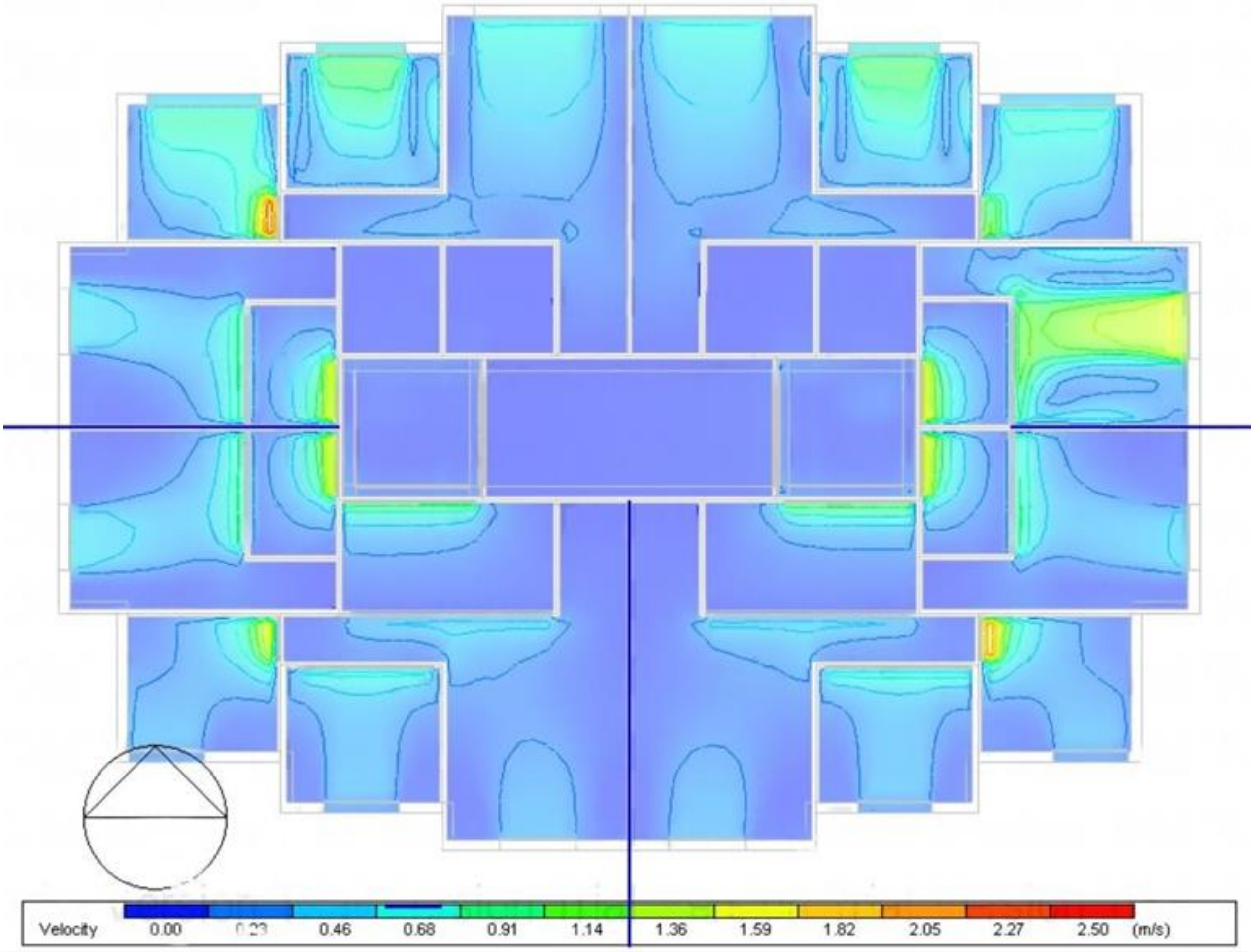


Figure 14 CFD slice showing the Velocity contours direction ground floor plan while using the solar chimney treatment

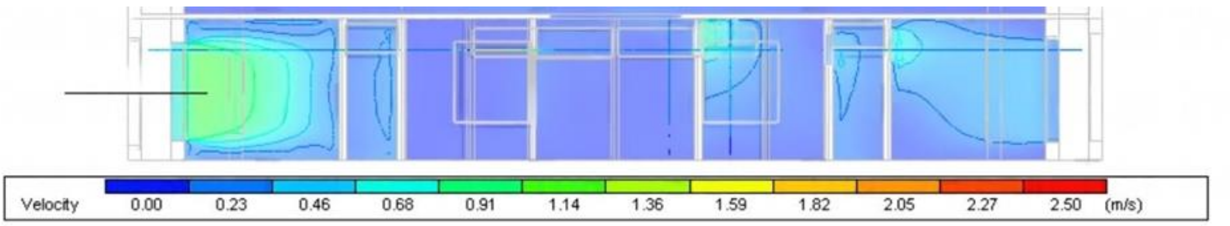


Figure 15 CFD slice showing the Velocity contours direction in longitudinal section 1

4.3.2 Typical Floor Plan (3rd floor)

CFD Simulation shows a variation of operative temperature and the air velocity pattern through the CFD domain, with points closer to the façade showing slightly warmer temperatures. The Design builder calculated air temperature and the air velocity per zone of the solar chimney, additionally indicates an average of air temperature approximately 29.45 C^{o} to 30.55 C^{o}, while the velocity ranges from 0.62 to 1.59 m/s compared to the base case without solar chimney with 30.1 C^{o} to 33.5 C^{o} and 0 to 0.09 m/s air velocity.

Like in ground floor plan it is also noticeable that a staggered cross ventilation is created in the southern, eastern and western zones that due to a combination between the stack effect created by the solar chimneys in the two courts and the placement of the inner wall openings.

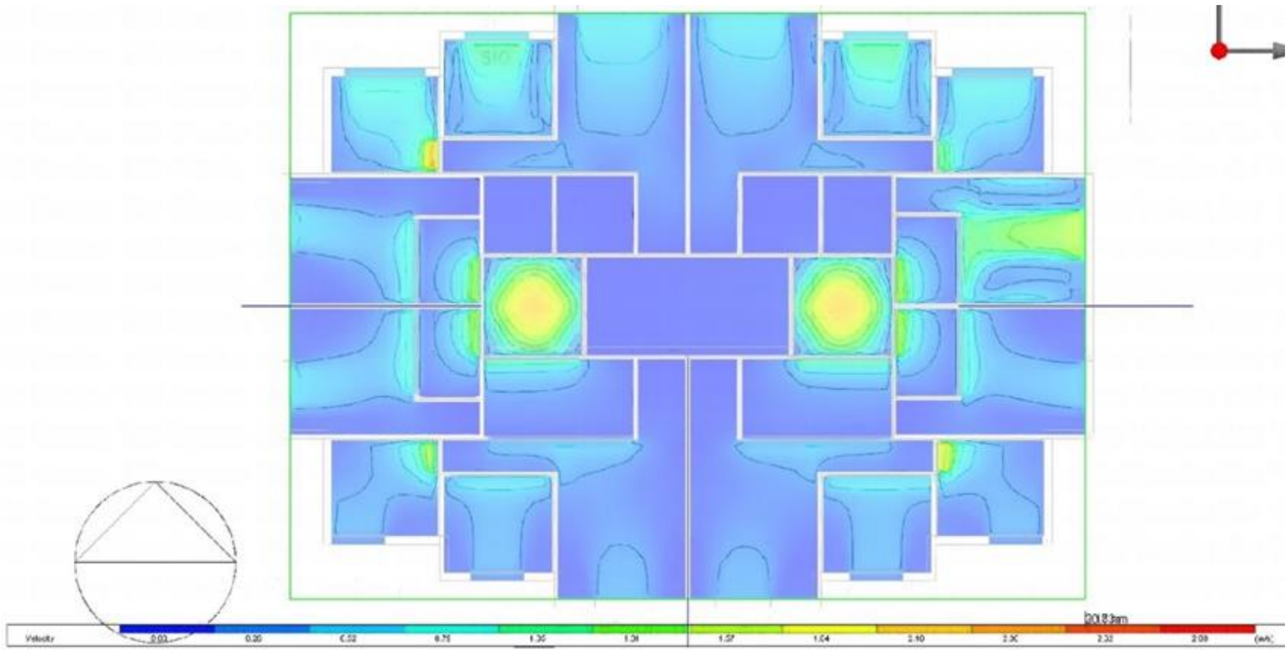


Figure 16 CFD slices showing the air velocity pattern of Typical Floor Plan (3rd floor) on using solar chimney showing the best and highest airflow circulation

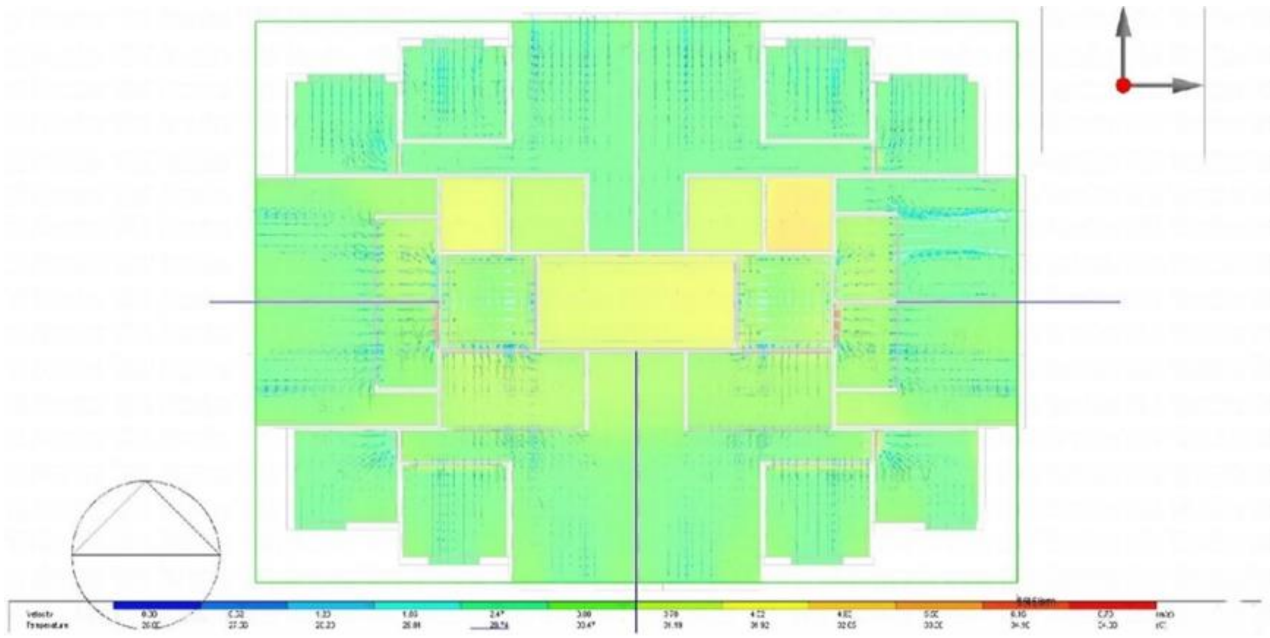


Figure 17 CFD slices showing the operative temperature and the air velocity pattern of the Typical Floor Plan (3rd floor) using solar chimney

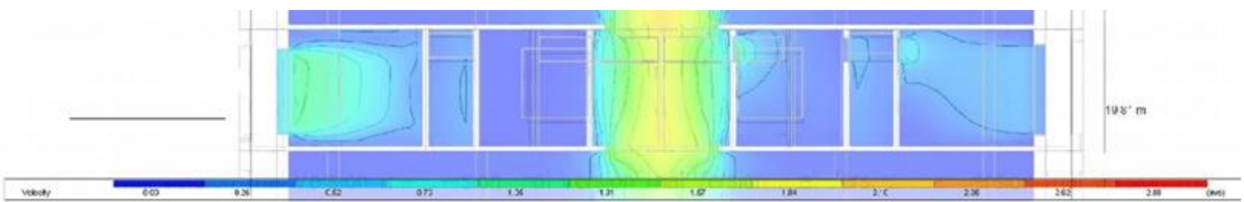


Figure 18 CFD slice showing the Velocity contours direction in longitudinal section 1

4.3.3 Last Floor Plan: (5th floor)

CFD Simulation shows a variation of operative temperature and the air velocity pattern through the CFD domain, with points closer to the façade showing slightly warmer temperatures. The Design builder calculated air temperature and the air velocity per zone of the solar chimney, additionally indicates an average of air temperature approximately 29.47 C^{o} to 30.52 C^{o}, while the velocity ranges from 0.62 to 1.59 m/s compared to the base case without solar chimney with 30.78 C^{o} at the northern zones and up to 36.83 C^{o} at the southern zones and 0 to 0.09 m/s air velocity.

This drastic drop in operative temperature is due to the cross ventilation in the southern zones created by the stack forming in the solar chimneys preventing any heat storage as the air movement continuously replacing heated air with cooler fresh air from outside the building.

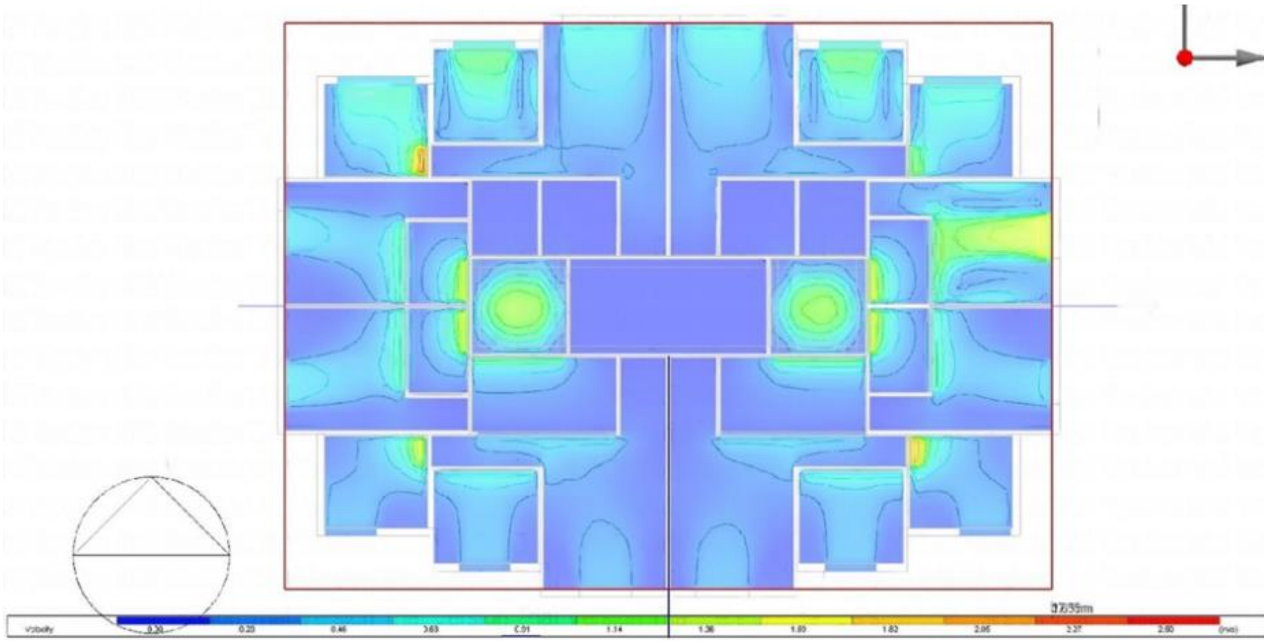


Figure 21 CFD slices showing the air velocity pattern of the Last Floor Plan: (5th floor) on using solar chimney showing the best and highest airflow circulation

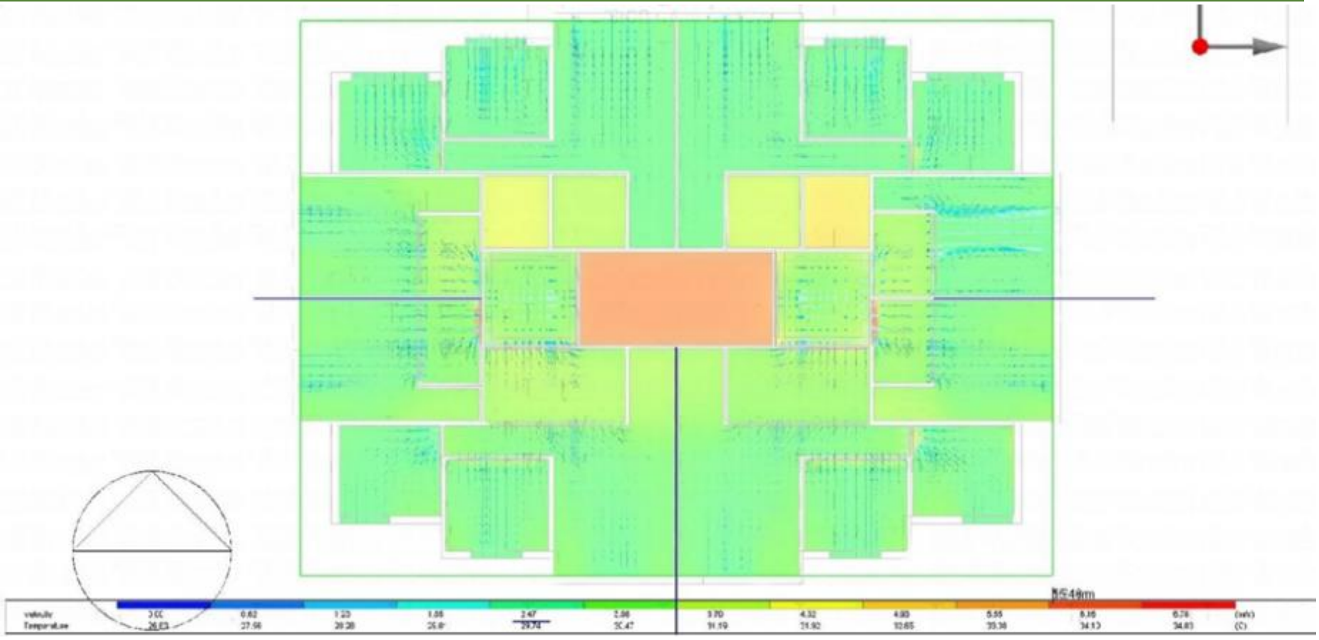


Figure 20 CFD slices showing the operative temperature and the air velocity pattern of the Last Floor Plan: (5th floor) plan on using solar chimney

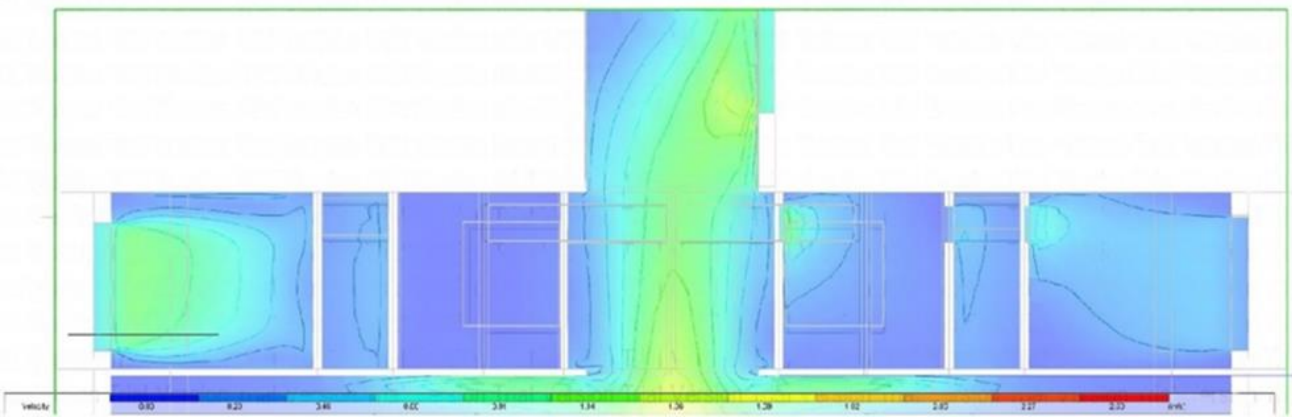


Figure 19 CFD slice showing the Velocity contours direction in longitudinal section 1

These conclusions and observations are shown in the following charts.

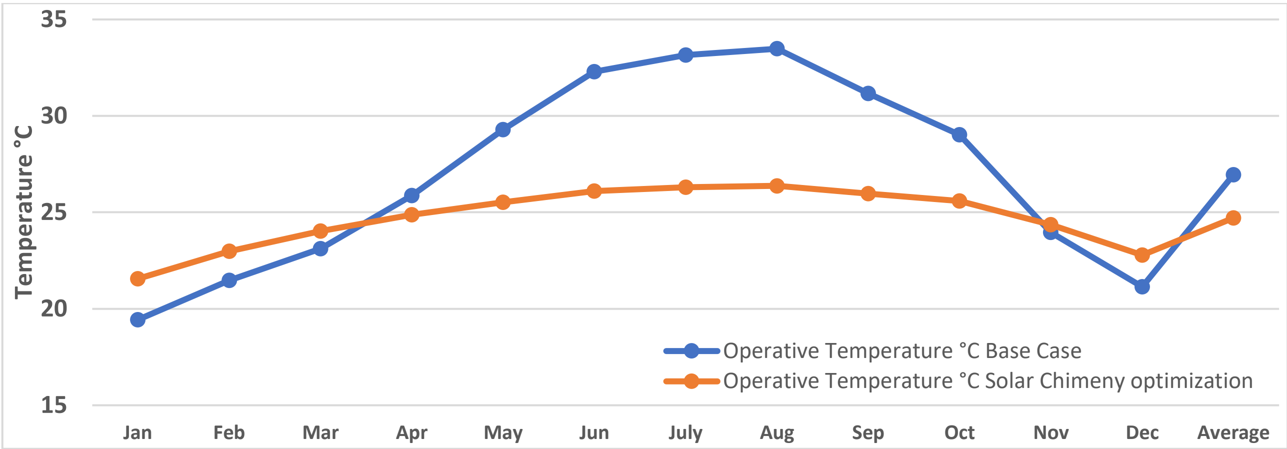


Figure 20 Comparison of Operative air temperature for Ground floor plan of the base case and solar chimney optimization

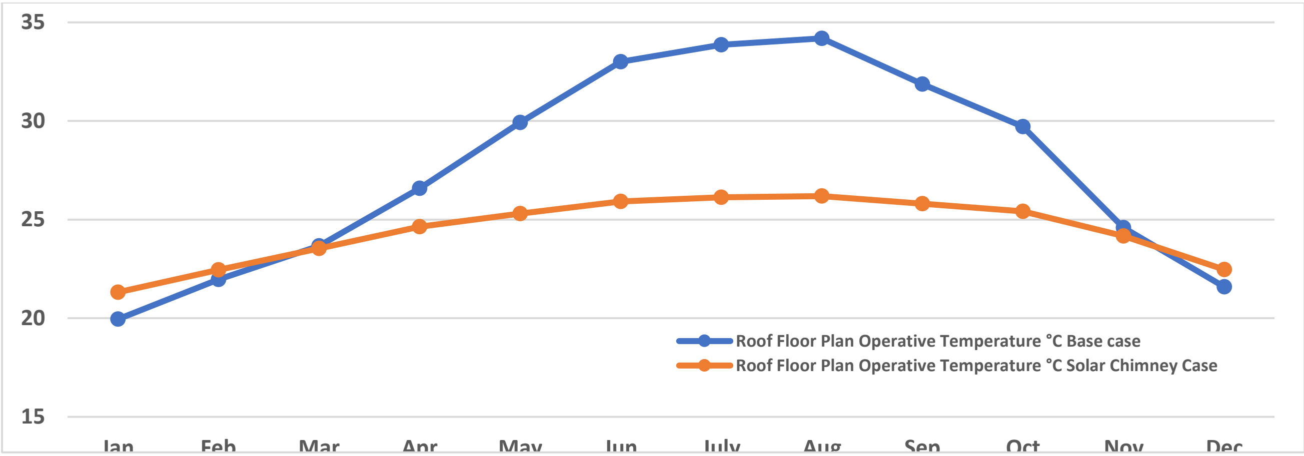


Figure 21 Comparison of Operative air temperature for Last Floor Plan: (5th floor) of the base case and solar chimney optimization.

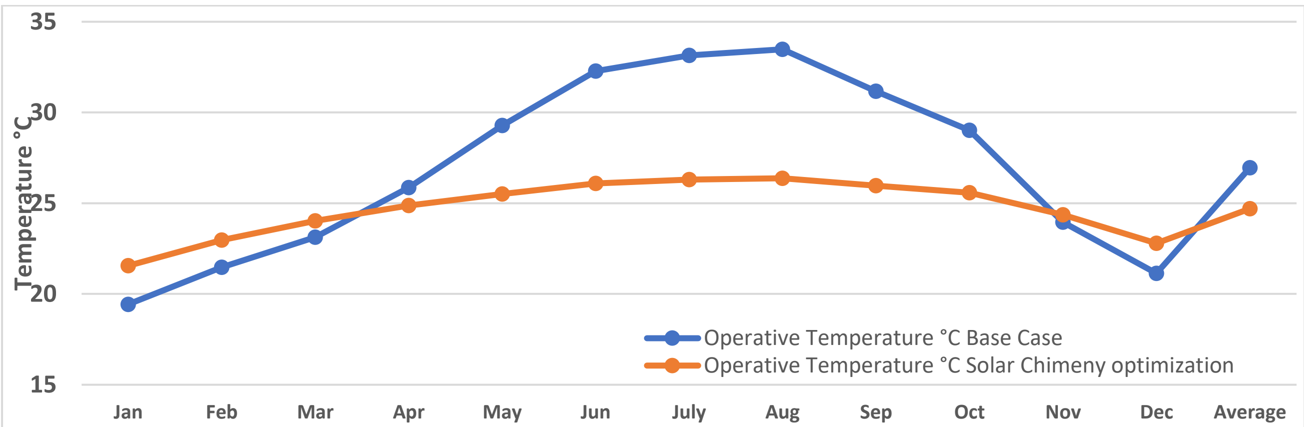


Figure 22 Comparison of Operative air temperature for Typical Floor Plan (3rd floor) of the base case and solar chimney optimization, source: the researcher.

Conclusions

This study presents a thorough investigation into the effectiveness of solar chimneys as passive design solutions for enhancing natural ventilation and thermal comfort in low-rise residential buildings, with a specific focus on Egyptian new cities. Through comprehensive simulations and analyses, significant improvements in indoor air temperature and airflow distribution were observed following the implementation of solar chimney treatments.

Initial simulations of the base case revealed disparities in thermal comfort between northern and southern zones, primarily attributable to solar radiation exposure and limited natural ventilation in the latter. To address these challenges, tailored passive treatments were devised to mitigate heat accumulation and enhance indoor air quality in the southern zones.

Integration of solar chimney treatments yielded promising results, with substantial reductions in operative temperatures observed across all building floors. Southern zones, previously experiencing temperatures as high as 36.83°C, saw significant drops to an average range of 29.47°C to 30.52°C, effectively aligning with the recommended thermal comfort range specified by the Code for improving energy use in buildings (ECP 306-2005). Concurrently, average air velocities increased to a range of 0.62 to 1.59 m/s, ensuring more efficient natural ventilation and airflow circulation throughout the building.

Moreover, the simulations demonstrated the creation of staggered cross ventilation in southern, eastern, and western zones, facilitated by the combined effects of the stack effect generated by solar chimneys and strategically placed inner wall openings. This holistic approach contributed to maintaining thermal comfort and indoor air quality across all apartments, including those on the top floor.

Overall, the application of solar chimneys emerges as a promising and sustainable solution for addressing indoor thermal comfort challenges in low-rise residential buildings within Egypt's new cities. By harnessing solar energy and natural airflow, solar chimneys offer an effective means of improving indoor environmental conditions, ultimately enhancing the quality of life for building occupants while reducing reliance on mechanical cooling systems.

This study's findings, coupled with the demonstrated efficacy of solar chimney treatments in enhancing thermal comfort and natural ventilation, provide valuable insights for architects, engineers, and policymakers involved in sustainable building design and urban planning initiatives. Further research, including long-term monitoring and interdisciplinary collaborations, is recommended to validate and refine the proposed passive design strategies for broader application in diverse climatic contexts.

While this study provides valuable insights into the efficacy of solar chimneys in improving natural ventilation and thermal comfort in low-rise residential buildings, there are several avenues for future research to explore and expand upon the findings presented here. Firstly, conducting long-term monitoring and post-occupancy evaluations of buildings equipped with solar chimney systems would offer valuable data on their real-world performance and occupants' satisfaction over extended periods. This would help validate the effectiveness of solar chimneys in diverse climatic conditions and building typologies, thereby informing future design decisions and regulatory frameworks.

Secondly, further investigations into the integration of advanced materials and technologies, such as phase change materials (PCMs) and smart control systems, could enhance the performance and versatility of solar chimney systems. PCMs, for instance, have the potential to store and release thermal energy, thereby regulating indoor temperatures more effectively and reducing energy consumption. Similarly, smart control systems can optimize airflow and ventilation rates based on real-time environmental conditions, maximizing comfort while minimizing energy usage.

Moreover, exploring the impact of architectural and urban design strategies on the performance of solar chimneys would provide valuable insights into their scalability and applicability in larger urban contexts. By analyzing factors such as building orientation, layout, and urban morphology, future studies can optimize the placement and design of solar chimneys to maximize their effectiveness in mitigating urban heat island effects and improving overall urban microclimates.

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