

Research Paper

A Numerical Study of Airflow and Average Temperature in Different Canyon Aspect Ratios: Case Study of Shiraz

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Abstract

The utilization of natural ventilation in urban canyons plays a substantial role in lessening energy consumption and heat island effects. Determining the appropriate street canyon form is then very influential. In this study, Ansys Fluent was used to numerically measure airflow, heat transfer, and solar radiation in five three-dimensional urban environments with aspect ratios (3, 2, 1, 2/3, 1/3). The $k-\epsilon$ turbulence model was used for the initial modeling and large eddy simulation of the final one. Three types of materials (gray aluminum composite, gray concrete, and white stone chipping) were considered for buildings and asphalt as ground material. The results showed that increasing the building surface fraction increased the walls' average temperature and decreased the walls' net longwave flux for three material types. Moreover, the aspect ratio was directly related to the average wall temperature and inversely related to the net long-wave flux of walls. Furthermore, the results showed that eddy height tracked the street canyon height at different aspect ratios. Comparisons also revealed that the magnitude of the vortices generated next to the buildings is approximately the same for the three materials.

Keywords: Local climatic zone, Urban canyon form, Large eddy simulation, Surface material.

INTRODUCTION

The discussion of natural ventilation and the utilization of natural resources by urban structures is a neglected topic in urban and architectural studies. Few studies have assessed the impact of urban ventilation on the urban heat island effect from the perspective of the local climates (Shi et al., 2022). Moreover, early planning and urban design models can be very important for the direct or indirect use of renewable energy, such as wind energy (Guo et al., 2022). On the other hand, the use of renewable energy can directly or indirectly reduce the urban heat island effects. This study is quite remarkable in several respects:

a) The need for natural ventilation to reduce thermal island effects (Ai & Mak, 2015; Guo et al.,

2025; Hashemi et al., 2025);

b) The necessity of employing natural ventilation to decrease (Ai & Mak, 2015; Y. Chen et al., 2025; Muqoffa et al., 2025)

c) The necessity of utilizing natural ventilation to enhance indoor and outdoor quality (Ai & Mak, 2015; Huang et al., 2025).

On the one hand, employing non-renewable energy in developing countries such as Iran causes pollution and heat generation. Thus, the energy consumption and urban heat island effects are increased. On the other hand, blockages in the corridors impede the natural air flow as the wind patterns change. Moreover, the complexity, cost, and time-consuming aspects of urban heat island calculations and urban canyon ventilation calculations meant that an

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interdisciplinary loop among architecture, urbanism, fluid dynamics, and geography is lost.

Shiraz is the largest city in terms of population in southern and southwestern Iran. Additionally, Shiraz could be a good case study for climate change due to its hot and dry climate. Contrary to previous studies (Bakarman & Chang, 2015), heat transfer simulation and numerical solution of fluid flow were used to study the daily heat cycle at the city scale. In fact, in this study, unstable simulations with solar, wind and heat loads are solved simultaneously. In contrast to previous studies (Nazarian & Kleissl, 2016; Yaghoobian & Kleissl, 2012), wind speed and direction (Blunn et al., 2022) and inlet temperature were considered realistic and time-varying in this study. In addition, the use of full-scale building heights was another innovation in this study.

The purpose of this study was to investigate the effects of urban canyon material type and geometry on daily average temperature and net long-wave wall flux. Therefore, the question arises of how urban canyon forms affect average daily temperatures and wall long-wave net fluxes. In this study, five types of urban densities (compact mid-rise, compact high-rise, open low-rise, open mid-rise, open high-rise) (Stewart & Oke, 2012) and three types of materials (aluminum gray composite, gray concrete, white stone component) were considered. Firstly, these urban models were modeled in AutoCAD 2021 as local climate zone classification. Then, the airflow was simulated in Ansys Fluent 2021R1. Based on the solution strategy of this study, the problem was switched to the LES method after the initial solution was obtained using the model, and the final solution was also solved using this technique.

LITERATURE REVIEW

In recent decades, numerous efforts have been made to link urban microclimate studies with urban design in different climate zones (Chatzidimitriou & Yannas, 2017; Li & Cheng, 2025). The urban microclimate is influenced by the urban form and its surfaces (Wang et al., 2025; Zhao et al., 2025). Cities are characterized by more impenetrable surfaces (Prabhu et al., 2025) and higher concentrations of pollution from human activity, resulting in significantly warmer ambient air temperature (Zhang et al., 2025) and higher surface temperature compared to rural areas. This phenomenon is known as the urban heat island effect (Bakarman & Chang, 2015; Fogel & Penczykowski, 2025). Urban heat islands are associated with serious health risks (Matak & Momen, 2025), especially in tropical and subtropical regions. This is because the growing urban population has caused the replacement

of the natural environment with the built environment and thus the significant release of human heat (Erell et al., 2012). The complex phenomenon of the urban heat islands arises from several aspects. First, interactions between urban surfaces absorb shortwave radiation more effectively than in rural areas (J. Chen et al., 2025). In addition, urban surface roughness reduces average wind speeds (Sato & Takemi, 2025) and decreases convective heat removal (Eltaweel et al., 2025). Urban heat islands have been measured in various cities around the world and adversely affect the demand for building energy consumption, leading to peaks in electricity demand (Rossi et al., 2015). Microclimate and outdoor heat conditions are greatly influenced by urban geometry and building configuration (Aly et al., 2022; Guo et al., 2022; Hogan, 2019; Shareef & Abu-Hijleh, 2020; Zanon & Veronesi, 2013).

The distribution of air temperature within a canyon is affected by the canyon's shape (Yang et al., 2025), orientation (Fu et al., 2025), and thermal properties of building materials. The geometry of the urban canyon (Yang et al., 2025) and the thermal properties of the urban areas (Tarkhan et al., 2025) are considered to be two important parameters that influence urban climates (Pearlmutter et al., 2007). During the day, when the building facades are heated by solar radiation, the buoyancy effect enhances turbulence (Stull, 2012; Xiong & Chen, 2022), and the combination of buoyancy and inertial forces increases heat transfer from the street canyon (Li et al., 2025). Furthermore, although the windward wall is hotter than the air, the upstream buoyancy flux contrasts with the resultant forces at the base of the building canyon, and the current structure of the urban canyon caverns is modulated by these counteractions. Varying positions of the sun and insolation throughout the day result in three-dimensional non-uniform heat flow distributions over urban surfaces (Nazarian & Kleissl, 2016).

Non-isothermal boundary layers are a common atmospheric phenomenon. Unstable conditions usually occur during the day due to anthropogenic activities and solar radiation, which are absorbed by the Earth. In contrast, on clear nights, there is a stable boundary layer over the ground. In contrast to neutral conditions, the buoyancy effects due to temperature differences play an important role in non-isothermal boundary layers and should not be neglected (Pearlmutter et al., 2007).

Numerous studies of urban canyons have been carried out in recent decades. The effect of surface temperature on heat exchange in flow fields and street canyons was investigated by numerical simulations (Li et al., 2012; Xie et al., 2006), wind tunnel experiments (Park et al., 2020; Uehara et al., 2000;

Xiong & Chen, 2022), and field measurements (Offerle et al., 2007). Most previous computational fluid dynamics studies used simple shapes such as rectangular cubes to simplify building geometry calculations to reduce computation time and cost (Mughal et al., 2021; Xiong & Chen, 2022).

Middel et al. (Middel et al., 2014) used ENVI-Met to measure changes in wind speed (Koutsanitis et al., 2025) and temperature in the built environment. Other software, such as the Integrated Environmental Solution IES-VE and Energy-Plus, focused on internal thermal parameters and performance. This software was developed primarily for simulating the microclimate parameters in urban space coverage. ANSYS-FLUENT is a highly flexible application in airflow modeling and can take into account a wide range of parameters related to fluid flows in microclimates.

In general, the LES and RANS turbulence models have been utilized simultaneously in only a few studies (Dawood et al., 2025; Shirzadi et al., 2020). Based on research conducted by Toparlar et al. (Toparlar et al., 2017), only two of 183 studies used the LES and RANS models simultaneously. The computational cost of LES models is one of the most important reasons. The next section of this study describes the research theory, data, and methods, including the overall problem, input data, boundary conditions, and mesh convergence. Findings are then discussed.

MATERIALS AND METHODS

There were four variables in this study, including

pressure, temperature, density, and wind speed. Airflow was simulated by the Navier-Stokes equation. According to the solution method of this research, after obtaining the initial solution using the k-ε model, the problem was switched to the LES method, and the final solution was obtained by this method. In addition, convective, conductive, and radiation flows were calculated through the governing equations of fluid dynamics. To this end, the solar radiation during the June 21st Summer Revolution was simulated by a Monte Carlo model. Note that this problem has common variables, so the equations must be solved simultaneously. The analytical methods are summarized in Table 1.

Five models were simulated in this study. Each model contains a 3x3 matrix of buildings with equal volumes and a cross-sectional area of 27x27 square meters. The computational domain height was 6H (Nazarian & Kleissl, 2016) to achieve a fully developed flow field, where H represents the building height. The range of building densities analyzed was between open mid-rise and compact high-rise, classified by Stewart and Oke (Stewart & Oke, 2012) (Figure 1) (Table 3). For this purpose, two-building surface fractions were defined, including 56% for compact (case 1) and 25% for open (case 2) (Table 3). In this study, input data based on the city of Shiraz with a hot and dry climate were considered. In addition, the effects of different materials on temperature were investigated (Table 3). Furthermore, CFD solvers were based on the finite volume method (Versteeg & Malalasekera, 2007).

Table 1. Summary of Analysis Methods

The main components of the solution	Description
Geometry	Geometry consists of 5 aspect ratios in the ground with dimensions 108 m by 108 m (compact arrangement) and 162 m by 162 m (wide arrangement) Gray aluminum composite
Solid domain	White stone chipping Gray concrete
Fluid	Air ideal gas density formula
Turbulent flow model	For the Initial solution is used k-ε model and for the exact solution is utilized LES model
Radiation model	Monte Carlo
Solver type	Transient
Time steps	864000 time steps with 0.1 Sub-Step100 iterations

Table 2. Material Specification According to Radhi et al. 2014

Materials	Symbol	Density <i>kg/m³</i>	Conductivity <i>w/mK</i>	Specific heat <i>Kj/KgK</i>	Infrared emittance
Gray aluminum composite	Al-GY	7680	45	420	0.89
Gray concrete	C-GY	2050	0.719	890	0.9
White stone chipping	ST-CH	2240	1.74	1686	0.93

Table 3. Geometric Characteristics of the Models

Aspect ratio	Density type	Building height	Distance between buildings	Building dimension fraction	Ground dimensions	Building surface
3	Compact high-rise (Figure a)	27m	9m	$27 \times 27 \text{ m}^2$	$108 \times 108 \text{ m}^2$ (case1)	56%
2	Compact mid-rise (Figure b)	18m	9m	$27 \times 27 \text{ m}^2$	$108 \times 108 \text{ m}^2$ (case1)	56%
1	Open high-rise (Figure c)	27m	27 m	$27 \times 27 \text{ m}^2$	$162 \times 162 \text{ m}^2$ (case2)	25%
2/3	Open mid-rise (Figure d)	18m	27 m	$27 \times 27 \text{ m}^2$	$162 \times 162 \text{ m}^2$ (case2)	25%
1/3	Open low-rise (Figure e)	9m	27 m	$27 \times 27 \text{ m}^2$	$162 \times 162 \text{ m}^2$ (case2)	25%

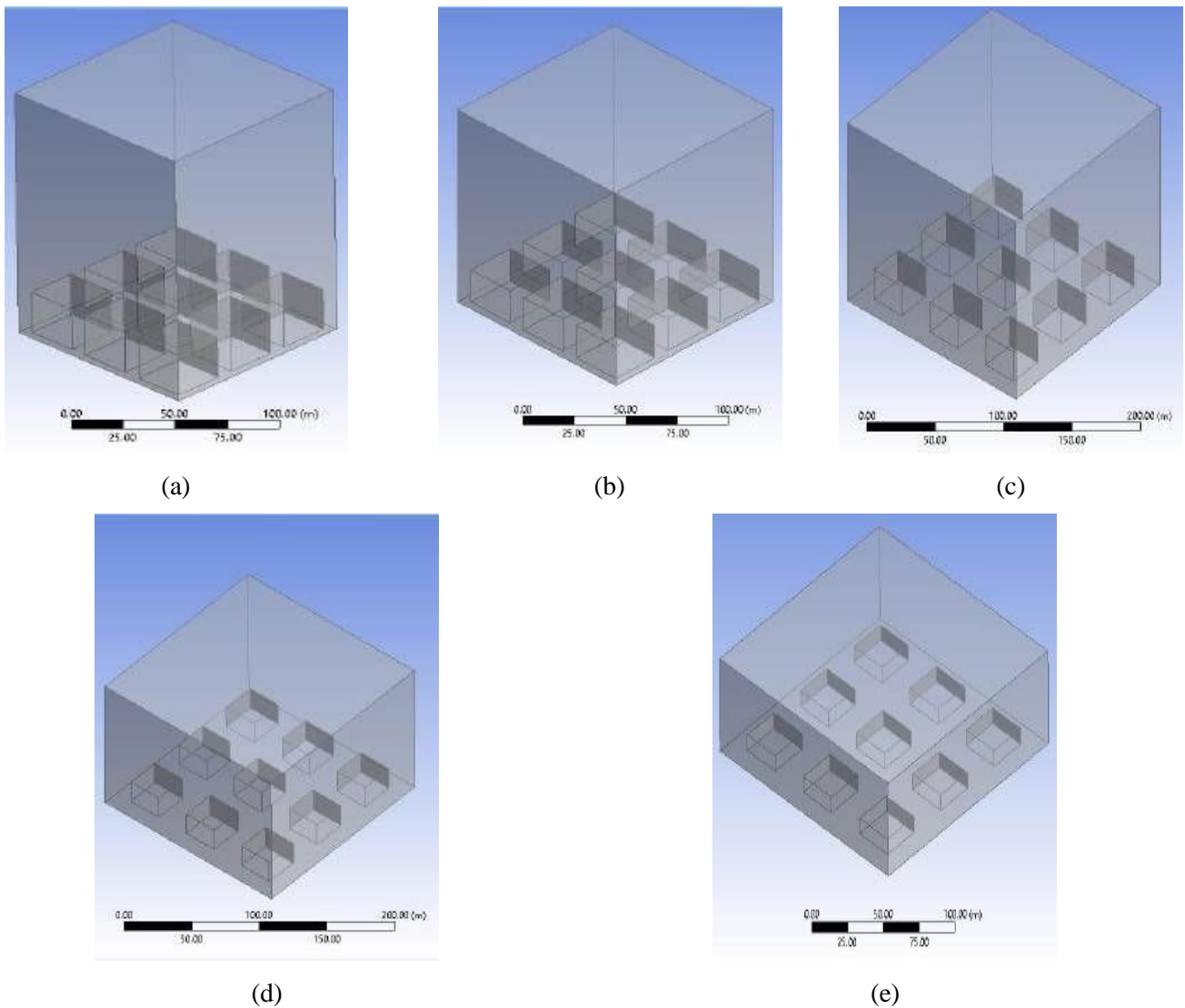
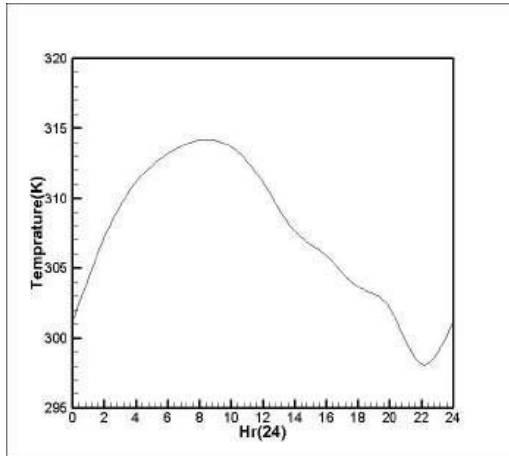


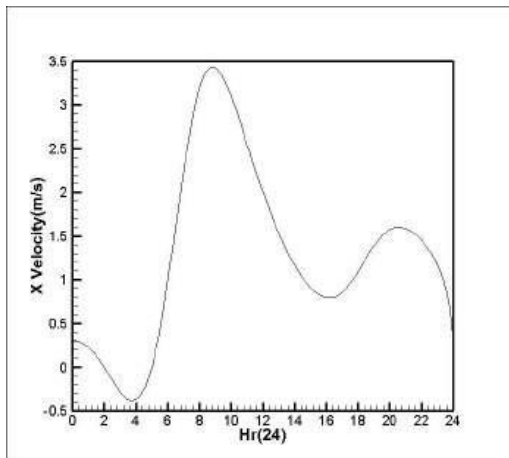
Fig 1. The Geometry of Five Defined Models: (a) Compact High-rise, (b) Compact Mid-rise, (c) Open High-rise, (d) Open Mid-rise, and (e) Open Low-rise

Introducing Data

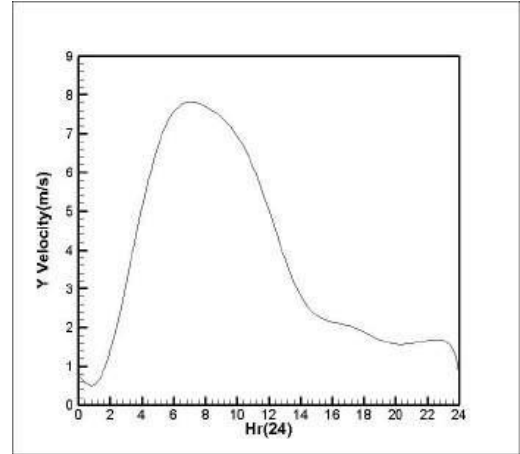
For this study, weather data for June 21 (the longest day of the year) in Shiraz was selected to drive the simulation process. Climate analyses for the region were obtained from www.worldweatheronline.com, which is recognized as one of the most reliable sources for weather data globally. The climate parameters necessary for modeling solar load were computed over a 24-hour period starting at 7 a.m., with the solver accessing the relevant data through user-defined functions (UDFs) implemented in C. The weather data for June 21 served as the reference for calculations, as detailed in Table 6. Given that data is available at three-hour intervals, Fourier analysis was employed to facilitate averaging over periods of missing information based on the defined range. Figure 2 illustrates the time-dependent boundary conditions for (a) temperature, (b) velocity along the X-axis, and (c) velocity along the Y-axis.



(a)



(b)



(c)

Fig 2. Time-varying Boundary Conditions for: (a) Temperature, (b) Velocity along the X axis, (c) Velocity along the Y Axis

Boundary Conditions

This model used symmetric boundary conditions to simulate an urban area. In addition, the velocity inlet was considered as the inlet boundary condition and the mass flow as the outlet boundary condition. Furthermore, the no-slip boundary condition of the stationary wall was employed for the top view. Note that the problem was resolved at 864000 time steps. Each time step had sub-steps of 0.1 s. Every 0.1 seconds, this problem was solved up to 100 iterations. So the perfect solution for each problem was 864×10^5 iterations.

Grid Convergence

Grid convergence is one of the most important stages of any research conducted by CFD. In this study, four grid models (Table 4) were designed. These models have similar y^+ values but different grid sizes. In the current investigation, two mesh convergence groups, including compact high-rise (Figure a) and Compact mid-rise (Figure b), were selected. We have developed 3 types of materials for each case. The mesh convergence parameter was the average daily wall temperature. As can be seen in Figure 3, grids #4 and #3 converge in this problem. Based on the calculations in Table 5, the average distance from the wall to the first node is 0.5 mm.

Table 4. Table of Grid Providers with Different y^+

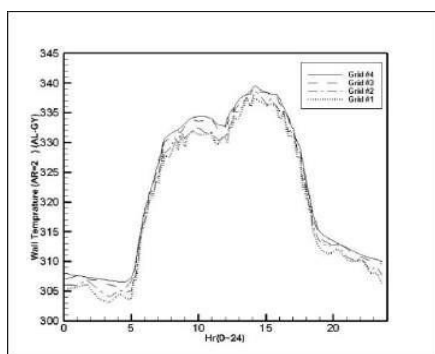
Grid number	y^+
Grid 1	200
Grid 2	100
Grid 3	40
Grid 4	2

Table 5. Calculating the Distance of the First Node from the Wall

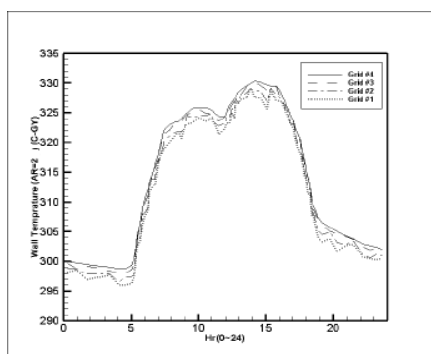
Building height	Reynolds number	friction coefficient	shear stress	friction coefficient	y
H=9m	4.7×10^6	2.68×10^{-3}	$0.107 \frac{kg}{ms^2}$	$0.3 \frac{m}{s}$	$y(l = 9)$ $= 5.29 \times 10^{-4}m$
H=18m	9.4×10^6	2.33×10^{-3}	$0.093 \frac{kg}{ms^2}$	$0.28 \frac{m}{s}$	$y(l = 18)$ $= 5.67 \times 10^{-4}m$
H=27m	14.1×10^6	2.15×10^{-3}	$0.086 \frac{kg}{ms^2}$	$0.27 \frac{m}{s}$	$y(l = 27)$ $= 5.88 \times 10^{-4}m$

Table 6. Three-hourly Weather Data

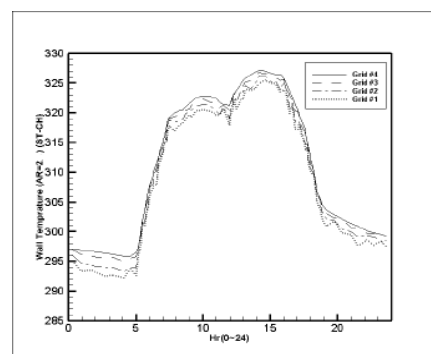
Hour	Second	Wind speed	Wind direction	Components	
	km/h	m/s	Orientation	x	y
7 0	3	0.833333	WNW	0.318903	0.7699
9 7200	5	1.388889	W	0	1.388889
12 18000	24	6.666667	W	0	6.666667
15 28800	30	8.333333	WNW	3.189029	7.698996
18 39600	24	6.666667	WNW	2.551223	6.159197
21 50400	11	3.055556	WNW	1.16931	2.822965
0 61200	8	2.222222	WNW	0.850408	2.053066
3 72000	8	2.222222	NW	1.571348	1.571348
6 82800	6	1.666667	NW	1.178511	1.666667
7 86400	3	0.833333	WNW	0.318903	0.7699



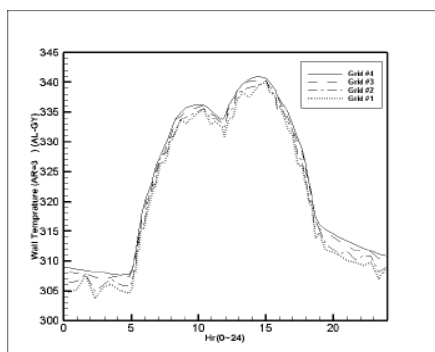
(a1)



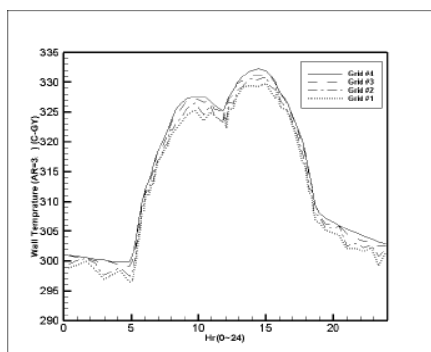
(a2)



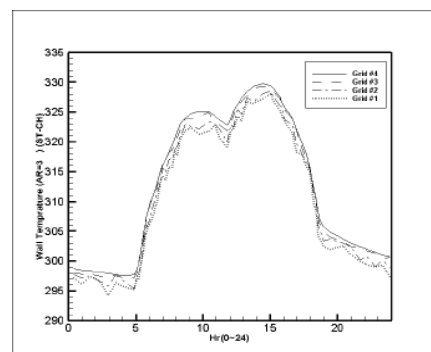
(a3)



(b1)



(b2)



(b3)

Fig 3. Grid Convergence for: (a) Compact Mid-rise (b) Compact High-rise (1) Gray Aluminum Composite (2) Gray Concrete, and (3) White Stone Chipping

ANALYSIS

To analyze the effect of the flow field on surface temperature and net longwave flux, we simulated the daily average wall temperature (T_{sides}) and average net wall longwave flux (L_{sides})

A Study of the Effects of Different Materials and Aspect Ratios on T_{sides}

Aspect ratio determines the penetration of direct sunlight into a street canyon. In general, the amount of direct solar absorption with short-wavelength decreases as the aspect ratio increases due to mutual shadows between buildings and shadows on the ground. Figure 4 shows plots of the variation of T_{sides} for various materials and aspect ratios. As seen, in all aspect ratios from 5:00 AM to 7:00 AM, there is a sharp rise in the T_{sides} due to the low altitude of the sun. The increase in T_{sides} continues until about 2:00 PM and reaches its maximum value at the same time. And after 12 o'clock, the shadow area is gradually enlarged. So T_{sides} drops sharply from 14:00 to 18:30. The decrease in T_{sides} then continues until about 5:00 am, reaching a minimum amount for that hour. Furthermore, comparing various urban canyons, we find that T_{sides} are directly related to aspect ratio. Furthermore, the lowest value belongs to the aspect ratio of 1/3 around 5:00 AM and the highest one is related to an aspect ratio of 3 about 14:00. Furthermore, a comparison of the three material types shows that the lowest T_{sides} for all aspect ratios belongs to the white stone with an average temperature of 283 K, and the highest relates to the aluminum material with an average temperature of 341 K. Furthermore, comparing Case 2 and Case 1, we can see that increasing the building surface area percentage increases the maximum T_{sides} significantly. Therefore, the maximum T_{sides} difference between the two cases and among the three materials belongs to the aluminum and is about 15 degrees.

A Study of the Effect of Varying Materials and Aspect Ratios on L_{sides}

Figure 5 demonstrates the L_{sides} variation diagrams for different materials and aspect ratios; L_{sides} is also affected by aspect ratio. For all aspect ratios, L_{sides} increases steeply at the beginning of the day from about 6:30 AM to about 13:00, and this increase continues with a gentle slope until 15:00, reaching a maximum value at this time. Furthermore, these figures show that L_{sides} increases with decreasing

aspect ratio, with the maximum value observed for street canyons with an aspect ratio of 1/3. Then, from 15:00 to the next morning, L_{sides} drops relatively steeply. However, the decrease in slope during these hours is smaller than the increase in slope for L_{sides} during the earlier hours of the day. This decrease continues at a moderate rate until 18:30, reaching the lowest values for all aspect ratios during this time. L_{sides} decreases with increasing aspect ratio, reaching a minimum at a street canyon with an aspect ratio of 3. In this study, the effects of three material types on L_{sides} in five urban canyons were simulated. The simulation results (Figure 5) show that the minimum L_{sides} associated with the aluminum material at 6:30 AM is approximately equal to 23 w/m^2 ; in contrast, the maximum L_{sides} associated with the white stone material at 15:00 is approximately equal to 375 w/m^2 . The results reveal that at both day and night, the aluminum material has higher T_{sides} than concrete and white stone, but aluminum has the lowest L_{sides} at all aspect ratios. It can be concluded that aspect ratio change is a more significant parameter in L_{sides} variations than material changes. Furthermore, comparing Cases 1 and 2, we can see that decreasing the building surface fraction significantly increases L_{sides} . Therefore, the maximum L_{sides} difference in the two cases of the three materials belongs to the white stone material and it is about 100 w/m^2 .

Effects of Aspect Ratio Variations on Eddy Formation

Changes in the aspect ratio of the urban canyon bring about changes in flow structure, wind shadow, and convective heat transfer. Figure 6 demonstrates the eddies formed between buildings with different aspect ratios for three material types. As seen in Figure 6, changing the aspect ratio changes the wind shadow and the formation of eddies between buildings. Interestingly, the vortex magnitude follows the height of the urban canyon; Therefore, the higher the eddy height, the larger the eddy usually formed. For instance, comparing Figures 6b and 6d at a height of 18 m, we can see that higher densities produce stronger eddies, as the flow is not uniform. The comparison also reveals that the eddies created adjacent to the buildings are approximately the same size for the three material types.

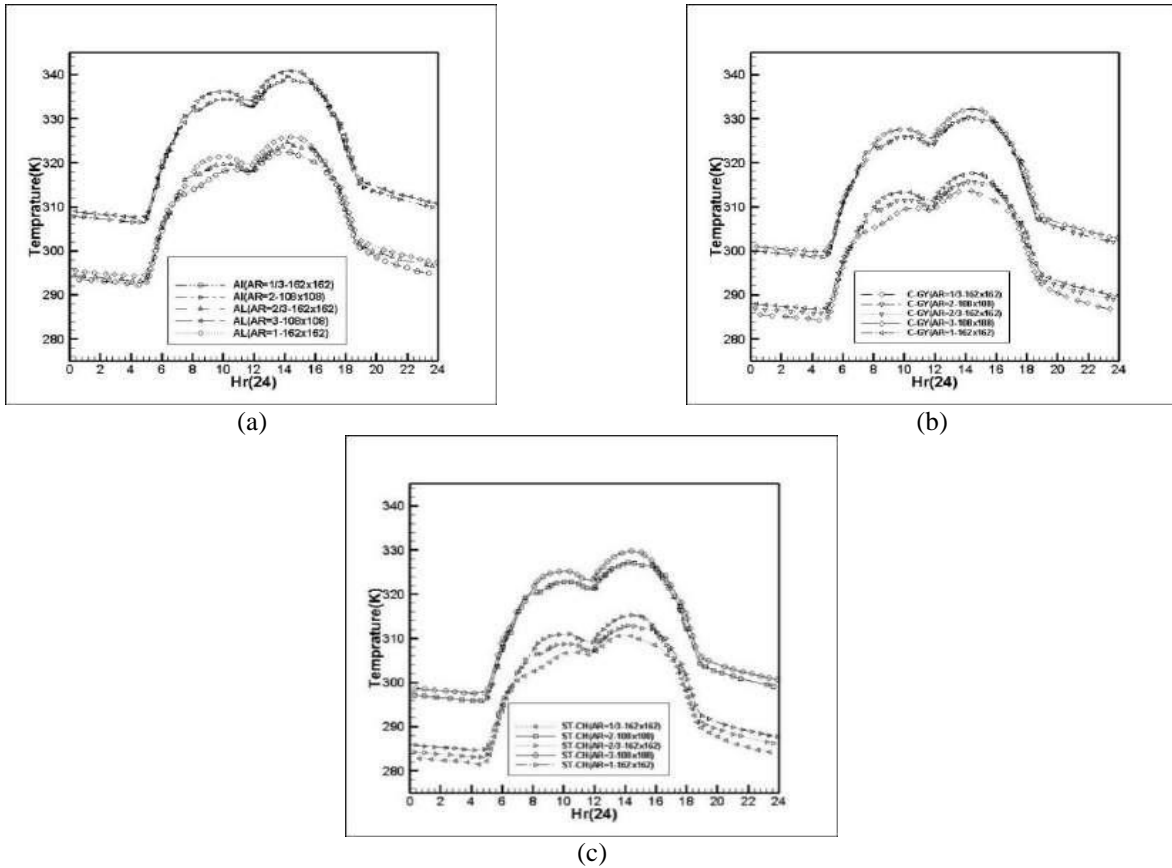


Fig 4. Comparison of T_{sides} Changes in Case 1 and Case 2 with Different Aspect Ratios for: (a) Gray Aluminum Composite, (b) Gray Concrete, and (c) White Stone Chipping

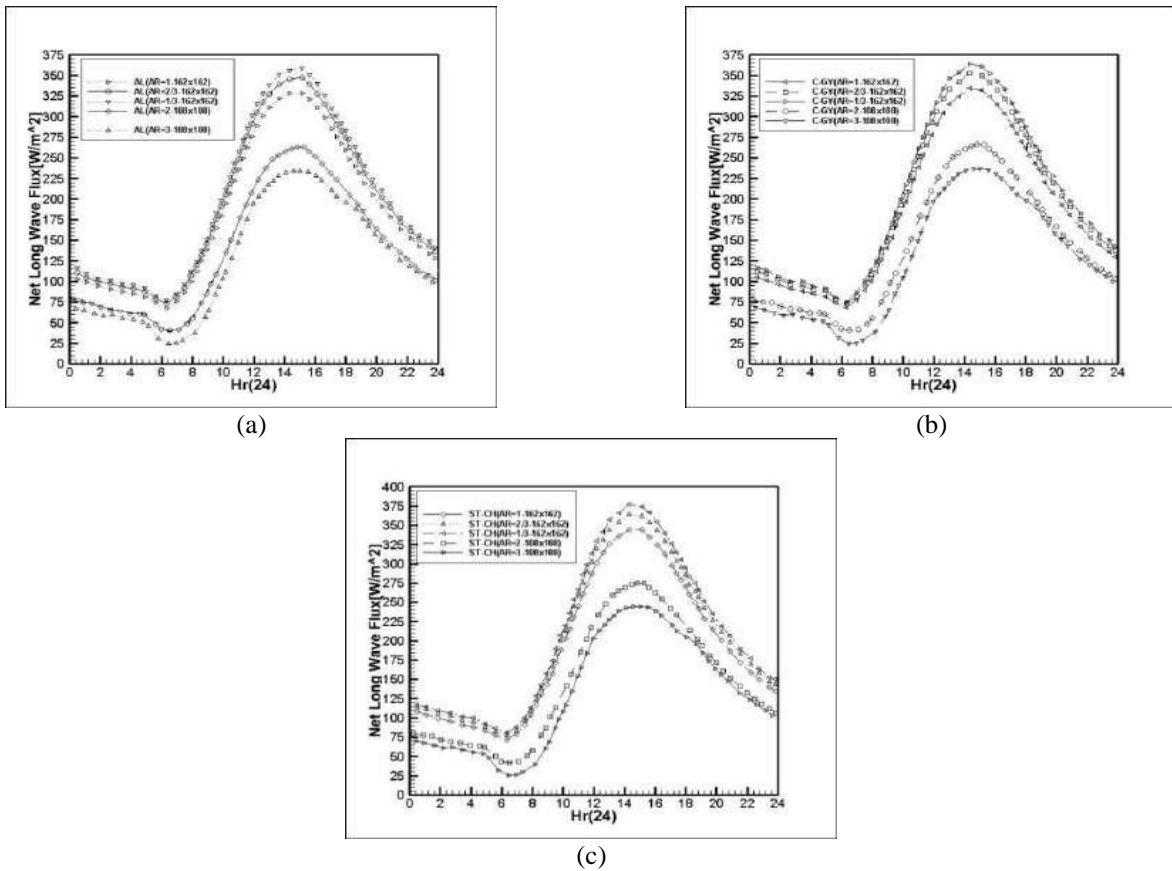
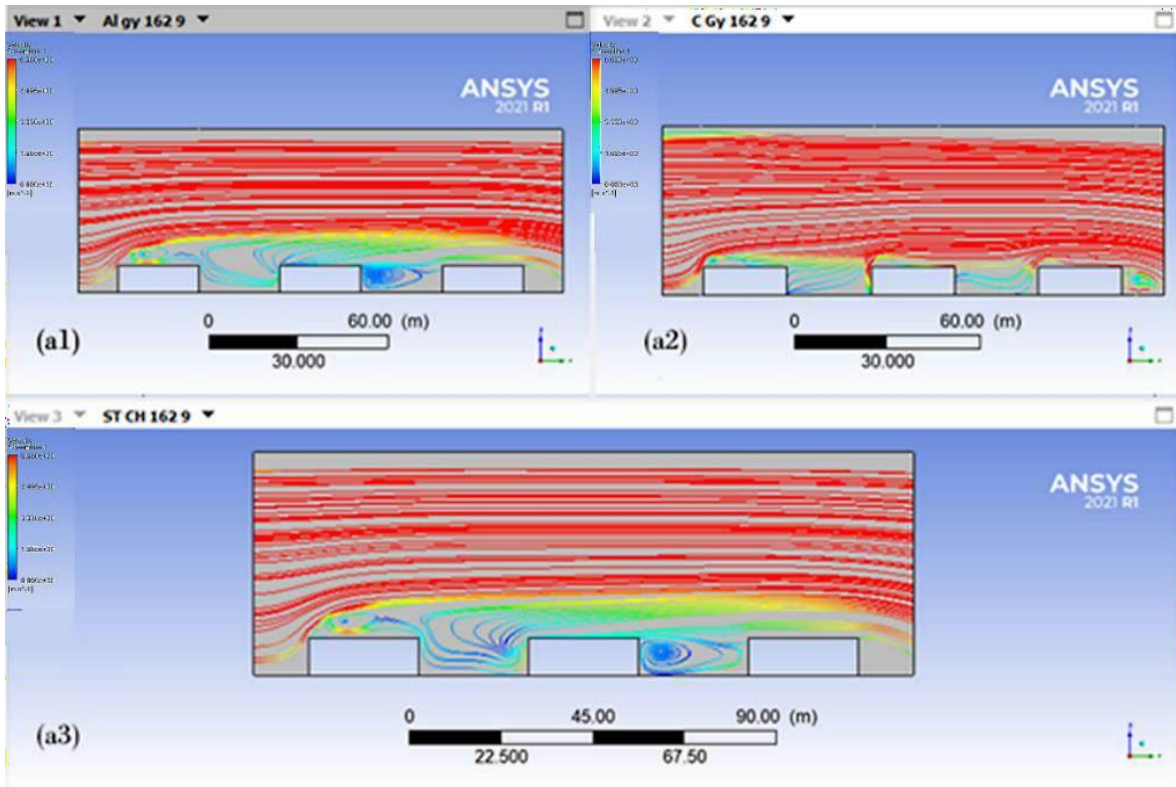
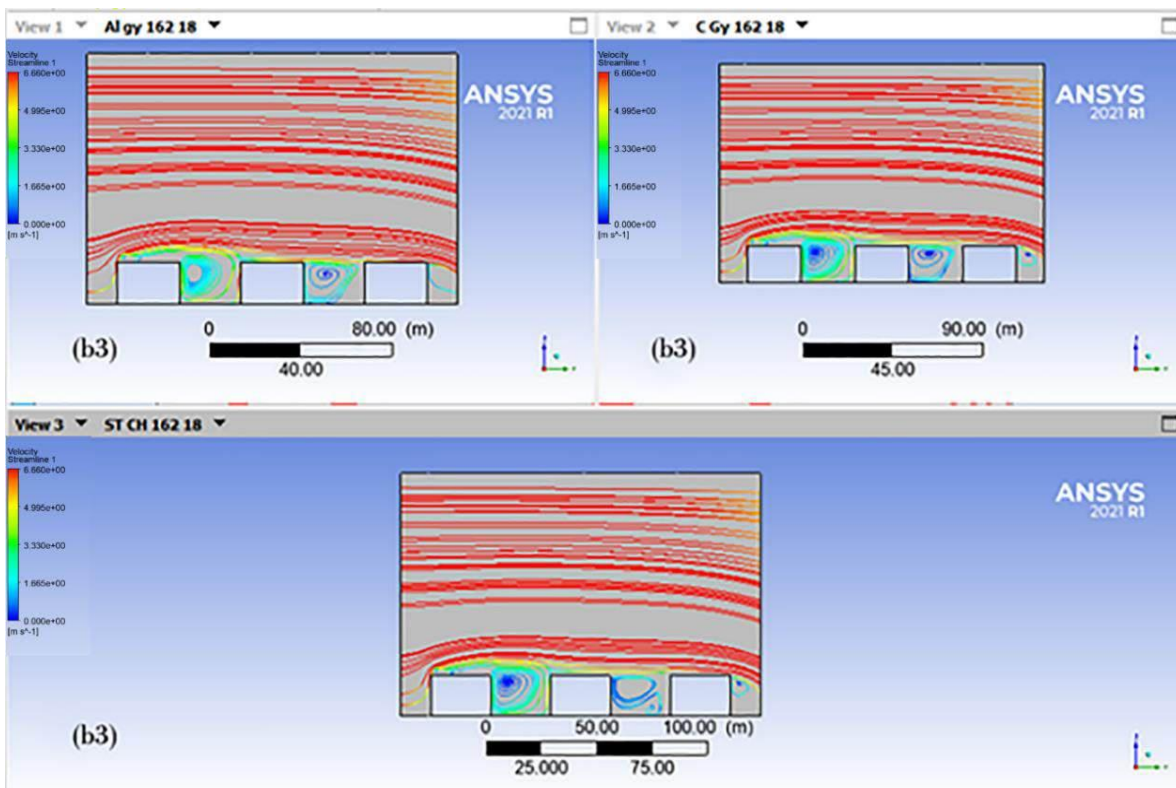


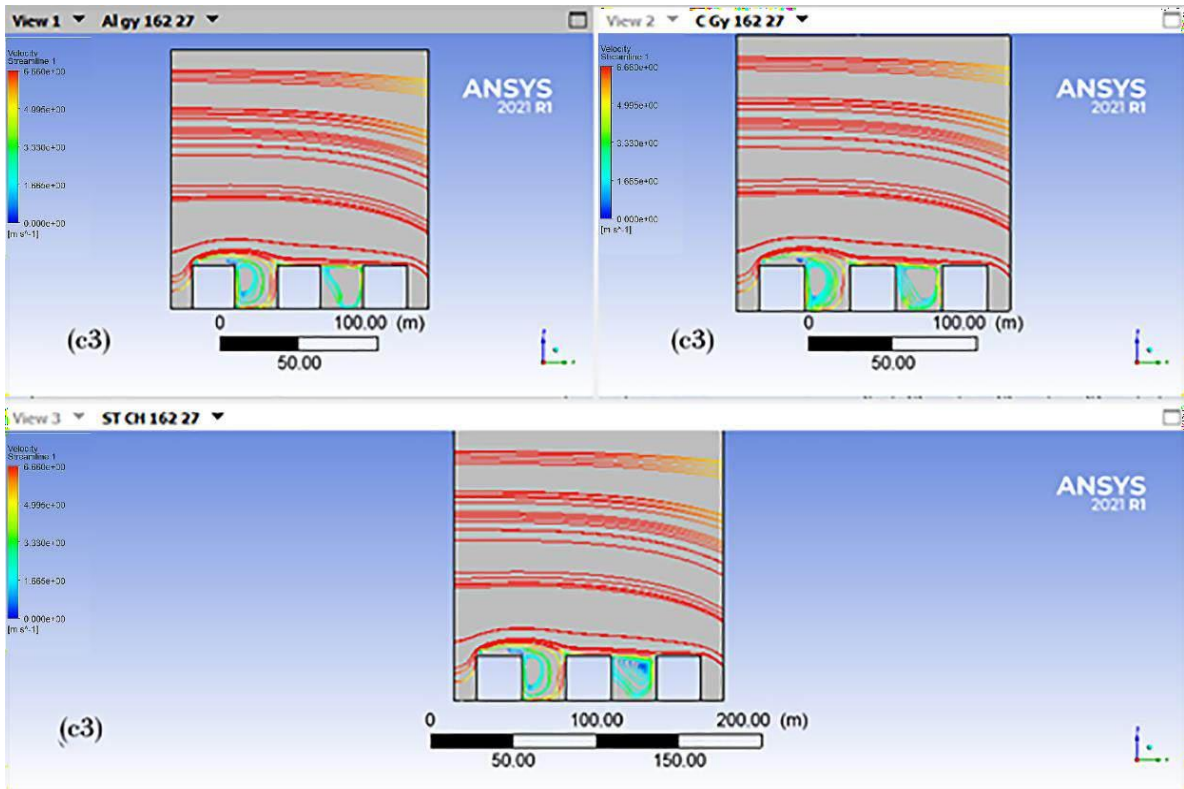
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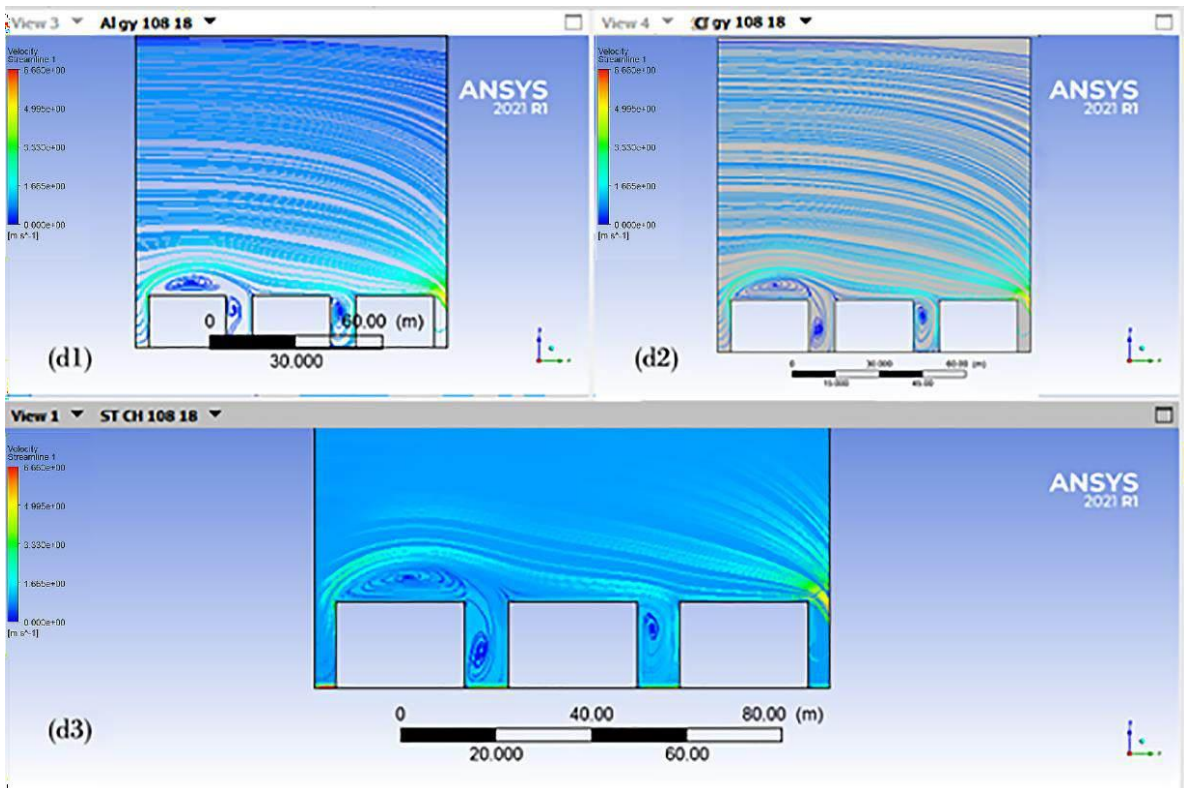
(a)



(b)



(c)



(d)

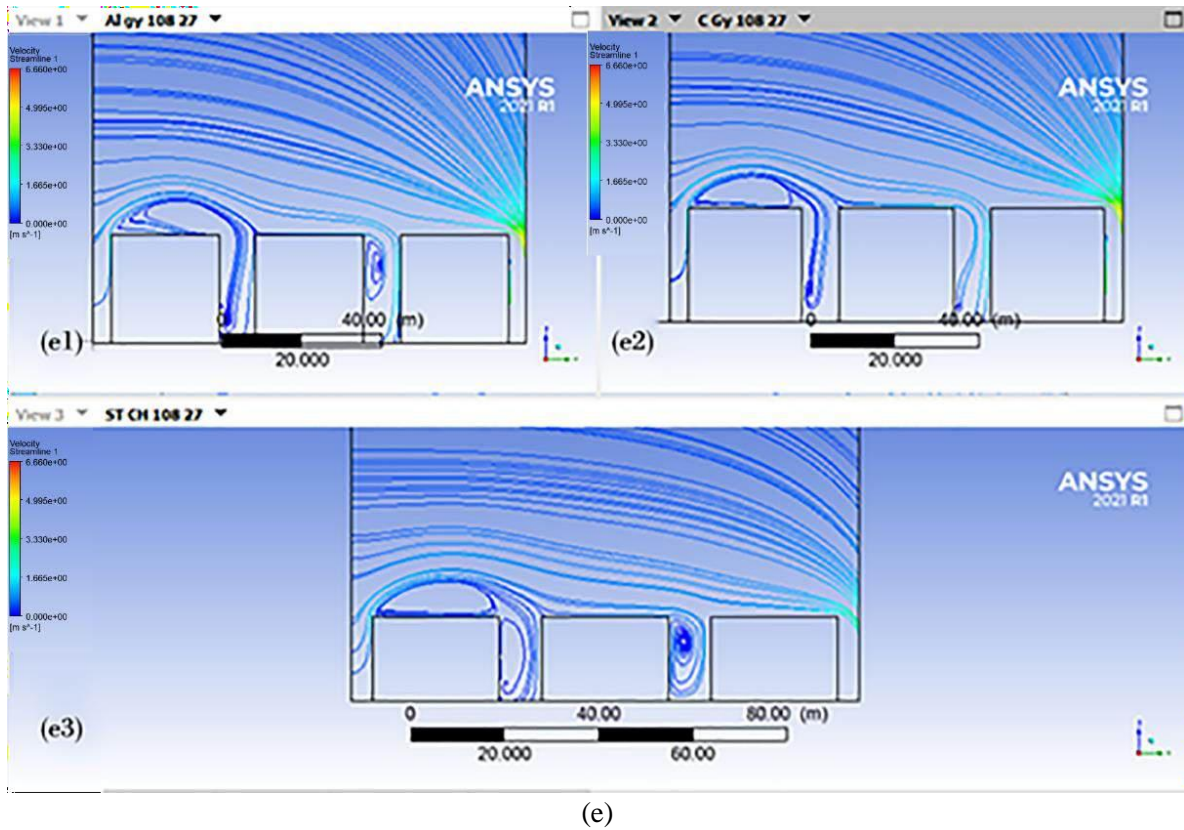


Fig 6. Velocity Streamline at Noon for Aspect Ratio (a) 1/3, (b) 2/3, (c) 1, (d) 2, (e) 3 and Three Types of Materials: (1) Gray Aluminum Composite, (2) Gray Concrete, and (3) White Stone Chipping

RESULTS AND DISCUSSIONS

This research investigated the daily average temperature and net longwave flux of walls across five different geometries of urban canyons using computational fluid dynamics. The geometries were based on real dimensions, encompassing five distinct urban densities: Compact Mid-rise, Compact High-rise, Open Low-rise, Open Mid-rise, and Open High-rise. Three different materials were utilized in the study: gray aluminum composite, gray concrete, and white stone fragments. The study simulated five different aspect ratios as proposed by Stewart and Oke (2012), employing the aforementioned materials. As noted by Yaghoobian and Kleissl (2012) and Nazarian and Kleissl (2016), our findings demonstrate that variations in aspect ratio and building surface fraction significantly influence urban surface temperatures and wall net longwave flux.

The results indicate that an increase in the building surface fraction leads to a notable rise in T_{sides} while simultaneously decreasing L_{sides} for all three materials. Furthermore, there is a direct correlation between aspect ratio and T_{sides} , while L_{sides} shows an inverse relationship with aspect ratio. Specifically, the lowest T_{sides} was observed for the white stone material with an aspect ratio of 1/3 at 283 K around

5:00 AM, whereas the highest T_{sides} was recorded for the aluminum material with an aspect ratio of 3 at 341 K around 14:00. Conversely, the lowest L_{sides} was associated with the aluminum material (aspect ratio of 3) at 23 W/m² around 6:30 AM, while the highest L_{sides} was linked to the white stone material (aspect ratio of 1/3) at 375 W/m² around 15:00. Additionally, simulations revealed that changes in aspect ratio affect wind shadowing and vortex formation; interestingly, the size of the vortices created adjacent to buildings remains consistent across the three material types, aligning with the height of the urban canyon. In contrast to previous studies, such as that by Middel et al. (2014), which employed ENVI-Met software to simulate outdoor thermal performance and assess variations in temperature and wind speed within built environments, this research adopts a distinct approach. While Toparlar et al. (2017) utilized Integrated Environmental Solution IES-VE and Energy-Plus software, primarily designed for simulating microclimate parameters in urban settings, our study harnesses the advanced capabilities of ANSYS-FLUENT. This robust application offers significant flexibility in airflow modeling and accommodates a wide array of fluid flow parameters within microclimates. Moreover, prior research, such as that by Nazarian (2017), often relied on buildings with a

height of just 3 meters—a scale rarely seen in contemporary urban environments. In contrast, this study employs real-scale buildings, enhancing the applicability of our findings to current urban landscapes. Another noteworthy aspect of this research is its incorporation of actual meteorological models. Unlike previous studies that treated wind speed and direction as constant (e.g., Nazarian, 2017), this study accounts for temporal variations in wind speed and direction based on real meteorological data. This methodological advancement contributes to a more accurate assessment of thermal performance in urban settings.

It is also worth noting that some researchers, such as Taha (1997) have drawn differing conclusions, indicating variability in research outcomes related to the thermal characteristics of various materials and the geometric impacts on surface temperatures. This variability may arise from differing environmental conditions or methodologies employed in these studies.

CONCLUSIONS

This study comprehensively examined the impact of urban canyon geometry, building surface fraction, and material type on wall surface temperature and net longwave heat flux using CFD simulations. By analyzing five distinct urban canyon forms with varying aspect ratios and surface materials (aluminum composite, gray concrete, and white stone), the research highlighted the strong interplay between urban morphology and microclimatic performance.

The findings revealed that increases in building surface fraction notably elevate surface temperatures while reducing net longwave flux, with this trend consistent across all materials. Aspect ratio exhibited a direct correlation with maximum surface temperature (T_{sides}) and an inverse relationship with net longwave flux. Among the materials studied, aluminum showed the lowest flux values, while white stone consistently recorded the highest. Additionally, diurnal variations in surface temperature emphasized the sensitivity of thermal performance to both geometry and material choice, particularly under extreme radiative conditions.

Furthermore, variations in aspect ratio were found to significantly influence wind patterns, shadow distribution, and vortex formation, although the size and structure of vortices remained largely consistent across materials. These aerodynamic characteristics, combined with thermal outcomes, underscore the critical role of canyon design in urban heat mitigation.

Overall, the study advances our understanding of how urban design parameters influence thermal behavior and longwave energy exchange. These

insights provide valuable guidance for sustainable urban planning, particularly in hot-arid climates, by promoting geometries and materials that minimize heat accumulation while maintaining energy efficiency.

FUTURE SUGGESTIONS

While this study has provided valuable insights into the dynamics of urban microclimates, there are still many aspects that require deeper exploration. The findings presented here should be seen as a starting point for further work, rather than a complete solution to the challenges of sustainable urban design.

Future research should focus on evaluating the scalability and applicability of the current findings across diverse climatic and geographical contexts. Advanced modeling approaches, such as integrating computational fluid dynamics (CFD) with machine learning and AI-based optimization techniques, can improve the accuracy and predictive capability of urban microclimate simulations. Comparative studies involving different urban canyon geometries and experimental field measurements are essential to validate and refine the proposed models. Furthermore, exploring innovative urban design strategies, including the use of green infrastructure, reflective surfaces, and renewable energy solutions, would provide a holistic framework for sustainable and climate-resilient urban development.

NOMENCLATURE

AI-GY

Gray aluminum composite, 9

1 CFD

Computational Fluid Dynamics, 5, 7, 11, 25, 7, 26

2 C-GY

Gray concrete, 9

3 H

Building height, 7, 11, 26

4 12

23

5 LES

Large Eddy Simulation, 5

Lside

Average net wall longwave flux, 13

6 RANS

Reynolds-averaged Navier–Stokes, 5

7 ST-CH

White stone chipping, 9

Tsides

Daily average wall temperature, 13, 14, 15, 21

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