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Towards Environmental Retrofitting of Egyptian Transitional Spaces: Courtyard-Building in Alexandria University, Egypt

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***Abstract*—Consuming huge amount of energy and emitting large amount of heat can be assumed as one of the main problems facing urban environment in the world today. These problems associated with current high urban density and less of vegetation within urban fabric. For instance, in Egypt, Universities are today facing rising problem of offering more educational spaces especially in large cities such as Cairo and Alexandria. The study thus focuses on Revival Egyptian buildings in Alexandria University based on hierarchical transitional spaces. As Egyptian transitional spaces, such as courtyards historically were essential outdoor spaces for multiple uses and purposes.**

As part of retrofitting research project of existed transitional spaces in Alexandria University, this paper focused on one parameter which is building height. This is by targeting to find the maximum height of courtyard building with minimum negative effect on air and thermal flow. This simulation is done with consideration to the surrounding urban context in Alexandria University. The simulation approach is based on two years of field measurement of thermal conditions and air velocity in the University's transitional spaces. The study is usingfield-measurement data for nurturing the Computational Fluid Dynamics (CFD) model, and for validating the simulation results. The Computational Fluid Dynamics (CFD) study is done by introducing four cases of different building heights to investigating the changing air and thermal flow inside the existed courtyard.

***Index Terms*—Computational Fluid Dynamics (CFD),Egyptian Courtyard building, Environmental retrofitting,Transitional spaces, Air flow pattern**

I. Introduction

Transitional spaces can be effectively traditional way to improve indoor climatic conditions. In Egypt, these transitional spaces had a long history of multi-purpose uses specially related to social and environmental advantages. Within Egyptian view, transitional spaces used as hierarchical spaces between public and private spaces which have environmental benefits such as decreasing sand storms' effect, enhancing daylight levels and improving thermal performance. Within this paradigm, the study focuses on courtyard building in Alexandria University, as currentlythere is a relative lack of knowledge on the effect of transitional spaces on the air and thermal flow in educational buildings, as in the meantime most studies focusedmore on residential and commercial buildings. As there is an increasing demand of offering new educational spaces in the Alexandria University, the case study is focusedon the treatment of changing height of existed building through four defined case studies. The existed building is considered within a context of a chain of hierarchical transitional spaces.

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II. The Context

In Alexandria University, the Egyptian revival style buildings imitate the traditional old Egyptian courtyard concept that maintains a number of Egyptian values in urban context. The context of the case study building is situated at latitude and longitude of 31° 12'/29° 55' respectively.

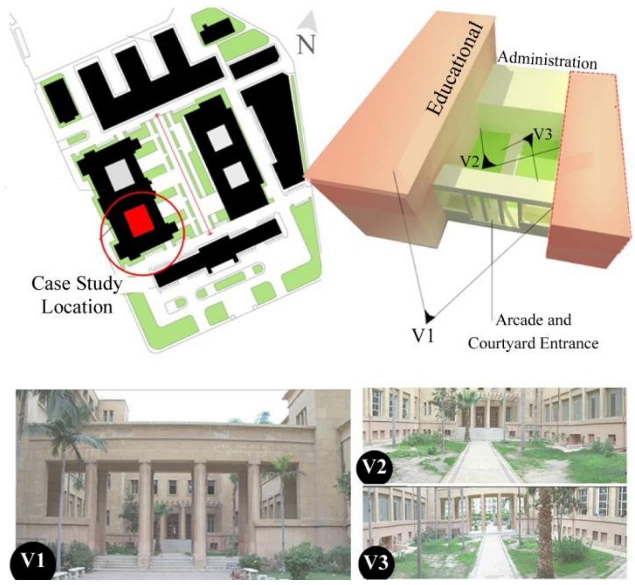

Fig. 1. Defining the location of the Egyptian case study

As shown in figure1, the selected courtyard building was selected as a case study to be investigated by using field measurement method.

III. Field Measurement

According to obtain the input data for the simulation process, field measurements obtained through using e-instrument multi-meter sensor to trace wind speed and temperature rates. Within the urban context, the data was measured in October as this study was done within two years from 2013 to 2015. This data plays two main roles in the study as it acts as input data for the simulation study, and to compare simulated results with field measurement data to optimize the simulation process and findings.

Table I. Multi-meter sensor used in the study, its range,resolution, and accuracy (e-instrument AMI 300 manual)

Sensor - model	Settings	Air velocity readings (m/s)		Temperature (°c)
E-instrument Multi-meter – AMI 300 	Range	0.2-3	3.1-35	-20 °C - +80°C
	Resolution	0.01 m/s	0.1 m/s	0.1 °C
	Accuracy	±3% of reading ±0.1m/s	±1% of reading ±0.3m/s	±0.4% of reading ±0.3°C

As show in Table 1, the e-instrument multi-meter is used in field measurement. According to E-instrument manual, the accuracy ranges of air velocity is ±3% of reading ±0.1m/s and ±1% of reading ±0.3m/s, and for Temperature rates is ±0.4% of reading ±0.3°C [1]. The e-instrument is used to trace measurements through points adapted to defined grid resolution.

A. Grid Resolution

The tracing points are distributed in rectilinear grid, as the distribution of points was divided as 6 tracing points in arcade space and 42 tracing points in the courtyard space with grid size of about 4m x 4m. This grid resolution is designed to compromise between the consuming time used in tracing data and the more availability of data in target transitional space.

The field measurement process of the selected tracingpoints was done in October as mid-month which represents the first educational semester in the college as students used transitional spaces actively in this month. The data was taken in the 7th and 21th day in October. The tracing process was done between 9:00 to 11:00 clock at daytime. The findings of this study are then focusing on the mean values traced.

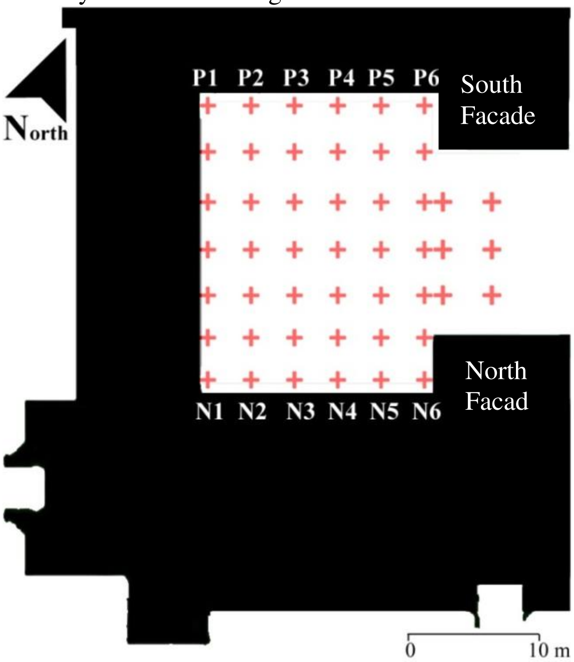

Fig. 2. Monitoring points in courtyard and arcade

Figure 2 shows 6 points at South Façade (SF) and North Facade (NF). The SF points are coded as P points, while the NF points are coded as N points.

B. Findings of Field Measurement

The field measurement of air velocity shows different pattern of tracing points as it depends on the roughness length (z_0) which can represent the differences of surface features from one place to another and at different heights [2]-[3]. The tracing points of air velocity are about 12 points, they are selected in the urban context surrounding the courtyard building. This site is surrounded with open field which means that air velocity can be high and with little changes. On the other hand, air velocity shows high variety of ranges from about 0.1 m/s to 7.0 m/s in selected urban fabric.

As shown in figure 2, the outer air velocity at height 1.5 m reached to around 2.7 m/s at point P11 and decreases inside the courtyard of the case study to reach to around 0.2 m/s. This was expected as urban fabric can highly decrease air velocity.

In tracing temperature, the results of field measurement process were visualized as contours of the traced data temperature distribution. The mean temperature traced was ranged from around 25ºc to 27ºc. The temperature increases at the Southern Façade (SF) to reach about 27 ºc, while temperature decreases at Northern Façade to reach about 25.5ºc.

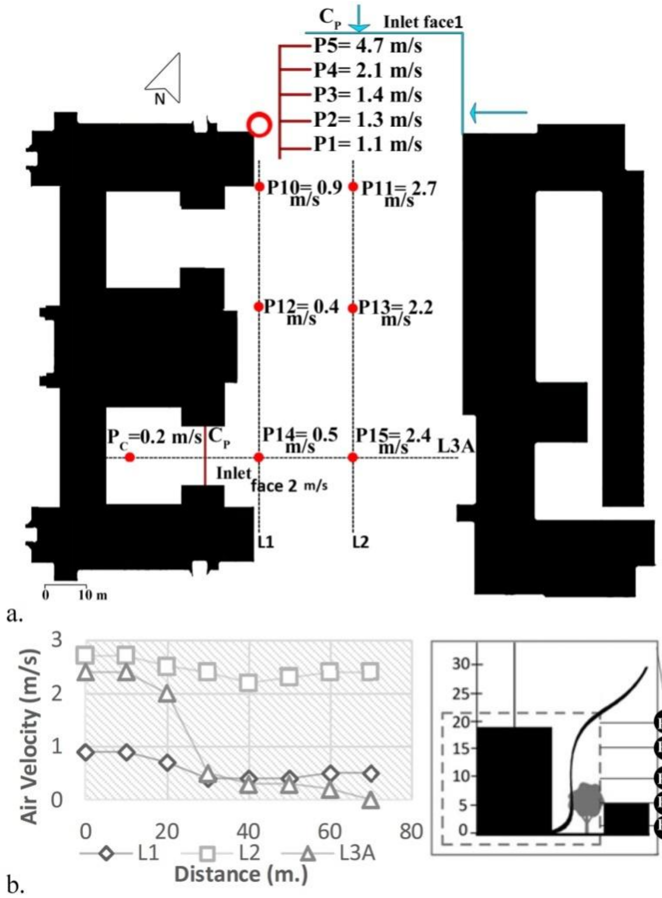

Fig. 3. (a) Selected Monitoring points for tracing air velocity in the university; (b) graph of the selected monitoring paths and the five points at different heights

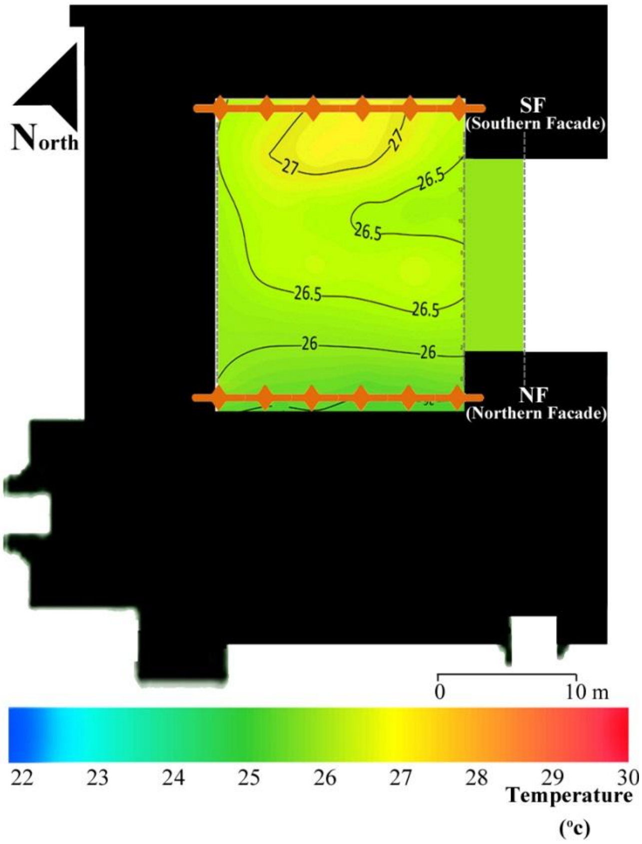

Fig. 4. Mean temperature contours in courtyard and arcade

IV. CFD SIMULATION STUDY

The geometrical model of the courtyard building is simplified to a level of basic 3d model with elimination of details such as doors and windows in Autodesk Revit, depending on the mean-values of traced data to nurture the input values and to set up the simulation process. The building is three-sided courtyard with different height for every side, the southern building side is four floors high, the western building side is three floors high, and the northern building side is two floors high. The four cases used in this study is manipulating with these heights. As the four cases of courtyard are depending on observing the effect of changing height of the western and northern building side and their effect on the thermal flow in the courtyard space.

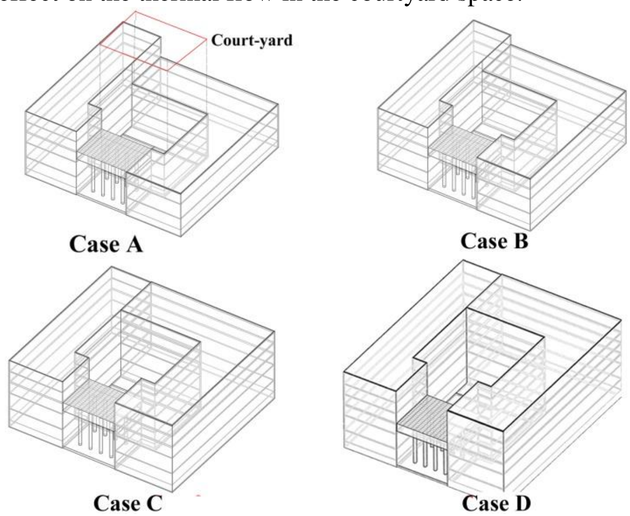

Fig. 5. Experimental models of case study building with different heights

The width of the courtyard space is actually about 24m. And the three cases A, B, and C have height ofnorthern building of 11m, 14m, and 18m respectively, while the southern building is fixed at its actual height of 18 m. While in case D the whole building increased to a height of22m. These four cases are simplified to undergone meshing process.

A. Meshing Sensitivity Study

Grid cell generation or meshing process is an essential part in CFD process which has its own requirements and characteristics. As mesh size decrease, the more detailed the results, more accurate results, and more computational power is required [4]. To solve this problem, a balanced strategy is required to have a good quality meshing process within the computational abilities and limitations. To indicate the appropriate dimensions of the refinement zones, a meshing independence study was used to determine the dependence of the flow field on the refinement of the mesh ranges to determine the area of impact of the geometry on the flow.

In this study, the meshing is unstructured tetrahedral cells which used within hierarchical meshing to provide flexibility in meshing different regular and irregular geometries. Four meshes were used; the first mesh had three layers of enhancement with a total number of 320,210 grid cells and the second mesh had five layers of enhancement with a total number of 471,458 grid cells throughout the rest of the computational domain. The second mesh shows different results rather than the first mesh especially at the lower region of the courtyard and the upper region. The third mesh increased to 1,825,959 cells with fifteen layers of enhancement which show also slight improvement in results. The Fourth mesh is about 2,109,857 cells with fifteen layers of enhancement didn't show significant improvement of results. Thus, it can be concluded that the third mesh is adequate for running the simulation with refining the mesh in zones of complex flow phenomena.

The described sensitive meshing study is used to find the effect of meshing process on results. The used meshing is firstly applied as automatic then manually increase meshing in observed areas with errors such as at the ground level of central courtyard and at intersection between walls and courtyard floor.

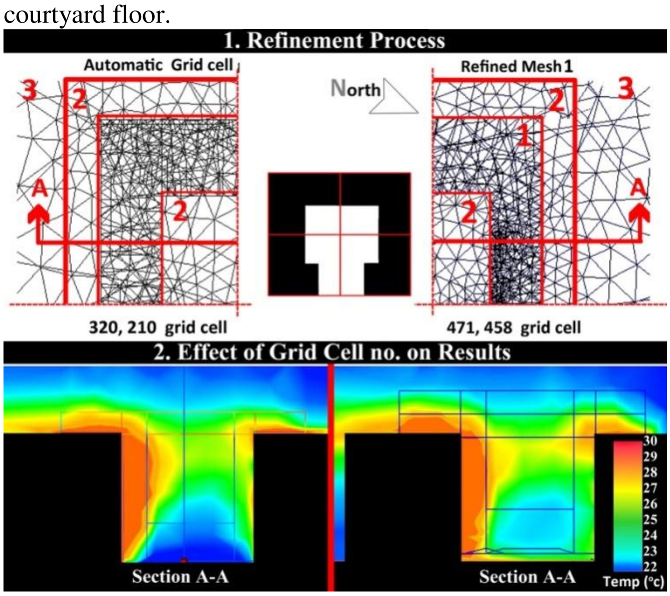

Fig. 6. The effect of increasing grid cells and refining hierarchical mesh on CFD simulation of air temperature

In sensitive meshing study, mesh 3 and mesh 4 shows relative similarity of results. In mesh 3 and mesh 4, the average grid cell size is about 0.2672 and 0.2145 respectively. The results of sensitive meshing-study show that the mesh 3 predicted temperature distributions at different heights of 2, 7, and 12 m respectively which can deliver a compromising balance between the required computational resources and the optimized results.

Table II. Sensitivity of grid cell numbers on Temperature at different heights

Mesh	Layers of enhancement	No. of grid cells	Average Air temperature at height 2.0 m.	Average Air temperature at height 7.0 m.	Average Air temperature at height 12.0 m.
Mesh 1	3	320,210	24. 28 (°C)	28.89	29.76
Mesh 2	5	471,458	25.94	28.35	29.56
Mesh 3	15	1,825,959	26.35	28.23	29.27
Mesh 4	15	2,109,857	26.36	28.23	29.26

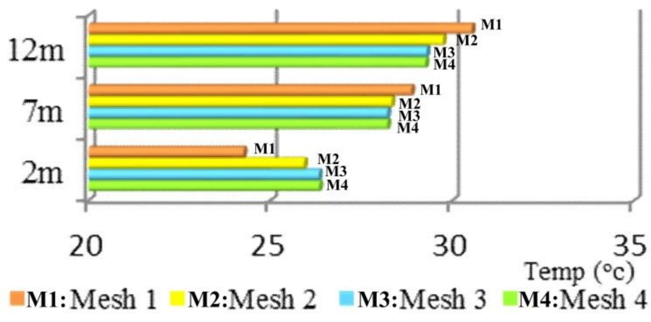

Fig. 7. Sensitivity of four meshes on temperature

B. Boundary Conditions

Boundary conditions setup is considered essential part in CFD process. Boundary conditions are random virtual conditions for an experiment to imitate a context of natural phenomenon [5]. Thus, Boundary conditions can be defined as: conditions which are essential to be fulfilled at all or part of the boundary of a region to let a set of differential equations to be solved within these setting conditions [5]-[6]. The boundary conditions setup with a Reynold number (Re) was to be further than 5×10^5 and the blockage ratio less than 5% to safeguard the growth of the air flow pattern around the building structures in a turbulent channel flow. Turbulence is another essential part of boundary conditions. As many researchers (Ramponi and Blocken [7], Daniel Micallef*etal*[8], and Abohela[9]) found out that Menter's Shear Stress Transport (SST) k- Ω is a stable turbulent model which gives best agreement with observational data for air velocity in central open spaces [7]-[8]-[9]. Thus, K-Ω SST (Shear Stress Transport) is used in this study.

For the domain, the bottom of the domain would be a non-slip wall with standard wall functions, top and side would be symmetry, outflow would be pressure outlet at pressure=0 and velocity inlet with piecewise linear data input nurtured from the field-measurement data. Wall boundary condition is assigned with different heat fluxes depending on surface temperatures that were recorded during the field measurements work. Heat Flux conditions are indicated at the surfaces of measured walls.

Table III. : Summary of initial boundary conditions and material setup of thermal flow study used in courtyard

	Boundary condition	Element	Material	Specification and input properties
1	Velocity input	Northern inlet face	Air	Air speed: Piecewise linear at z=1m, v=1 m/s, at z=4m, v= 5 m/s, at z= 8m, v=7 m/s, at z=11 m, v=9 m/s (according to field measurement data in October)
2	wall	Ground surface		- non-slip wall
3	Top and side walls	Top and side surfaces	Air	-Input of measured temperature (Piecewise linear)
4	Pressure outlet	Southern face	Air	
5	wall	Building structure volumes	Brick for walls and concrete for roofs	Symmetry

The solution was initialized by the values of the inlet boundary conditions. As default, initial Air setup is used to run under operating pressure of about 101325 Pascal. Air is considered as an incompressible-ideal-gas. The Far-field Omega is about two. Also, the solution was using intelligent Wall Formulation with ADV5. According to Autodesk (2014), using this option to keep the y+ values above 11.225 to act exactly at the classical law of the wall function is essential to have no poor performance [10]. The solar heating is adapted to run at the longitudinal and latitudinal coordinates of Alexandria at 10:00 clock morning. The simulation is running up till it converged after 445 iteration process.

C. Simulation Results

In this study, the CFD modeling process was done on personal computer with limited computational power as the computation of one model regularly took many hours of calculations. After calculations, the airflow pattern and thermal flow results are showed. Firstly, the airflow pattern shows that air velocity increases at the arcade which acts as suction zone of airflow. The air velocity in this cross-section study in 21st of October shows very low air velocity ranges from 0.02 m/s to 0.3 m/s. This low velocity can lead to discomfort at the courtyard space and can decrease ventilation rates in courtyard's adjacent spaces.

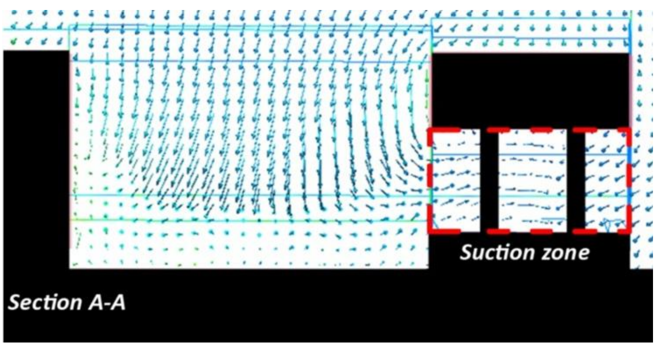

Fig. 8. Section shows Air Flow Pattern (AFP) in courtyard

D. Simulation Results: The Effect of Changing Building Height: TheComparison of the Four Cases

By comparing the four cases of the courtyard with different heights, as case A is the lowest height and case D is the highest height. The thermal results show that case D extends the temperature at the Northern Façade (NF) as it reaches more than 28.5°c at the center of the NF. On the contrary, Case C show optimum results as temperature at the NF is distributing less heat flow with keeping a little contrast of thermal rates which maintain vitality of the space.

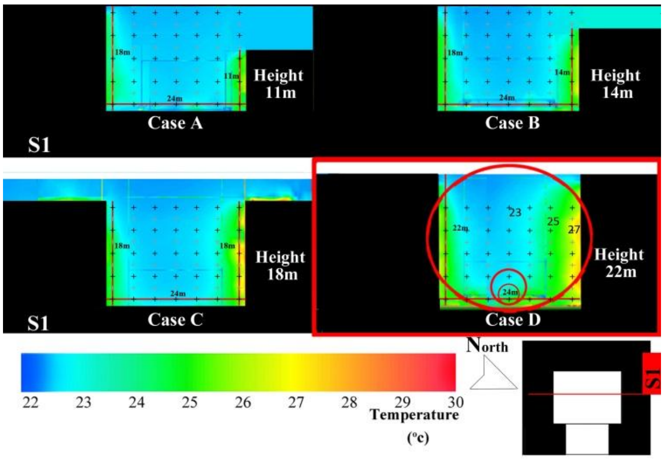

Fig. 9. Sections show air temperature in the four cases of different heights

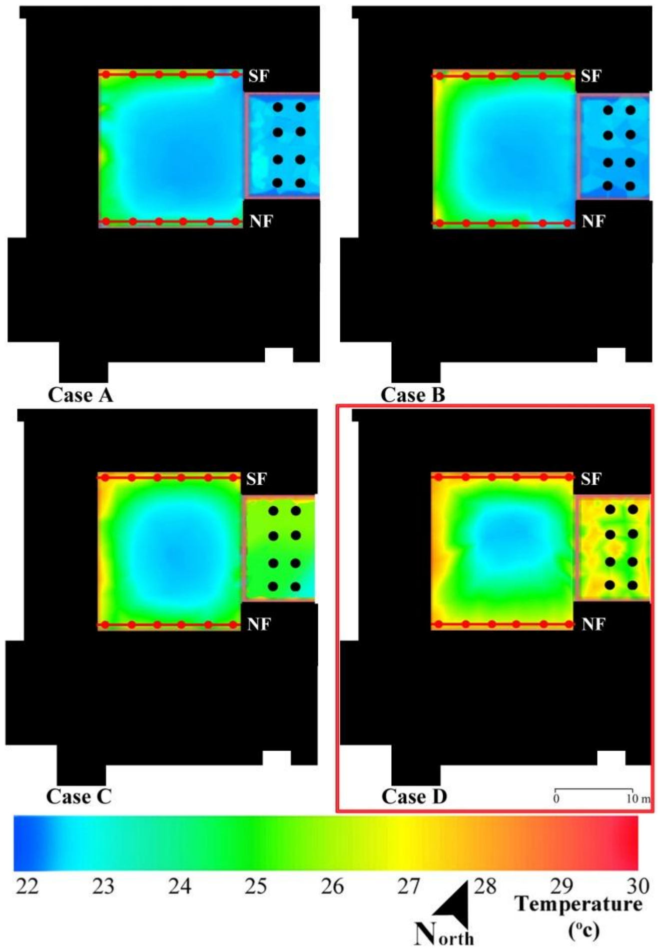

Fig. 10. Plans show the air temperature in the four cases of different heights

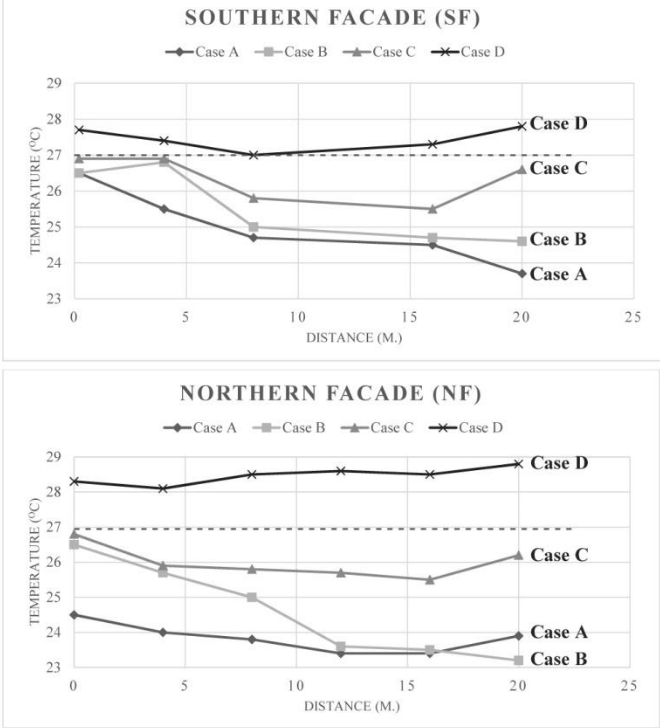

Fig. 11. SF and NF graphs of the four cases

As shown above in figure 9, 10, and 11, case D show high temperature rates at the Northern and Southern Façade. So according to this study, it is recommended, in the case of extending the building for future needs, to reach to four floors heights at the three sides of the courtyard to maintain thermal and Air Flow Pattern (AFP) performance.

V. Results anddiscussion

While many researchers such as Hu [11] Chen and Zhai[12] established that the validity of a CFD flow simulation in which might puzzle even experienced users should be based on strategies and assumptions [11]-[12]. As the used CFD process was complex, and enormous number of independent variables which used to construct them. In this study, the CFD process used the two years traced data in site for inputting data and for comparing traced results with computational results. To sum up the findings:

1. Ranges of traced temperature don't show difference in rates of temperature more than 2°c, while simulated CFD temperature shows in some cases ranges more than 5°c differences.
2. Sensitive meshing study shows that hierarchical meshing of 1,825, 959 grid cells have optimized results and doesn't require more grid cells.
3. The air velocity simulated according to field measurement data ranges from 0.02 m/s to 0.3 m/s inside courtyard space with low turbulence intensity. This air velocity can lead to discomfort of students using the courtyard.
4. Simulation study shows that increasing height ofcourtyard building for future uses acts in a good manner forair and thermal flow till the height of the courtyard building reaches to around 22m as in case D, leads to highertemperature rates. Thus according to this study, it is recommended as a retrofitting strategy that the courtyard building height shouldrange from 11m to 18m.

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