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BIOCLIMATIC OPTIMIZATION: SKYLIGHT GROUND FLOOR NEW BUILDING, UDLA PARK TORRE II

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When high thermal comfort and energy efficiency are provided in an academic environment many beneficial effects on student's comfort, performance, productivity, and health are shown. The research provides a parametric airflow evaluation of a skylight in a ground floor of new educational building assuming a variation of 4 stages with eight scenarios for the admissions office. By means of the bioclimatic analysis, Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) indices, the best internal airflow performance for the study area applying natural ventilation is achieved with the air flow optimization. A minimum area of 1.79 m^2 has been established for extraction and movement of the internal flow, both with the natural extraction louvers system measuring 12 inches by 60 inches and the 18 inches by 60 inches, they work properly. However, the 18 inches by 60 inches system has better effectiveness as it has fewer louver units to be placed, is more homogeneous, avoids turbulence and provides better air extraction. In addition, by having fewer louver units distributed along the length of the skylight, it will allow the operation to be more controlled during the operation of the building. The use of 8 louvers of those proportions, with an individual effective area of 0.23 m^2 and a total of 1.84 m^2 was recommended in accordance with the results obtained.

Keywords: Bioclimatic design, Natural ventilation, Effective area, Tropical climate, Energy efficiency, Thermal comfort, Building performance, Educational building.

1 INTRODUCTION

The building and construction industry represent the largest portion of global final energy consumption totaling 36% (IEA 2020). In Ecuador, energy consumption in existing buildings accounts for 16% of the total energy consumption (Ministerio de Electricidad y Energía Renovable 2017). Educational buildings are responsible for significant energy consumption required for thermal comfort. The educational role of schools' place significant social responsibility on them. Consequently, it is necessary to reduce energy demand, and research studies have been actively conducted to improve energy usage (Belussi *et al*. 2019).

Energy efficiency and thermal comfort are important in this type of construction, along with acceptable requirements for indoor environmental quality (Yang and Mak 2020). Previous studies have shown a beneficial effect on students' comfort, performance, productivity, and health when high levels of thermal comfort were provided in an educational environment (Sensharma *et al*. 1998). Moreover, student wellbeing and health in classrooms must be addressed because students spend a third of their day at school. In tropical regions, encouraging health in an energyefficient building environment is a challenge (Yannas 1995). Even in cold countries, classrooms reached inappropriate high temperatures. The main reason is low ventilation rates because the radiation heat due to sunlight entering through the windows and the heat load caused by the occupants is unable to be released (Gil-Baez *et al*. 2017).

1.1 Previous Studies on the Positive Impact of Natural Ventilation

An extensive study by Dear *et al*. (2015) and Zomorodian *et al*. (2016), found that ventilation is a critical factor for indoor air quality, thermal comfort, and energy savings, most of which rely on natural ventilation. Natural ventilation was proved as an effective passive strategy throughout the cooling period in accordance with Gil-Baez *et al*. (2017). The assessment demonstrated that the energy consumption for technical cooling is substantially reduced, reporting primary energy savings by natural ventilation are between 18% to 33% whilst maintaining comfort levels in the classroom.

Becker *et al*. (2007) reviewed that the implementation of improved ventilation schemes in a well-designed energy conscious building achieved energy savings of 17%-18% in southern and 28%-30% in northern classroom orientations, respectively. Equally important, passive strategies and appropriate envelope treatment are necessary to guarantee thermal comfort and simultaneously reducing energy demand (De Abreu-Harbich *et al*. 2018).

1.2 Building and Location Description

The educational building is situated in Quito, in the north highland region of Ecuador with a latitude of 0.16°S and longitude of 78.45°S. The Andean region commonly experiences four seasons every day: spring mornings, summer at midday, fall during the afternoons, and night like a mild northern winter (Exploring Ecuador 2020). In general, Quito has a temperate climate characterized by regular air humidity of 75% and external average temperature of 17.8°C throughout the year. UDLA Park Campus is situated around 2714 meters above sea level where the minimum outdoor air temperature is 6°C and the maximum outdoor air temperature is 25°C. The average wind speed on site is 2.0 m/s but is reduced to 1.5 m/s considering that wind comes with a prevalent wind direction from east with 130˚C (Stackhouse 2020, Energyplus.net 2020).

The study area chosen was the admissions office, located on the ground floor in the eight-story building Block II of the UDLA Park Campus. The study area was delimited, considering the internal divisions. Thus, simplifying the study area to an atrium with escalators and south wing of the ground floor. See Figure 1.

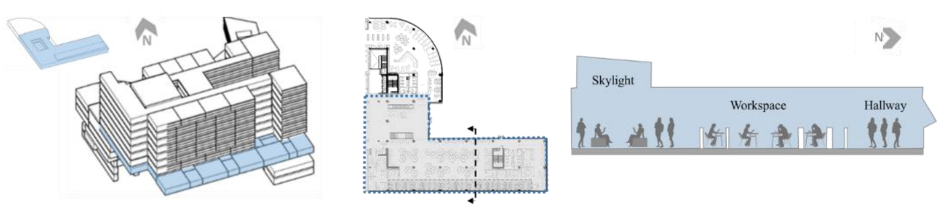

Figure 1. Study area: Block II-UDLA park, ground floor and skylight section area.

The architectural plan illustrates longitudinal shape along the west-east axis. The building is orientated in the direction of prevailing angles of wind and sun, even though it has a glazing façade, the apertures and windows faced north-south elevations which released half of the radiated heat from the sun (Zaki *et al*. 2012). Building corridors create cross ventilation along the building increasing indoor air velocity in tropical climates to produce a comfortable environment.

In order to achieve effective natural ventilation, vertical air movement occurs throughout stack ventilation, where cool air has been warmed up in a building by human activity and is discharged out from the building by internal courtyard and specifically in the ground floor through skylight.

2 METHODOLOGY

This present study has been carried out on an educational building. The following analysis provides a parametric review of 4 stages with 8 different scenarios for the admissions office using the ANSYS Fluent 2019 program. The objective is to achieve the best internal airflow performance for the study area. The scenarios evaluate the comparative analysis of airflow variation by distributing louvers along the skylight opening of 56.0m x 0.8m given as a basis designed by the architectural department. The Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied (PPD) indices are used to assess the indoor environment regarding thermal comfort-discomfort perception in students.

In stage one, three scenarios with open doors and no furniture are developed. The best performance scenario in the first phase is selected to assess further stages. Starting with the second stage, scenario 4 completes the last evaluations considering close doors for scenario 3: interspersing closed module plus louvers. After considering the study area as open plan, stage three studies two additional scenarios that include internal furniture with open and closed doors. For stage four, two scenarios with furniture and closed doors are developed, distributing specific louvers sizes of 12"x 60" and 18"x 60" along with the skylight. See Figure 2.

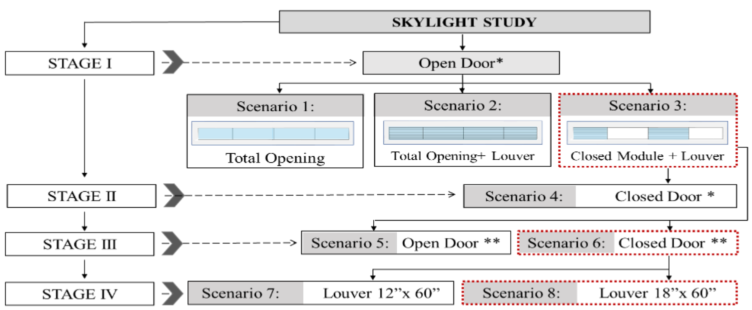

Figure 2. Research methodology. * without furniture/ ** with furniture.

2.1 Computational Flow Analysis – CFD Software

Computational fluid dynamics software is utilized to assess airflow rates across building openings. The methodology process begins with a 2D model using AutoCAD, followed by a 3D model of the study area in Workbench. The building is tested with ANSYS Fluent 2019 which measured airflow rates for the research area, setting the wind speed of 1.5m/s and direction of both inlet and outlet: Blue and Red arrows represent wind input and output, respectively. See Figure 3.

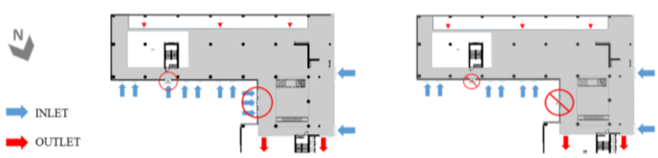

Figure 3. Wind input and output location for CFD modeling, Open/Closed door.

The user plane is chosen under anthropometry measurements from the floor to a height of 1.0 meter for educational activities (Hetreed *et al*. 2017). It is used as the cutting plane to obtain the airflow rates in three different areas: hallway, working space, and skylight over the four stages of the research. Results show both: air movement speed and percentage of indoor airflow received compared to the external air speed of 1.5m/s. See Table 1 and Table 2.

Table 1. Airflow rates found at different stages/ Wind velocity input: 1.5m/s.

Area	Stage I						Stage II		Stage III				Stage IV			
	Scenario 1		Scenario2		Scenario 3		Scenario 4		Scenario 5		Scenario 6		Scenario 7		Scenario 8	
	(m/s)	(%)	(m/s)	(%)	(m/s)	(%)	(m/s)	(%)	(m/s)	(%)	(m/s)	(%)	(m/s)	(%)	(m/s)	(%)
Hallway	0.75	50%	0.75	50%	0.75	50%	0.75	50%	0.75	50%	0.75	50%	0.75	50%	0.75	50%
Working Space	0.67	45%	0.67	45%	0.75	50%	0.25	17%	0.58	39%	0.17	11%	0.33	22%	0.42	28%
Skylight	0.50	33%	0.58	39%	0.42	28%	0.33	22%	0.42	28%	0.33	22%	0.25	17%	0.33	22%

Table 2. Effective Area: Ground floor skylight number of louvers.

Airflow:	1640.00 cfm
Flow velocity	85.00 fpm
Brand:	Greenheck
Model:	FDS-602

Area	Louver (Sq.ft)	Louver (Sq.m)	Skylight (Sq.ft)	Skylight (Sq.m)	(u)
Effective			19.29	1.79	?
12" x 60"	1.09	0.101	19.62	1.82	18
18" x 60"	2.48	0.230	19.84	1.84	8

3 RESULTS AND DISCUSSION

3.1 Natural Ventilation Analysis Results with Ansys Fluent (CFD)

In the first stage, the skylight is optimized with scenario 3, reducing 65% of the opening area from 44.80m^2 to 15.51m^2, and maintains a constant speed of 0.75m/s in the working area. Stages two and three demonstrate how furniture influences the air movement in the room, decreasing the airflow 30% relatively in both scenarios. This depends on the input velocity for the open plan from 0.25 to 0.75m/s and with furniture from 0.17 to 0.58m/s (Figure 4). In general, the selected louvers at the final stage show good performance whether the door is closed, with or without furniture.

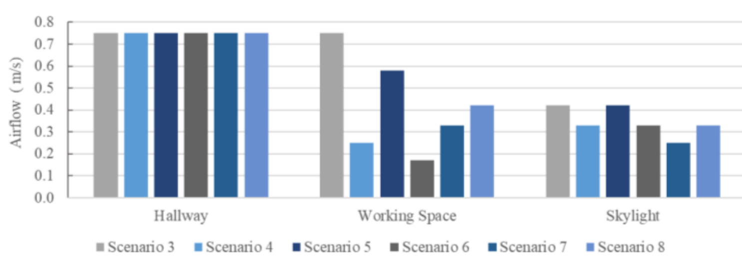

Figure 4. Comparison of different airflow rates at different stages/ Wind velocity input: 1.5m/s.

Overall, it is noticeable that air velocity along the hallway decreases half the intake air from 1.5 to 0.75 m/s, which remains constant for all scenarios due to the proximity with the casement windows. Whereas the working area identifies an air-speed constant variation of 30% between scenarios for both stages first and second. Scenario 3 allows a better air intake of 0.75 m/s and scenario 6 the worst with 0.17 m/s. The skylights on the other hand, show that air movement varies from 0.25 to 0.42 m/s, with a constant 6% difference between the scenarios for every evaluated stage.

3.2 Thermal Comfort Conditions (CBE Thermal Comfort Tool)

The average and highest indoor temperatures are evaluated based on ASHRAE 55-2013 (Tartarini *et al.* 2020) thermal comfort standards using the different air speed variation achieved in stage 4. The Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied (PPD) indices specify that the average indoor temperature of 18˚C represents a critical thermal comfort-discomfort perception in students. In contrast, when the maximum temperature reaches 25˚C, the PMV and PPD comply with acceptable thermal comfort standards. See Table 3.

Table 3. Calculation of PMV and PPD using the CBE thermal comfort tool. Metabolic rate: 1.4 met.

		Clothing Level (0.65)							Clothing Level (1.0)						
Op. Temp (˚C)	Air speed (m/s)	ASHRAE 55	PMV	PPD (%)	Sensation	SET (˚C)	DB at still air (˚C)	Cooling Effect (˚C)	ASHRAE 55	PMV	PPD (%)	Sensation	SET (˚C)	DB at still air (˚C)	Cooling Effect (˚C)
25.0	0.25	✓	0.11	5%	Neutral	25.9	22.7	2.3	✗	0.57	12%	Slightly Warm	29.0	22.9	2.1
	0.33	✓	0.01	5%	Neutral	25.5	22.3	2.7	✓	0.50	10%	Neutral	28.6	22.5	2.5
	0.42	✓	-0.07	5%	Neutral	25.0	21.9	3.1	✓	0.43	9%	Neutral	28.2	22.2	2.8
	0.75	✓	-0.29	7%	Neutral	24.0	21.1	3.9	✓	0.27	6%	Neutral	27.3	21.4	3.6
18.0	0.25	✗	-1.67	60%	Cool	18.3	15.6	2.4	✗	-0.85	20%	Slightly Cool	21.4	15.9	2.1
	0.33	✗	-1.79	66%	Cool	17.8	15.1	2.9	✗	-0.93	23%	Slightly Cool	21.0	15.5	2.5
	0.42	✗	-1.90	72%	Cool	17.4	14.7	3.3	✗	-0.85	26%	Slightly Cool	20.7	15.1	2.9
	0.75	✗	-2.2	85%	Cool	16.3	13.5	4.5	✗	-1.21	36%	Slightly Cool	19.8	14.1	3.9

4 CONCLUSION AND RECOMMENDATIONS

In the final analysis, 12 inches x 60 inches and 18 inches x 60 inches systems comply with the effective area required and confirm that the optimization of the skylight opening area has better performance. Therefore, the use of 8 louvers with 18 inches high by 60 inches wide, with an individual effective area of 0.23 m^2 and a total of 1.84 m^2 was recommended in accordance with the results obtained. In addition, the 18 inches x 60 inches system has better effectiveness as it has fewer units to be placed, is more homogeneous, avoids turbulence and provides better air extraction. In addition, by having fewer louver units distributed along the length of the skylight, it will allow the operation to be more controlled during the operation of the building (Figure 5).

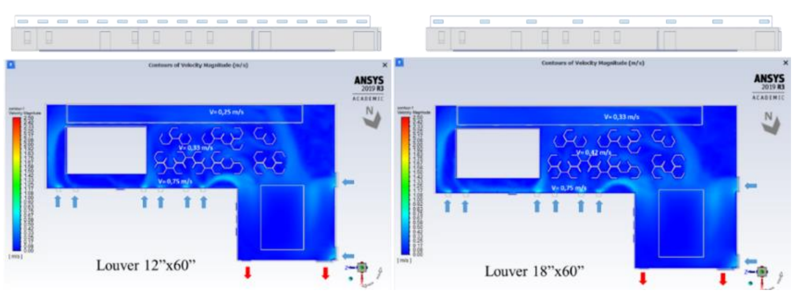

Figure 5. Scenario 7 vs scenario 8, ANSYS fluent 2019.

As expected in tropical climates the air temperature does not vary much from the indoor temperature. Therefore, air extraction becomes challenging due to smaller pressure differences. However, it was proved that ventilation rates increased by 30% when doors are open and represent a good strategy for cooling purposes when the temperature rises. On the other hand, when the ambient temperature falls, it is recommended to avoid heat loss, by closing the doors and windows to increase the main heat gain from internal sources such as occupants, lighting, computers, etc. This could be a potential further analysis to confirm the real impact of those appliances on the indoor thermal comfort and improve the adaptative conditions, as it is shown on Table 3 where the higher the interior temperature, the better the results obtained. Thus, reaching the levels of thermal comfort.

As could be seen in Table 3, students felt thermal discomfort with the average indoor temperature of 18˚C. However, the student's thermal satisfaction could be improved whilst saving energy at the same time, by fixing the metabolic rate and increasing clothing level. Therefore, a more detailed analysis per hour, field surveys, and adaptive approach could result in a proposal to enhance the research and improve the number of satisfied students.

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