The impact of internal gains on thermal stratification for public buildings

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Abstract. The indoor temperature in public buildings varies according to its internal loads scenario. In fact, this building typology in temperate climates is generally non-air conditioned and naturally ventilated. In order to improve indoor thermal conditions with appropriate solutions, it is necessary to study the vertical temperature profile. The main objective of this study is to show the impact of thermal stratification on thermal comfort of public buildings. The thermo-airodynamic modeling using TRNSYS (©) and CONTAM (©) have been performed in this numerical simulation study. The indoor air volume is vertically subdivided into several levels to evaluate the evolution of temperature profile taking into account the different inside-outside air exchange and air coupling between sub-zones. This study is performed in the city of Morocco that represents Mediterranean climate region with a moderate temperature. The effect of several parameters, such as indoor occupation pattern, internal lighting, sub-zones air exchange and vertical thermal stratification are studied. Numerical simulation results show that thermal stratification of buildings affects the occupant’s comfort level.

1. Introduction

The building sector accounts for 33% of total national energy consumption in Morocco which is 25% consumed by the residential sector and 8% by the tertiary sector [1]. The main problem in tertiary buildings is their low thermal performance. The improvement of its thermal performance with better indoor air quality and low energy consumption becomes a great challenge in the building sector. Recently, some studies have been conducted [2] on various strategies to improve the energy performance of heating/cooling system [3] and integration of passive solutions in the building envelope [4–7]. Nevertheless, still few studies that have been conducted in evaluation of indoor thermal stratification although it is one of the main factors causing local discomfort (ASHRAE 55). This study is focused on the evaluation of the thermal stratification of a public building by thermo-airodynamic approach. The sub-zones air coupling can be simulated by different method: (a) TRNFLOW with COMIS model (conjunction of Multizone Infiltration Specialists) in TRNSYS environment (type-56), or (b) coupling between CONTAM (type-97) and TRNSYS (type -56). In this study, the second method has been considered for air flow rate simulation. Please note that indoor thermal stratification is affected by different factors such as air flow rate, internal gains, heat gains/losses through the building envelope [8]. CONTAM represents different facilities, generally it is a numerical tool that considers the external environment and the inner zones as knots characterized by their pressure and temperature. To take into account the air exchange between sub-zones, the air flow path in each zone should be determined [9].

The description of the building thermal model including the effect of airflow rate on low-rise public buildings is presented in the first part of the present document. The thermo-airodynamic model to evaluate the air flow inside and around of building is presented in the second part. Finally, the impact of indoor vertical discretization on thermal stratification will be evaluated and analyzed.
2. Methodology

2.1. Building description
The studied building consists of a concrete-brick structure and an air gap. The height of the building is 7.5 m. A 10.5 m² glass surface is located on the four facades i.e west, south, east and north. This building is located in Tangier city in Morocco which is characterized by a hot Mediterranean climate. According to occupation scenario, it is occupied five times a day for a short period (one hour). The height of the occupation zone is 1.8 m that corresponds to the occupant high.

Figure 1. 3D plan of the monozone building

2.2. Thermal Model
This modelling requires input parameters to determine the thermal balance. In order to obtain results with a better accuracy specially for naturally ventilated building, the knowledge of the building behaviour immersed in the air is essential for a dynamic thermal simulation.

The soil has a significant inertia that cannot be negligible. The Type56 of TRNSYS software allows to study more precisely the thermal behavior of this building, while modelling the vertical and horizontal distribution of the soil temperature.

The present study investigates a 3D model. According to the NF ISO 13370 standard, there are three types of heat transfer through a floor on land-fill:

- The heat transfer through the floor surface depends on the thermal properties of the soil, the total depth of the soil considered here is 10 m. The soil temperature at this depth is calculated by the equation of Kusuda (Eckert and Drake Jr, 1987; Kusuda and Bean, 1984).
- Lateral heat flow from the ground at the periphery to the outer surface of the soil at the near field.
- Thermal transfer relative to the thermal bridge effect.

2.3. Aeraulic Model
The modelling of the air flows is carried out by the computer program CONTAM, which can be useful in a variety of applications. This study was carried out on evaluation of airflow rate: Infiltration, exfiltration, pressure difference between zones and natural ventilation.

Aeraulic exchange modelling is designed to determine the aeraulic balance (air flow includes infiltration and exfiltration, flow rates of air permeability through the envelope, etc.) and contaminant concentrations.

CONTAM considers the external environment and the inner zones as knots characterized by their pressure and their temperature. It connects all these zones by the nodes to take into account aeraulic exchanges between these different zones (airnodes).

To draw the plans on the scale of the building, ContamW makes it possible to integrate the dimensions, the geometry of the different zones and the air flow path via the SketchPad tools.

In our model, two airflow elements are investigated:

- One way airflow element using Power law model to describe the leakage area in the four orientations for the exterior walls;
Two way flow model due to the stack effect generated by the density difference. There are two possibilities to calculate the flows for large openings (windows and door): the first is to calculate the flow by subdividing the opening into several Power law elements to have a surface equivalent to the original one. The second, which is used in this model, is to create a single piece of air flow that represents the flow over the entire opening using the theorem of Brows and Solvanson 1962. This is faster than the multiple flow theory but it requires knowledge of the vertical temperature profile.

The effects of wind direction in the flow elements are considered in the pressure profiles. The regimes and wind flow around buildings are characterized by turbulence and are strongly affected by the building’s geometry and local shielding. This turbulent flow varies the pressure coefficient on each surface of the building. The pressure coefficient \( C_p \), is the ratio between the surface pressure minus the static pressure of the free flow and the dynamic pressure in the undisturbed flow (Swami and Chandra, 1988).

2.4. Thermo-aeraulic global Model

After defining the thermal-airdynamic models, a coupling of the two numerical simulation tools is carried out. After creating the model on Contam-W and exporting it to Contam3D, the Type 56-98 coupler is used to create coupled files by automatic connections: infiltration and exfiltration respectively from and to ambient, interzone airflow rate and ventilation flow. This later coupled file is considered as a dynamic-static performa, it replaces the dynamic performa made by the previous type 97.

The general methodology of coupling is as follows: CONTAM need the zone temperature as the input data that provided by Type 56- in TRNSYS simulation tool. At the same time Contam provides air flowrate between zones to Type 56 to calculate the convection heat transfer model.

![Coupling scheme](image)

**Figure 2.** Coupling scheme

![Wind pressure coefficient](image)

**Figure 3.** Wind pressure coefficient on the four facades of the building: south, west, east and north.

2.5. Volume discretization

In this study, a zone model was considered. The building is subdivided vertically into 15 cells of 0.5 m. The internal gains are divided according to their relative location to each cell. Occupancy in cells 1, 2, 3 and 0.3m of the fourth cell. The lighting is existing in the last cell-15.
3. Result and discussion

3.1. Interzone airflow rate

The airflow between the areas within the building is shown in Figure 5. The result shows that the largest interzone flow occurs in the middle of the building’s height: Cell-07 to Cell-11. This airflow increase is explained by the entrance of significant outside air density through window openings. This air flow rate decreases gradually until the last air node (Cell-15). It can be concluded that taking into account the thermal stratification gives results with better accuracy in the case of the presence of large openings (10.5 m²).

![Figure 5. Interzone air flow rate (m³/h⁻¹), 1 January 08h00](image)

3.2. Indoor Temperature

A comparative study was conducted to evaluate the effect of occupancy (40, 80, 120, 160, 280 occupants) and the effect of vertical discretization of building volume on the vertical gradient of temperature.

The Figure 6 shows the vertical profile of the nodal model temperature in 15 horizontal airnodes (Cells) during the peak periods of the year: winter 13-16 January and summer 15-19 July (mediterranean climate). This temperature represents the average value of the daily temperature during these two periods.

- **Discretization effect**
  The temperature difference, vertically between Cell-01 and Cell-15 obtained by this model fluctuates between 0.2 and 9 °C. This amplitude of 9 °C at the roof is due to the solar intake absorbed by the roof, the thermal gain of lighting and the thermal pull effect. The same behavior is obtained also by Lapisa and al. [8].

- **Occupancy effect**
The four cases of occupation show similar results with a maximum average temperature difference of 0.9 °C and 0.58 °C respectively in each cell during peak periods of the year, i.e. in January for the winter and in July for the summer. Figure 7 shows the impact of the occupation pattern on the dynamic temperature for a typical day of summer. The internal temperature of the building with 40 occupants presents the same tendency of the external temperature with a maximum difference of 1°C. This behaviour can be explained by the presence of occupants within the building, as well as the building thermal inertia. It is important to note that the increase in occupancy from 40 to 280 persons increases significantly the interior temperature of the building of about 3°C.

**Figure 6.** Air temperature profiles in building, vertical distribution-Occupancy impact

**Figure 7.** Air temperature profiles in building

- Internal lightning effect

In the second part of the study, the impact of the internal lighting on air temperature is investigated with a particular attention on the vertical temperature in the cell-15 where the lighting exists. The figure 8 shows that the augmentation of the total heat gain from the basic scenario 1 (5 W/m²) to the scenario 2 (10 W/m²) and to the scenario 3 (17 W/m²) raises the air temperature of the Cell-15 by 0.17 °C and 0.3 °C respectively. It can be concluded that there is a strict correlation between the internal lighting and the air temperature in the last Cell-15.
4. Conclusion

The thermal comfort and the air quality depend on several parameters that affect directly and indirectly the indoor air quality. Generally, these parameters can be divided into two categories: technical factors and human’s factors. Concerning the worship buildings, one of the important factors that limit the control of the indoor conditions is the large volume of the building. The thermal stratification is one of the important phenomenon that should be studied to better predict and ensure the air quality. This study reveals the importance of the consideration of thermal stratification by analyzing a thermo- aeraulic model in a worship building. The coupling of two tools for each aspect, thermal and aeraulic was necessary to develop the study. The analysis of the simulations confirms the limit of the thermal model (single zone) on the predictions of the vertical temperature profile and interzone airflows and gives more precise information on the assessment of thermal comfort.

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