ATRIA FOR VENTILATION EFFICIENCY IMPROVEMENT IN URBAN OFFICE BUILDINGS

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ABSTRACT

In this paper the effects of atrium and other similar architectural design features (e.g. shafts) on ventilation efficiency are examined in a multi-storey office building. Attention has been given to simulate the use of the main entrances, the vestibules and the various shafts. An atrium and an non atrium solution were compared for the examined building. Stack effect was the dominating force and wind effect was present yet not significant, but enough to produce negative pressures at the area of the atrium, mainly due to the form of the atrium's roof. Among others, it was concluded that the implementation of the atrium increased ventilation efficiency especially at the upper floors, generating incoming flows from the atrium and increasing the infiltration and ventilation rates, even for high density urban areas. The outcomes are useful for IAQ control during winter and for passive cooling during the summer. Special attention is needed to evaluate the user's behavior, since the effects proved to be intense and often overturn initial ventilation and energy design.

KEYWORDS: atrium, ventilation efficiency, stack effect, natural ventilation, simulation.

INTRODUCTION

The initial purpose of the atrium in ancient Greek and Roman architecture was to allow the daylight to penetrate and the smoke from fire to come out. This form was extended to a larger courtyard area in traditional middle-east architecture. The contemporary form of the atrium was firstly appeared during the 19^{th} century where the cast-iron industry produced extensive iron frames which allow the use of extensive glazed areas. The use of the atrium in modern architecture was spread after 1960's and became popular in large commercial and office buildings, where it was used as a core circulation space (Bednar 1986, Saxon 1994). The last few decades there has been a vast increase in the use of air conditioning especially in urban office buildings, following the tendency to provide improved indoor environmental quality in both new and refurbished buildings in urban Mediterranean climates. Special attention has also been given to hybrid ventilation during recent research projects and several case studies were presented (Aggerholm 2002, Densante et al. 2002, Heiselberg 2002, Koinakis 2004).

In urban environments the possibilities of adjusting the building's envelope and form are usually very limited. In these cases the forming of atria inside a building could be a very effective tool to improve ventilation efficiency and to provide increased solar gains and day lighting capabilities. Atria could also help implementing passive control techniques, decreasing or eliminating the use of HVAC systems.

ATRIA AND OTHER ARCHITECTURAL FEATURES IN VENTILATION DESIGN

Several building architectural features can be utilized for natural ventilation design and most of them are already included in the architectural design. Shafts, elevator shafts, stairwells and chimneys should also be considered together with atria, because of the similarity of the natural driving forces and the usually increased interactions among different type of building features. For example, shafts and stairwells should be examined as individual ventilation zones in order to avoid unwanted and uncontrolled interzonal flows between an atrium and a stairwell. The distribution of these building elements within the hole building is also important to control intezonal flows (Koinakis 2005). A description of the examined building is presented in Figures 1 and 2.

Shafts

In the examined building shafts are placed near the WC area to serve local ventilation demand without interfering with the rest of the building. The interaction between the shaft and the atrium is strongly depended on the combination of the openings (windows and doors) which are facing the shaft. The air supply at the shaft can be described be the exponential law:

$$Q = C\left(\Delta P\right)^{\frac{1}{2}} \tag{1}$$

The effect of the shaft in the examined cases is strongly depending on the combination of the opened or closed windows and doors between the shafts and the floor zones. The flow coefficients C in the above equation are 100 to 150 greater if the large openings are opened. In this case an interaction between the shaft and the atrium is significant and dispersion of indoor contaminants usually appears, because of the increased horizontal interzonal flows.

Elevator shafts

The modeling of elevator shafts has similarities with stairwells and atria. Experimental data for the flow characteristics in elevator shafts were not traced in the literature. Airtightness measurements implementing pressurization tests are only referred in literature within the frames of test protocols proposed during research projects, not evolving the effect of the lift-cage movement and the use of the elevator (CMHC 2005)

Atria

The atrium is modeled by dividing it vertically to separate zones with very low flow resistances (flow coefficient or shaft resistance less than 0.005). In this way the temperature variations along the atrium's height could be adequately modeled (Dols et al. 2002, Walton et al 2003).

The atrium's roof shape

The ventilation efficiency of the atrium is strongly related to the interactions between the atrium's roof shape, the configuration of the top of the atrium , the wind direction and the effect of the surrounding buildings. Wind tunnel studies were carried out to investigate the airflow performance of various atrium roof shapes for various urban densities (Sharples et al. 2001). It was concluded among others that the shape of the atrium roof and the orientation of the wind affects the ventilation differentials much more than the urban area density. For example a tilted roof with openings on it at the leeward side of a vertical obstacle appeared to produce the strongest pressure differentials for both 0^0 and 45^0 wind direction. These were also the conditions in the examined building. A more efficient roof design is needed to exploit Venturi effects or vortex generation effects but in this case detailed wind data of the close area are needed.

Use of doors.

In multi-storey office buildings a significant amount of airflow is incoming and outgoing from and to outdoor through the entrance doors at the ground level as well as at the floor entrances near the elevator and staircase shafts. Few studies about the air leakage and the large openings airflow through manually swinging doors and automatic sliding doors are referred in the literature. This phenomenon also appeared at the building examined in this paper, where manual swinging doors were used in both ground floor main entrance and floor stairwell shaft entrances (Figure 1). The main entrance has two double doors with an intermediate vestibule and the floor stairwell shaft entrances have one double door. Due to the heavy use of the building (60 to 85 persons per 5 minutes, according to sample measurements during the peak hours), the entrance inflows and outflows are very important for the ventilation and the overall energy design. Sample velocity measurements at the building main entrance showed mean maximum values of 2.5 m/s ingoing flow during winter and 2.1 m/s during summer.

The use of the various doors was taken into account through the effective opening area. The effect of the use of the double door as a function of the people passing through the door, was simulated implementing the approximation equations of the average opening area proposed by K. Kohri for office building generally (K. Kohri 2001).

$$r = 1.0 - 0.26\exp(-0.036X) - 0.74\exp(-0.0091X) \text{ (only outside double door)} \quad (2)$$

$$r = 1.0 + 0.27\exp(-0.019X) - 1.27\exp(-0.0096X) \text{ (double doors with vestibule)} \quad (3)$$

where r= the average opening area ratio of doors and X= the number of people passing through the doors

In the case of the central entrance door with a vestibule, the opening area ratio could be calculated implementing the following equations proposed by Kohri (K. Kohri 2001).

$$r = \frac{Ae}{Ae\max}, \text{ where: } Ae = \frac{Cd}{\sqrt{\frac{1}{Ao^2} + \frac{1}{Ai^2}}} \text{ and } Ae\max = \frac{Cd}{\sqrt{\frac{1}{Ao\max^2} + \frac{1}{Ai\max^2}}} \quad (4)$$

where Cd is the discharge coefficient for the large opening (=0.65),
Ao, Ai are the actual opening area of the outside and inside door respectively [m^2]
$Ao\max$, $Ai\max$ are the maximum opening area of the outside and inside door respectively [m^2]

Simulation details

The air movement through an 8-storey building was simulated. For this purpose the multizone airflow model CONTAM was implemented (Dols et al. 2002, Walton et al 2003). The use of the main openings, the interaction of the building architectural features (e.g. shafts, atrium etc) and the air temperatures in various spaces as the result of the operation HVAC systems were obtained from measurements in the existing building. Hybrid ventilation with few low supply fans was the only ventilation system installed in the building. The effective opening area of the doors connecting the zones of the building (entrance, lobby, shafts and atrium) were obtained from in-situ sample measurements (passing persons per door) and from the implementation of the equations 2 to 4.

The elevator and the staircase are sharing the same lobby, while the atrium is independent from the rest of the shafts and extends from the 4th till the 7th floor (Figures 1 and 2). Two modes of door use were examined, one with moderate use and one with extensive use of the doors during peak hours. The wind effects were present yet not dominating, for the most common prevailing winds in the area (wind direction NNW and speed v=1.7m/s during December) for the existing dense wind environment in the location of the examined building. The airflow balance equations were solved for all the building zones.

As derived from Figures 3 and 4, on the lower floors the air enters from outdoors and from the lower parts of the shafts (elevators, staircases etc) and exits from the higher parts of shafts. On the higher floors the air enters from the shafts and the atrium and exits to the outdoor.

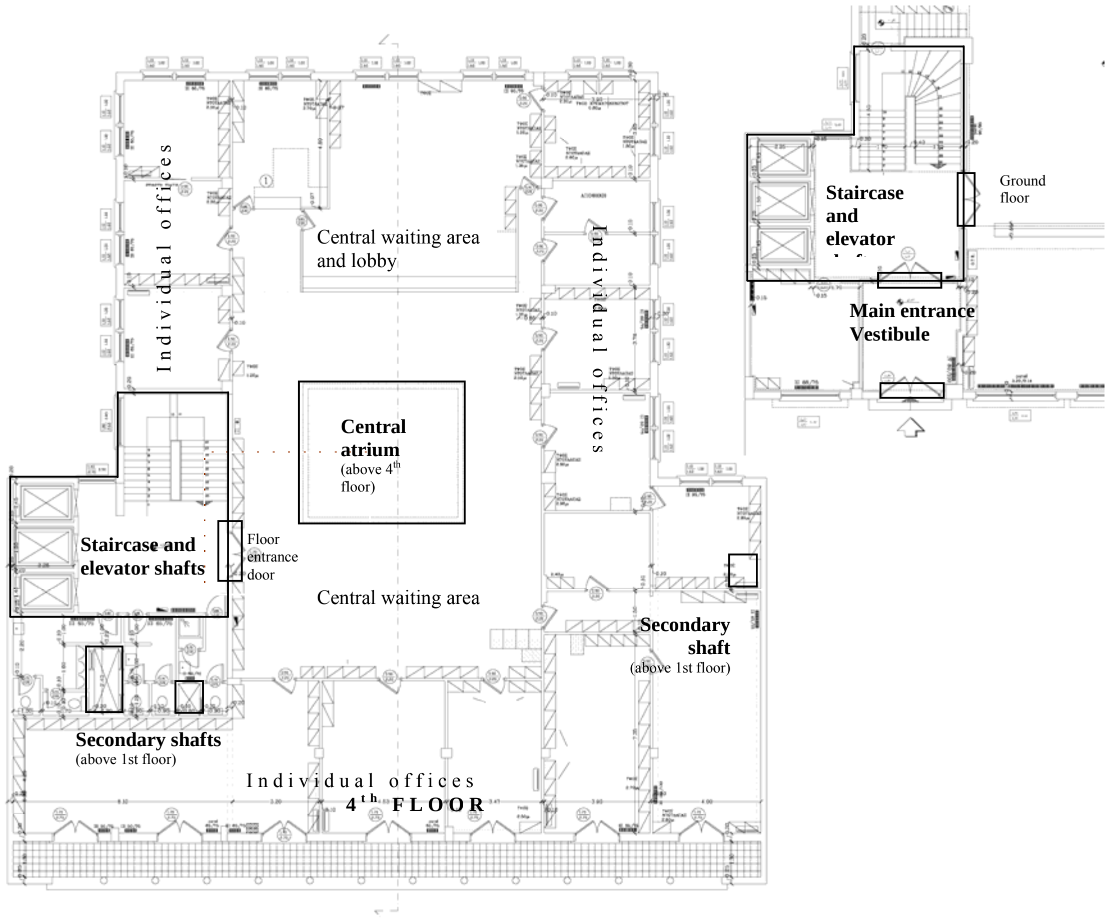

Figure 1. Left: Plan view of a representative floor of the examined building; upper right: main entrance and elevator shaft configuration in the ground floor. (Atrium, shafts and main entrances are highlighted)

RESULTS AND DISCUSSION

The parameters and the remarks mentioned in the above paragraphs were implemented during the simulations. The existing building was used for bulk and qualitative validation of part of the simulation results; special attention has been given to the validation of the direction of the interzonal flows and the zone air temperatures.

The simulations were presented for the two major traffic conditions: moderate and peak-hour use of the main entrances. Two building configurations were examined: one with an atrium above the 4th floor (existing case) and one with no atrium. The results are presented in Figures 3 and 4 for moderate and peak-hours use of main entrances, respectively.

As shown in the above figures the distribution of flows are triangle-like with outdoor air entering mainly at the lower floors and exiting at the higher floors. The outdoor flow rates are at the lower floor (incoming) and at the higher flow (upcoming).

The air change rate due to the incoming air flows from outdoors is 0.7 ach at the ground level. It is slightly increased compared to corresponding infiltration values of the building stock in

Greece according to relevant studies, (Papamanolis et al. 1996), because of the leaky entrance doors.

The atrium contributes significantly to the ventilation efficiency of the upper floors; most of the incoming air supply at the upper floors (approx mean value 55%) is entering from the atrium and not from the elevator and the other shafts. If no atrium exists, the incoming flows are only 0.5 ach/h of probably not fresh air from the lower floors through the shafts. This creates additional problems if the upper half floors are more crowded as in the existing building and therefore more fresh air supply is needed. If the peak-hours scenario is implemented, the incoming shaft flows appeared approximately 80% increased due to the extensive use of the elevators and of the main doors at each floor in both atrium and non atrium cases. Additionally, the triangle like flow and pressure distribution is disturbed due to the non uniform distribution of the traffic during peak hours in every floor. This is more likely to happen in the middle floors, because the interzonal flows there are weaker. For example the flows at the 4th floor are almost tripled during peak hours for both atrium and non-atrium cases. These phenomenon could be increased if there are vestibules at the main entrance of each floor (also see Sharples et al. 2001) .

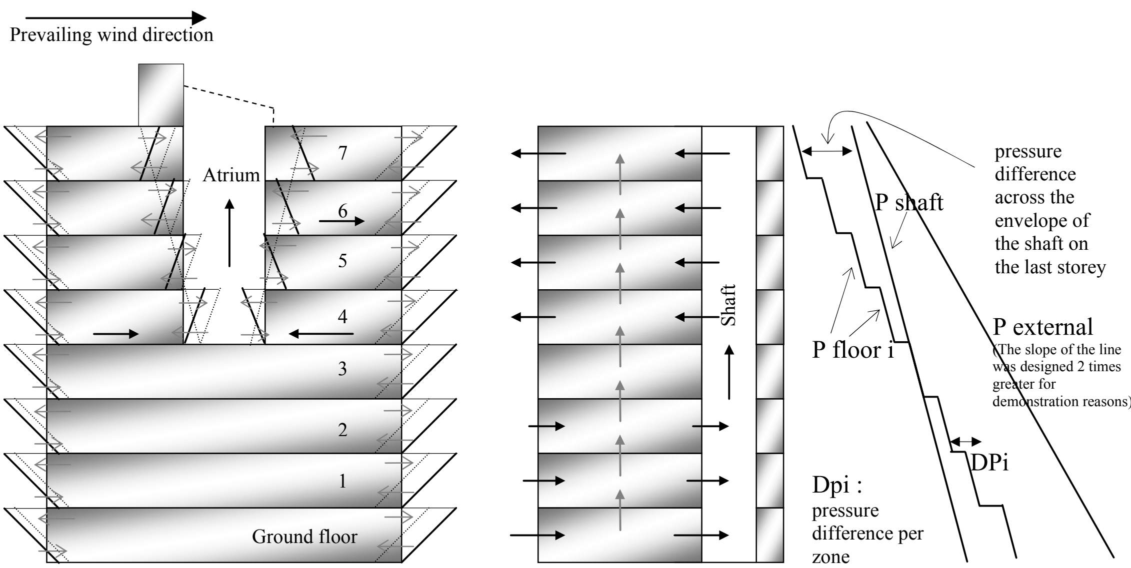

Figure 2. Pressure distribution and interzonal flows in the examined building; left: cross-section at the area of the atrium; middle: cross section at the area of the main shafts; right: internal and external pressure differences (slope lines)

It is therefore clear that it is not always true that "the more you open doors, the more you refresh". On the other hand, it could be said that the incoming flows from the lower floors to the higher floors through the shafts are less contaminated, due to the higher ventilation rates as a result of the extensive use of external doors. This hypothesis is not usually true because the indoor contaminant emissions are also increased due to the crowd. Documented results can be derived only after detailed simulation of the contaminant emissions and validated by proper measurements.

CONCLUSIONS AND FURTHER WORK

The main scope of this paper was to investigate the effects of atrium and other similar architectural design features (e.g. shafts) on ventilation characteristics and the interzonal flows in the zones of a multi-storey office building, for specific conditions and opening area of frequently used entrance doors in an office building. Simulation results agreed well with the bulk in-situ measurements which carried out mainly for qualitative assessment (e.g. validation of the direction and the magnitude of the interzonal flows). Stack effect was the dominating force and wind effect was present yet not significant, but enough to produce negative pressures at the aria of the atrium, mainly due to the form of the atrium roof. The simulation of the use of the main entrances based on data from literature and sample in-situ measurements proved essential for reliable simulation and affected the ventilation efficiency dramatically. The outcomes are useful for IAQ control during winter and for passive cooling during the summer.

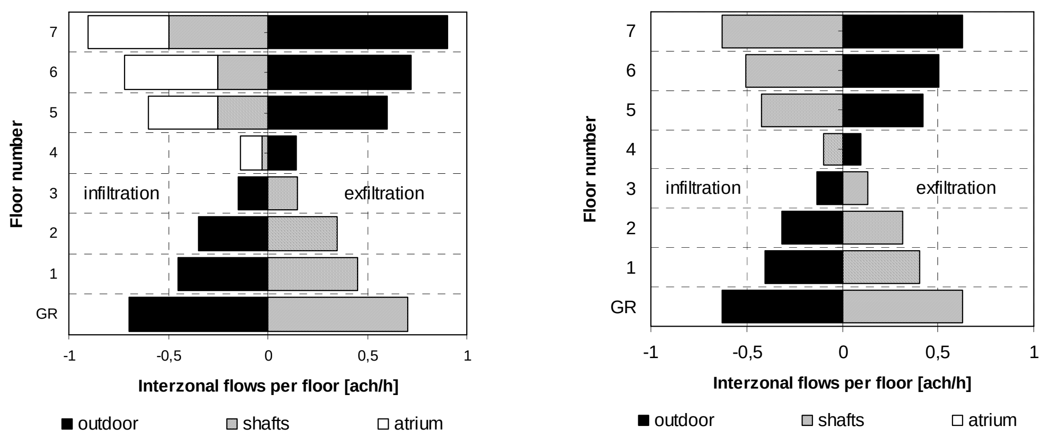

Figure 3. Flow balance per floor for moderate use of main entrances. Left: building with atrium above the 4th floor (existing case). Right: building without the atrium.

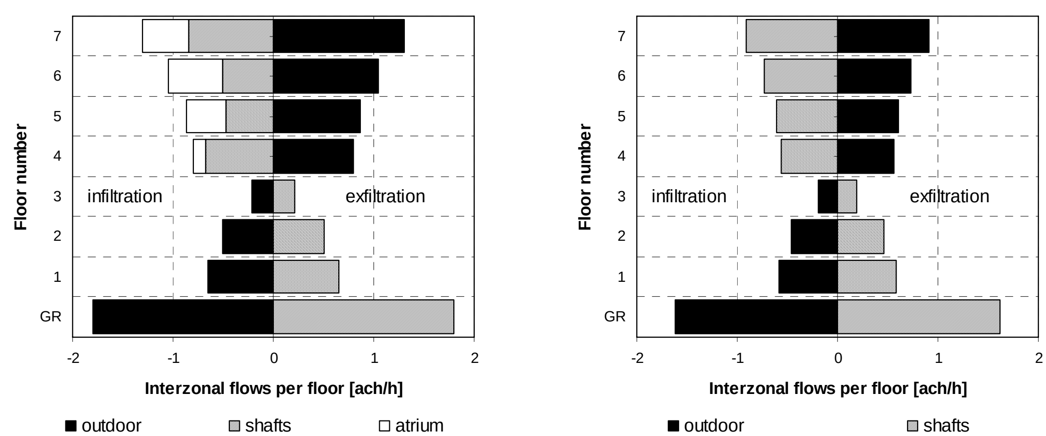

Figure 4. Flow balance per floor for peak-hours use of main entrances. Left: building with atrium above the 4th floor (existing case). Right: building without the atrium.

It was concluded, among others, that the implementation of the atrium increased ventilation efficiency especially at the upper floors creating incoming flows from the atrium and increasing the infiltration and ventilation rates, even for high density urban areas. The process of the simulation results in the form of flow balance per floor, appeared to be practical and comprehensive for the estimation of the airflow effects and for the comparison with the literature.

This work could be further deployed implementing ventilation strategies related to the use of atrium and shafts in the overall energy design. Further experiments and simulations are to be prepared by the author on energy efficient use of atrium in office buildings during winter and summer period. Further work is needed for the evaluation and the simulation of the user behavior, since the effects proved to be intense and sometimes overturn critical design parameters.

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