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EXPERIMENTAL APPROACH TOWARDS AIR FLOW THROUGH A DOOR CONNECTING ROOMS OF DIFFERENT TEMPERATURE

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1. SYNOPSIS

Air flow through doors, windows and other large openings constitutes a major factor in building ventilation. However, due to the complexity of the physical processes involved, relevant physical phenomena are not yet fully understood.

The paper presents data obtained from five consecutive experiments concerning air flow through a large opening (door) connecting two rooms (volumes 28.3 m^3 and 38.1 m^3 respectively) with different air temperatures. The experiments were conducted within the two chambers (Service and Test Room) of a PASSYS Test Cell, a fully equipped outdoor facility for thermal and solar monitoring. The experiments involved the heating of one room (Test Room) until there was a significant temperature difference between the rooms. After that, the door was opened, and the mass and heat exchanges between the two rooms were measured using the available equipment. More specifically, the experimental data, corresponding to 30 sec -step records, concerns the measurement of tracer gas (N2O) concentrations, indoor temperatures, air speed and direction in the middle of the door opening, outdoor temperature and wind speed and direction.

This paper attempts a qualitative analysis of the experimental results as a first step towards a more comprehensive study of the physical processes in operation in relevant phenomena.

2. INTRODUCTION

Ventilation, as an air change process in a building interior, is advantageous provided that the properties of the environmental air, which are related to the hygiene and comfort of the inhabitants (temperature, humidity, air pollutant concentration), are favourable compared with corresponding indoor air properties. Otherwise, a correction of the unfavourable properties of the inflowing air is necessary using energy consuming processes.

The above commentary comprises the correct framework for the study of the qualitative and quantitative characteristics of building ventilation processes. An important section of this study concerns the air flow through various opening types in construction elements. The corresponding air flow processes through large openings under steady state conditions have long ago been investigated. However, what is of great importance are the transient processes taking place during the establishment of communication between two spaces through a large opening. Relevant physical phenomena occurring during the opening of a door or window is empirically known to produce sudden and significant changes in the qualitative and quantitative ventilation characteristics of internal rooms. More specifically, the study is important both for external openings (windows, balcony doors) and internal openings (doors) between adjacent rooms. The prediction of these phenomena was, until recently, possible using empirical and simulation models. The recent work of Daskalaki *et al* (1996) has experimentally studied the establishment of communication between a room and the environment through a large opening (Single Sided Ventilation). In this paper the results are presented from a similar experiment concerning the establishment of communication between two rooms with different air temperatures. The experiment was designed (Argiriou *et al*, 1993) and theoretically analysed (Santamouris *et al*, 1993) under the PASCOOL Programme in order to contribute to the understanding of the processes involved in such phenomena.

3. METHOD

The experiments on which this paper is based took place in Athens during October 1993. They were conducted in the interior of a PASSYS Test Cell, a fully equipped outdoor facility for thermal and solar monitoring (Vandaele and Wouters, 1994). The Test Cell is divided into two rooms, namely the "Test Room" and the "Service Room" (Figure 1). The Test Room is highly thermally- insulated and airtight with its dimensions (Length = 5.00 m, Width = 2.76 m, Height = 2.75 m) based on an average room. The Service Room, with dimensions of 2.40 m, 3.58 m and 3.29 respectively, is the place where the cell equipment, such as the heating and cooling systems, control units etc., is installed. The two rooms are connected by a 1.01 m by 2.00 m internal door.

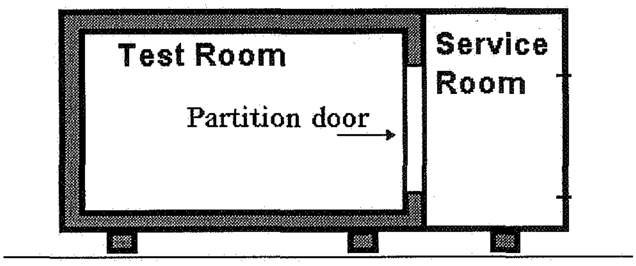

Figure 1: PASSYS Test Cell cross-sectional view

For the experiment, the Test Room was heated until a significant temperature difference between it and the Service Room was reached. At the same time, as the tracer gas decay technique was used to estimate the air exchange rate between the two rooms, N2O was injected into the Test Room and the concentration, in both rooms, was monitored by an infrared gas analyser. When the concentration of N2O in the Test Room was sufficiently high, the heating was stopped and the communication door was slowly opened.

The experiment was repeated five times. Each time it lasted about 25 minutes, with the door being opened after about 10 minutes. Throughout the entire experiment, a long list of physical parameters was constantly recorded. Namely, 74 parameters were recorded at 30 -sec steps. Among them are:

- Tracer gas (N2O) concentration measurements at six points inside the adjoining rooms,
- Indoor temperature measurements at different points inside both rooms,

- Surface temperatures at different points on the interior walls
- Air speed and direction measurements at seven fixed heights in the middle of the partition door opening (2.02 m2 area)
- Outdoor temperature and wind speed and direction measurements at heights of 1.5 m, 2 m and 10 m.

The instrumentation used included the following sensors, with corresponding accuracy in parenthesis:
Temperature: PT100 (0.01 °C), PT1000 (0.1 °C), T-fast (0.1 °C)
Air speed: DANTEC (0.4 %), Hot wire (2 %)
Wind speed: 3 cup anemometer (2 %)
Wind direction: vane (5 °)

4. RESULTS

Figure 2 - based on the first experimental data - presents the speeds of the air masses, at different heights on the layer of the partition door opening, during the air exchange processes which are triggered by the establishment of communication between the two rooms.

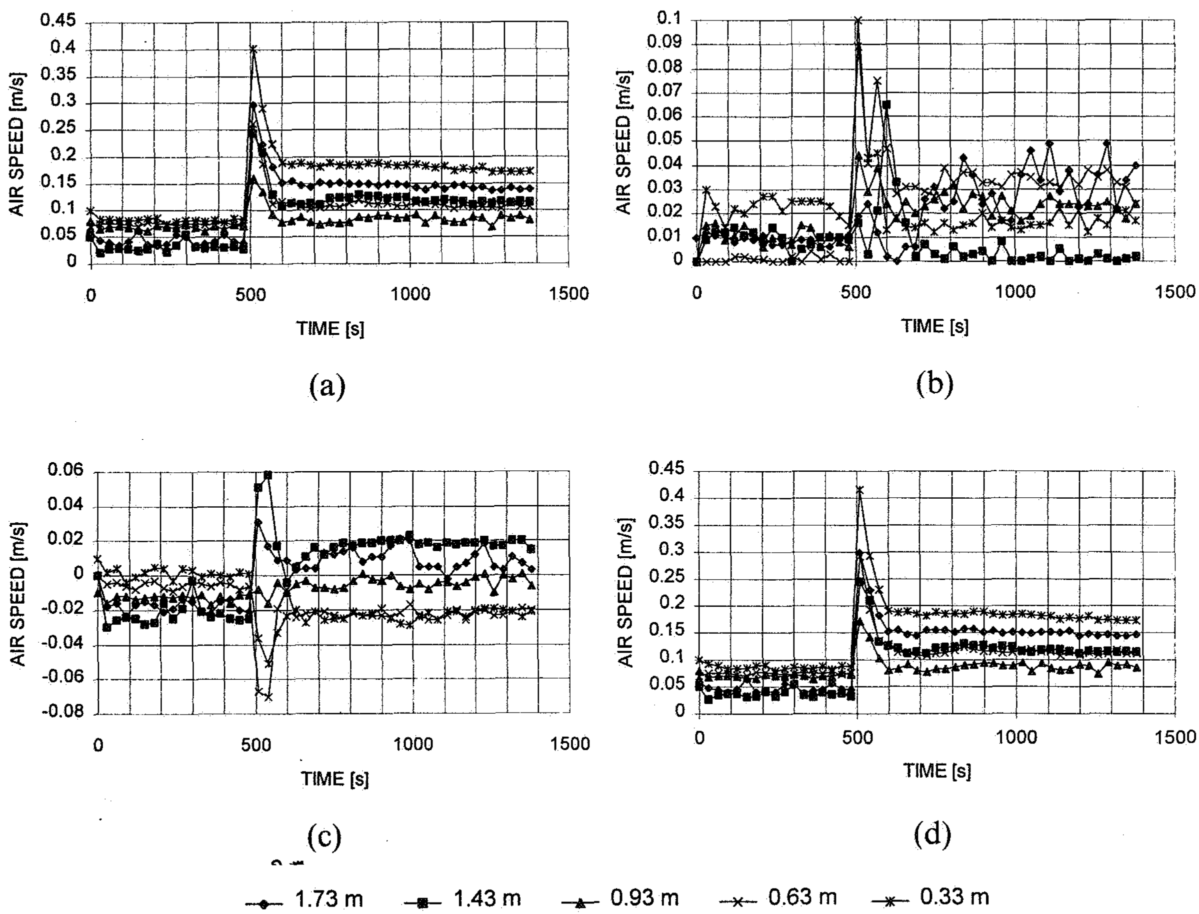

Figure 2: Air speed measurements on x (a), y (b) and z (c) axes, and total speed (d), at different heights on the partition door opening.

Air speeds records correspond to the directions of the x, y and z axes of an orthogonal system, with the x axis along the long dimension of the test cell. Based on this data, the total speed is calculated mathematically. From these diagrams we can observe that a sudden increase in air circulation is produced by opening the door which, after a short peak period, returns to a higher speed than before. The air flow is mainly along the x axis, with its magnitudes reaching values up to 0.5 m/s.

This finding is seen more clearly in Figure 3 where the consecutive speed profiles of the air moving through the door opening are displayed on 30 sec step intervals. Profiles 1 and 2, which are almost identical, correspond to the closed door. Profile 3 represents the sudden increase in air speed, while the next profiles, 4 and 5, represent the drift towards a more turbulent than before condition, with increased speeds at the upper and lower edges of the opening.

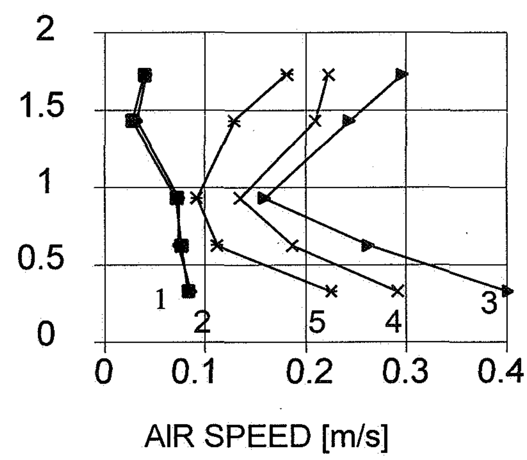

Figure 3: Consecutive air speed profiles - from 1 to 5 - vertical to the partition door, corresponding to 30 sec step recordings during the door opening

The air speed measurements represent absolute values in x and y directions with the direction of the flow only identifiable in the z direction (positive values represent motion upwards). In the x direction it is also possible to identify the direction of the air flow only at a height of 1 m, which corresponds to the midheight of the door opening. In all cases, as shown in the experimental results, at this particular layer, the flow was from the Test Room to the Service Room, which means that the neutral zone was always lower.

This circulation causes the air changes between the two rooms which is depicted in the diagrams in Figure 4, where the variation in the tracer gas concentrations with time are presented for all the experiments. From these diagrams, it is clear that after the door is opened there is a sudden and rather extensive bi-directional transfer of air masses between the two rooms which even results in the reversion of relative gas concentrations. This sudden and rather extensive air exchange, and the accompanying increased air circulation, is obviously not only caused by thermal convection forces but is also affected by the pressure forces imposed by the door opening process (Papamanolis, 1992).

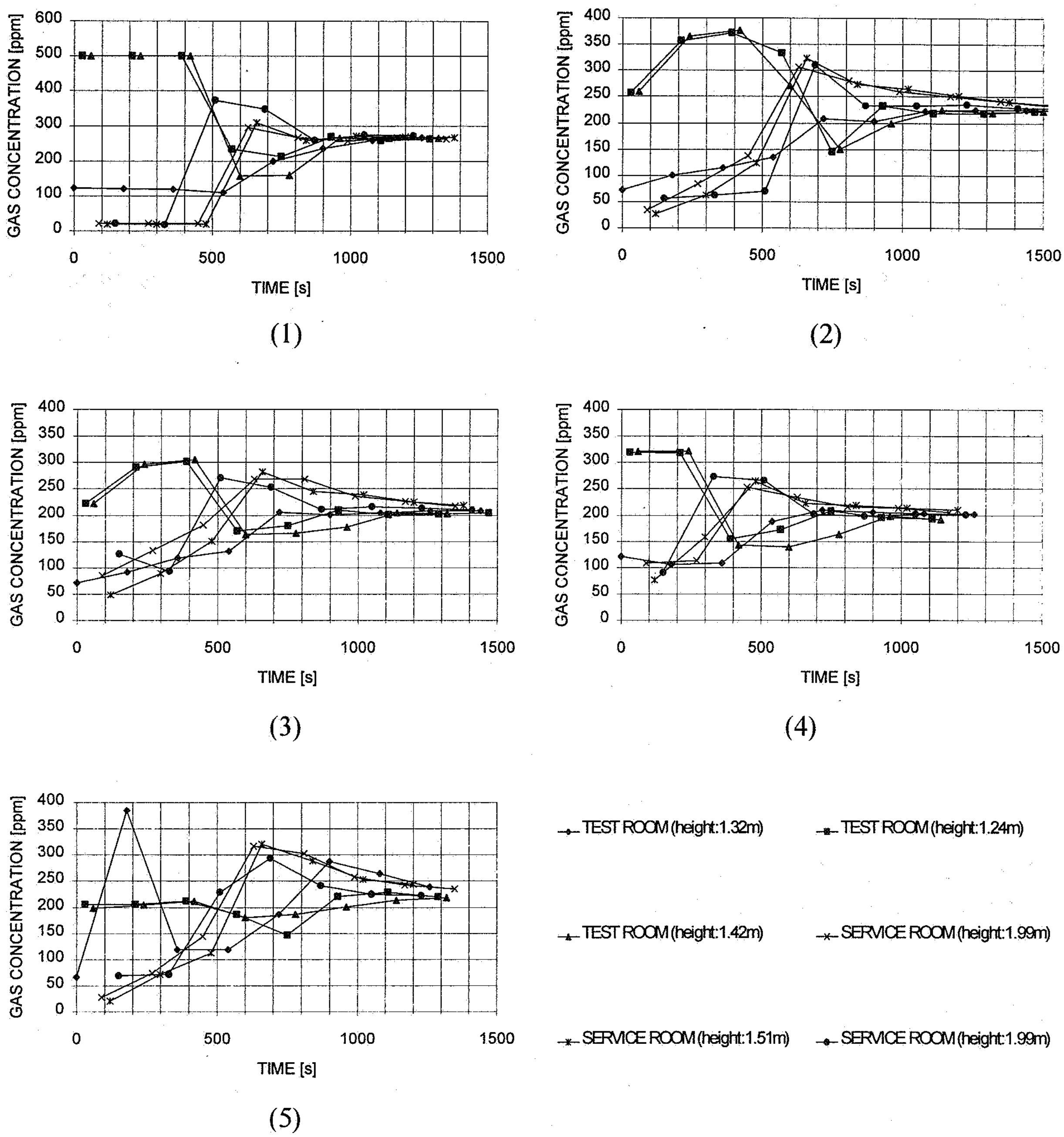

Figure 4: Tracer gas concentration measurements at fixed points in the Test and Service Room.

This phase of the phenomenon, which may be likened to a pulse, is of relatively short duration and is followed by a rapid convergence of tracer gas concentrations in the two rooms which denotes an adequate mixing of the corresponding air masses. More specifically, based on the results of the first experiment (Diagram 1 in Figure 4), we can calculate that during the first 500 s (approximately equal to 8 min) after the door opening we have this sudden air exchange phase and after that we have an almost complete mixing of corresponding air masses. Almost similar are the results coming from all the experiments.

The air exchange processes result in air temperature changes in both rooms. Figure 5 shows the temperature variation at different heights on the partition door opening. From these diagrams, it is clear that the temperature change is more pronounced at the lower layers where the cooler air masses form the Service Room are inflowing. However, even at higher layers, where at the first stages of the phenomenon the flowing air masses are substantially the same as before the door opening, there is a significant temperature reduction which at least makes the timing of the triggering event (door opening) obvious.

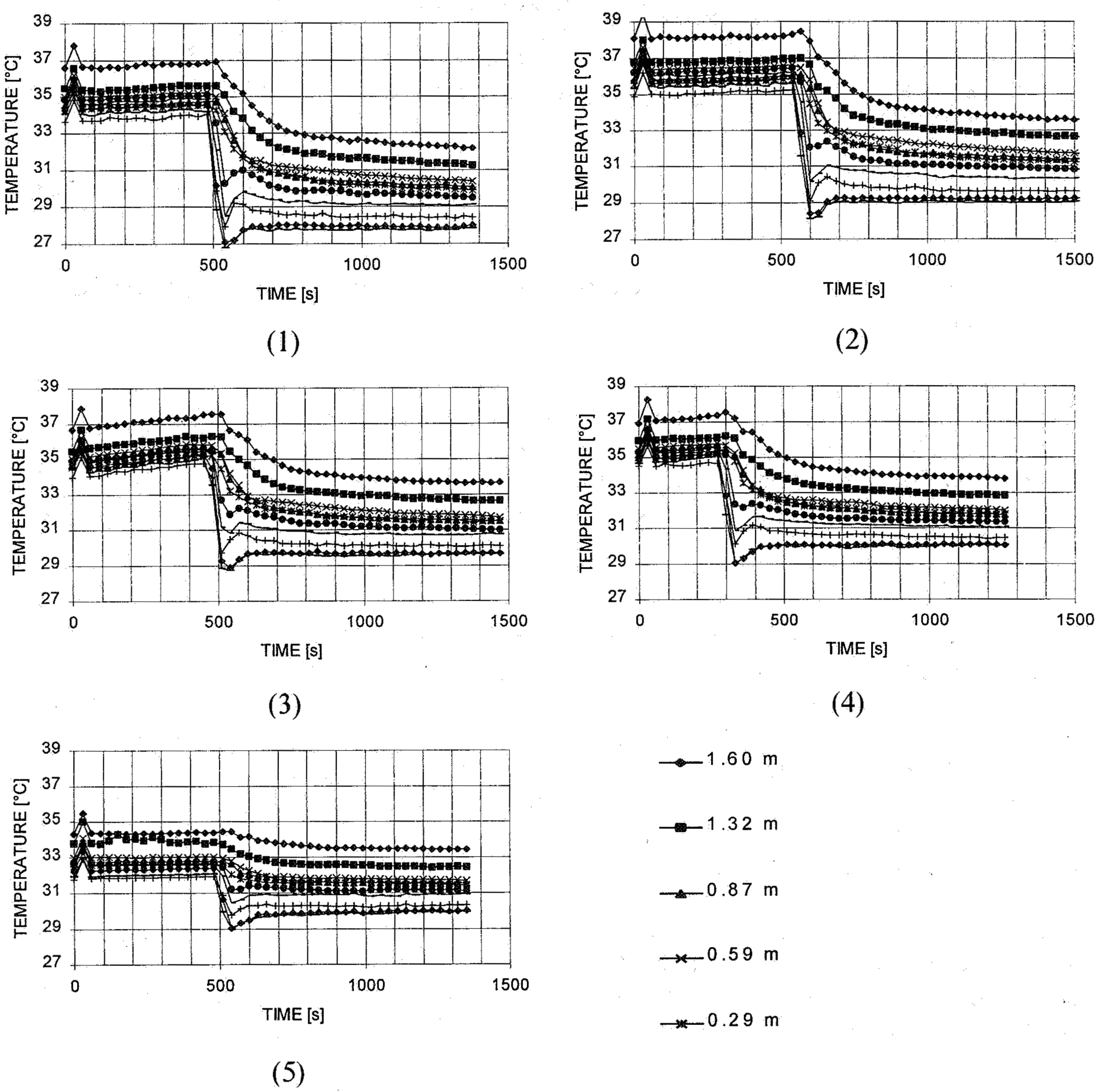

Figure 5: Air temperature measured with PT1000 sensors at various heights on the partition door.

In contrast to the temperature sensors at the opening layer, the air temperature sensors in the middle of the rooms do no reveal so clearly the mixing process initiated by the establishment of communication between the two rooms. In Figure 6, the air temperature changes are presented at different points in the middle of the rooms.

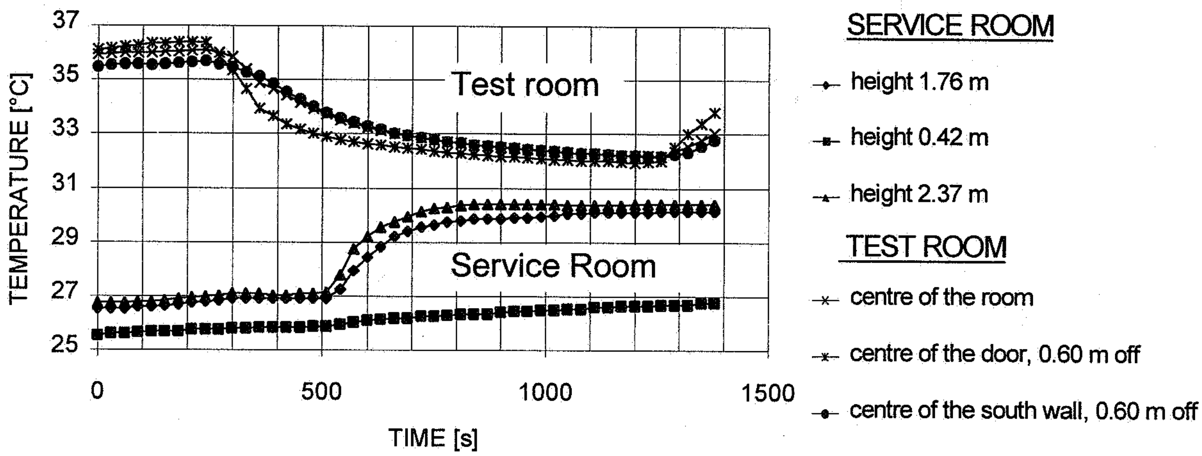

Figure 6: Air temperatures at different points inside the Service Room and the Test Room during the first experiment

It is easy to observe that air temperatures in both rooms are changing slowly and tend asymptotically to be identical. It is also apparent that at least some of the sensors do not respond well to the starting of the air mixing processes, which in the case of the diagram in Figure 6, which is based on the first experiment data, is located very close to 500 s.

5. CONCLUSIONS

From the data which was collected during the five consecutive experiments and which was presented in this particular paper, it can be concluded that the establishment of communication between two spaces of different temperature through a large opening is accompanied by processes of air mass exchange, which involve the mixing of the air masses and the balancing of their temperature. This exchange takes place in both directions of the air currents which are created through the opening. The greater the distance from the neutral zone, which is located approximately in the centre of the opening, the greater the respective air speeds become.

From the experimental data, it can be concluded that while the mixing of the air masses takes place for relatively short periods, the air temperature balance between the two spaces, in contrast, continues at a slow rate. This is obviously due to the influence of other factors, excluding convection, which control this balance (conduction)

The above conclusions which are drawn from the initial elaboration of the available experimental data are the most conspicuous. They offer an introductory qualitative approach to the phenomenon, as within the scope of this paper. A more complete and systematic analysis will enrich and better document relevant phenomena aimed at a more detailed and comprehensive understanding of the mechanisms involved and the transient processes taking place.

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