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MAPPING INDOOR AIR MOVEMENTS WITH A TRACER-GAS TECHNIQUE

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ABSTRACT. This paper describes how the tracer decay method was used to map all indoor air flows in a passive solar residence in Porto. A specific analysis of the influence of the fireplace chimney was made, showing that it accounted for a 50% increase in air exchange rate, and that indoor air movements were strongly affected in both magnitudes and directions.

1. INTRODUCTION

One of the major difficulties in the characterization of the performance of a passive solar building lies in the knowledge of air movement patterns inside the building. Passive solar buildings are typically multizone spaces at different temperature levels which cause convective currents that combine with outdoor air infiltration for complex circulation patterns.

Direct measurement of these air patterns is almost impossible because of the very low prevelant air velocities, /1/. Indirect forms of measurement are thus required, and the tracer-gas methods have been proven as a viable alternative, /2/. This method can be implemented in different ways, with the most common being the decay, /3,4/, and the steady-state concentration, /5/, techniques. While this latter technique requires a more sophisticated control apparatus, the former has no such requirements but, on the other hand, to obtain meaningful results, the air volumes in each zone must be know. The volume of air in a zone is a difficult quantity to get by direct measurement, because the furniture and finishing inside each zone, even those with well-established boundaries - which is not always the case -, make it all but impossible to accurately account for every detail.

A tracer decay methodologie that enables the simultaneous evaluation of the airflows and the airvolumes in buildings was however developed and validated in a laboratory under controlled conditions, /6/, and in a real house, under real climatic conditions, where airflows fluctuated as indoor and outdoor temperatures and outdoor wind conditions chanted, /7/.

This paper describes how such a technique was used to map all indoor airflows in a passive solar house in Porto and the results that were obtained. The objective was to quantify indoor airflows under several operating modes (e.g., opened or closed room doors, consequences of a fireplace and glazing protections, etc.) to allow for better insight into thermal energy flows, (e.g., the relative weight of radiative and convective energy transfer) and indoor air quality (effective air exchange rates) in ordinary passive solar buildings.

2. PASSIVE SOLAR HOUSE

The tests were carried out in a two-story passive solar house, the C.T.O., /8/, shown in Figs.1 and 2. The building, a three-bedroom single-family house with 150 m^2, is wholly oriented to the south. There are only small windows on the north, east and west sides, to allow cross ventilation in summer. The main rooms face south and the service areas are on the north side, providing a buffer zone around the main rooms.

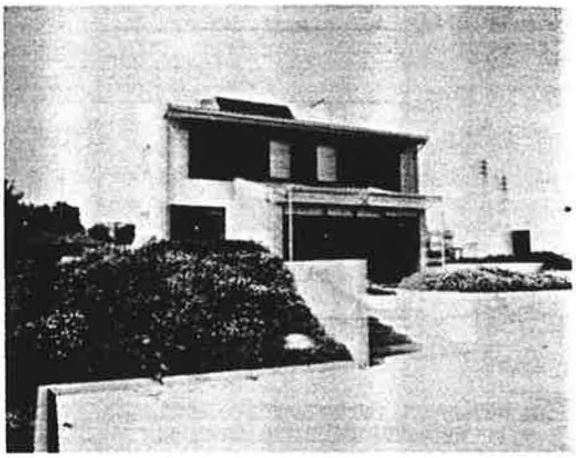


Fig.1 - The C.T.O.

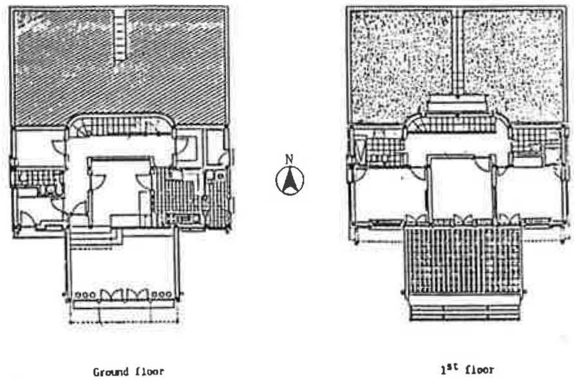


Fig.2. - C.T.O. Plans

The CTO has an all-electric auxiliary heating system that can thermostatically control individual rooms to the desired temperature level, but it also has a fireplace in the center of the living-room, in the lower-floor. Although great care was put during construction to ensure the tightness of the chimney and the duct that brings outdoor air for combustion when the fireplace is in operation, the results described in a later section show that the influence of the fireplace upon air infiltration and indoor air movements is quite important.

The attic above the bedrooms was completely sealed from the rest of the building to minimize its influence upon air infiltration and indoor air move-

ments. As such, the house could be considered as a two-zone space, as long as all the internal doors were kept open all the time, each zone corresponding to each of the two floors.
Tests other than those reported in this paper,/9/, have shown that, when a door is closed, the respective room behaves as a separate zone with little interaction with the rest of the house.

3. TEST METHODOLOGY

The tests were performed with CH_4 as the tracer-gas. For each test, a pulse of CH_4 was released in one of the zones and the ensuying varying concentrations were measured in both zones. The procedure was repeated with the CH_4 pulse released in the other zone. Fig.3 shows the concentration of tracer gas in both zones, in the two experiments of one of the tests carried out.
The concentrations were measured by a single calibrated infrared detector, which received air from all sampling points through a multiplexer programmed in an appropriate sequence.
To enhance uniformity of indoor air properties, small fans were placed in each zone to improve mixing within them. Furthermore, the outlets of the tracer-gas injection lines were placed downstream of the fans in order to spread the gas more evently.

4. RESULTS

Indoor air movements inside the CTO change of course, with the prevailing outdoor weather, i.e., wind speed, wind direction and air temperature, which strongly affect air infiltration. A thorough analysis of air infiltration in the CTO, /10/, carried out by standard tracer-gas techniques, /11/, has shown that the air infiltration could be correlated with wind speed, wind direction and stack effect according to the equation

$$I = 0.512 + 6.184E\text{-}3\ \Delta T + 0.014V^2_{south} + 0.008E\text{-}3V^2 \quad (1)$$

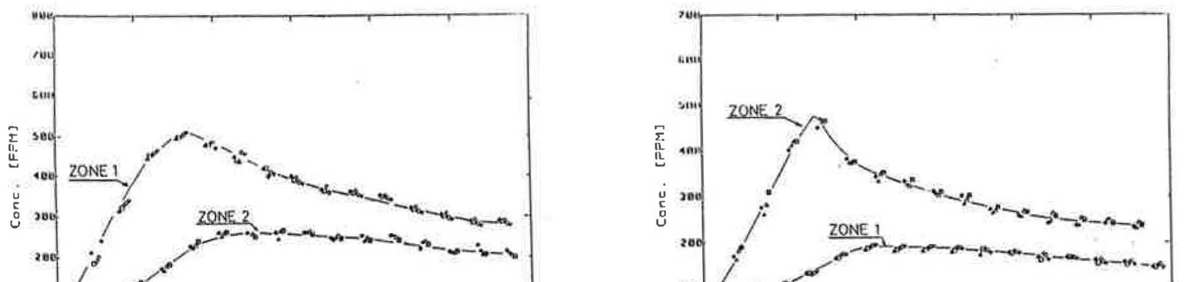
where:
ΔT - Temperature difference
V_{south} - Wind component acting on the south façade
V - Wind component acting on the other façades

The average air infiltration for the mean seasonal climatic conditions is 0.75 RPH.
These tests showed that the south wind plays a fundamental role in the air infiltration: as can be seen in equation (1), the regression coefficient for the south wind component has a significantly higher value when compared with the remainder weather coefficients, namely other wind directions and stack effect. Physicaly, this is related to the large glazed area of the south façade, and small wind variations in that direction have significant effects upon the subsequent air infiltration.
In order to verify the influence of outdoor weather conditions upon the indoor air movements in the CTO several tests were carried out following the methodology described in the previous section. Fig.4 shows the airflows inside the CTO under widely varying outdoor weather conditions, with winds blowing from several directions.
The main conclusions obtained from these results are the following:
- Each floor of this two-story residence exchanges air both with outdoors and with the other floor, through the staircase. There is a downward flow of cooled air along the north wall of the building and an upward flow of warmer air through the main shaft of the staircase.
- There is a net downward flow under most circumstances, which is related with the induced stack effect of the fireplace chimney.

As can be seen, the changes in indoor air movement with outdoor weather are more pronounced in magnitude, as the overall directions of the airflows remain relatively constant.
In order to verify the influence of the fireplace upon air infiltration in the CTO, the fireplace was completely sealed from the rest of the house, which therefore behaved as if the fireplace did not exist. Tracer-gas tests were then performed following the same methodology used in the tests just described. In this new situation, the air infiltration is related with wind speed, wind direction and stack effect according the following equation, /10/:

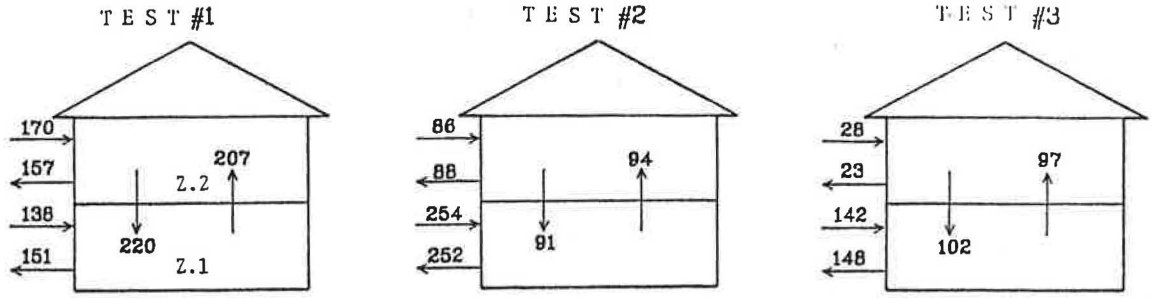
$$I = 0.294 + 0.014\Delta T + 0.019V^2_{south} + 0.008E\text{-}3V^2 \quad (2)$$

The average air infiltration for the mean seasonal climatic conditions is I = 0.47 RPH.
Once again, the south wind plays a fundamental role upon air infiltration, but there is a clear decrease of the magnitude of air infiltration - almost 50% - when compared with the usual running mode, i.e., with the fireplace not sealed.
Several two zone tracer-gas tests were also carried out when the fireplace was sealed, as shown in Fig.5. The main conclusions obtained from these tests are the following:
- The net airflow rate between the two stories of the CTO is now from the ground floor towards the first floor, i.e., it is the opposite of the direction identified in the previous case. This is related to the absence of the stack effect induced by the fireplace chimney.
- There is a decrease in the global air infiltration of the CTO when compared with the situation of open fireplace. This is in agreement with the single-zone



a) Pulse release in zone 1　　　b) Pulse release in zone 2

Fig.3 - Tracer-gas concentration profiles

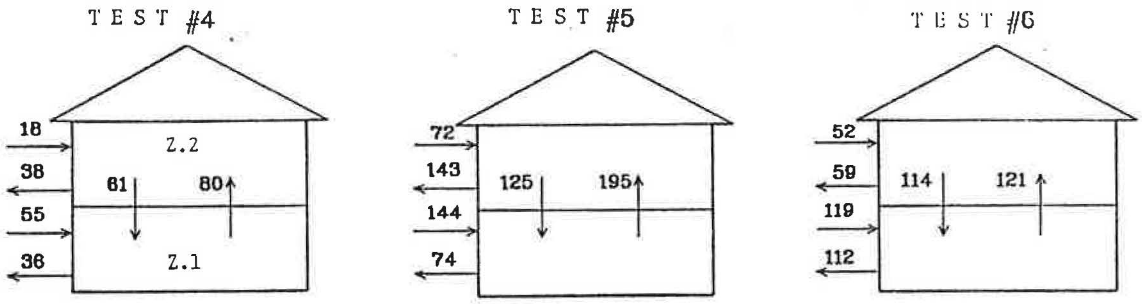


Test #	Climatic Conditions				
	Wind		Temperature [°C]		
	Dir [°]*	Int [Km/h]	Ext	Z.1	Z.2
1	188	26,6	15,6	20,7	21,6
2	315	28,5	13,8	22,0	22,4
3	264	12,6	14,4	20,4	21,4

*Azimute Angle: 0°=North; 90°=East; 180°=South; 270°=West

Test #	Infiltration [RPH]	
	Global	Multizone
1	1,0	0,98
2	1,0	1,0
3	0,52	0,54

Fig.4 - Measured airflow rates in the C.T.O.



Test #	Climatic conditions				
	Wind		Temperature [°C]		
	Dir [°]*	Int [Km/h]	Ext	Z.1	Z.2
4	108	9,6	13,8	21,0	21,9
5	90	29,2	9,3	18,9	21,4
6	256	18,2	14,7	21,7	22,2

*Azimute Angle: 0°=North; 90°=East; 180°=South; 270°=West

Test #	Infiltration [RPH]	
	Global	Multizone
4	0,22	0,23
5	0,72	0,70
6	0,54	0,56

Fig.5 - Measured airflow rates in the C.T.O. with the fireplace sealed.

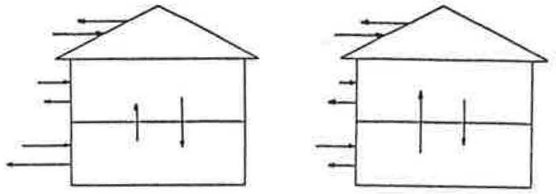
whole-house infiltration results obtained earlier (eqn.2).
Once again the sole effect of the outdoor weather upon the indoor air movements is in the magnitude of the airflows. The relative directions remained constant in most of the tests.

5. CONCLUSIONS

The tracer gas methodology used in this work has proven to be reliable for the measurement of indoor air movements in building under real conditions.
The tests performed in the CTO showed that:
- When the interior doors are open, each floor of the CTO behaves as an individual zone.
- Under normal conditions, both floors exchange air with outdoors and with each other.

If the doors are closed, the rooms with closed doors behave as additional zones with little interaction with the rest of the building . As the number of interior closed doors increases, the magnitude of the air infiltration rate decreases due to the higher resistance to airflow.
- Indoor air movements change in magnitude as the outdoor weather changes, but the mean directions of the airflows remain relatively constant, for most weather conditions.
- The fireplace is responsible for a significant increase in the global air infiltration of buildings. So, to reduce air infiltration when there is a fireplace, it is necessary to improve the tightness of the chimney and the window frames.
- A fireplace plays a fundamental role in the overall pattern of indoor air movement inside a house. In this particular case, an inversion of the net

airflow rate between both floors was observed: While there was a net downwards airflow when the fireplace was not sealed, there was a net upwards airflow after it was sealed.



Fireplace open   Fireplace sealed

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