EXPERIMENTAL DETERMINATION OF EMPIRICAL FLOW COEFFICIENTS FOR AIR INFILTRATION THROUGH PITCHED ROOFS

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ABSTRACT

The heating and cooling loads due to air infiltration may be estimated by a mathematical model that requires the knowledge of the leakage characteristics of each component of the envelope. To extend the modelisation to pitched roofs, empirical coefficients pertaining to the leakage characteristics of roofs were determined by a differential pressure method.

KEYWORDS

Roof structures; air leakage; modelling; building thermal performance.

INTRODUCTION

Roofs play an important part in the global energy balance of a building. The relative importance of the roofs depends on several parameters such as number of stories, the U-value of the walls, area of glazings and infiltration losses. The importance of the thermal exchange in the roof increases as the tightness and overall U-value of the walls and glazings increase and as the number of stories decreases. In addition, certain types of roofs also influence the air exchange rate in a building: whenever there is a communication between the roof and stairwells or elevator shafts, the stack effect is increased and infiltration is enhanced.

In Portugal, during the 70's, about 50% of the new construction had a single storey and 95% had no more than two storeys. The vast majority of these buildings has a sloped tiled roof with an attic space which can be accessed from within. Usually, no insulation is used in the roofs and attics, resulting in a roof U-value of 3 W/m^{2}K. Under these circumstances, it is clear that the thermal exchange through the roof in Portuguese buildings is responsible for a significant portion of their energy consumption for heating and cooling. A survey has shown that one third of the thermal exchange in such a building is through the roof, while infiltration is responsible for another third (Abrantes, 1980).

It is therefore important to be able to quantify the thermal performance of a roof-attic system, namely the air exchange rate in the attic and how it interacts with the rest of the building. The most common methods that can be used to estimate infiltration rates are the air change method and the crack length method. In addition, there are some more complex mathematical models which usually require numerical methods to obtain a solution (Kusuda, 1976). These models are more rational and less empirical than the other two methods and were thus chosen for this project.

INFILTRATION MODEL

This model considers the building as a control volume with the building envelope as the boundary. In the earlier versions, the control volume was considered as a single zone to simplify the mathematical treatment. Nowadays, however, the building is divided into several zones, usually one for each major room or group of rooms. This is important because significantly different pressure differences may occur within a building, in particular when there are horizontal partitions. Each zone is then treated as a separate control volume where the principle of conservation of mass applies, i.e., the sum of all flow rates entering or leaving a particular zone is nill.

For each zone (i), it is possible to write:

$$\sum_{j=1}^{n} \sum_{\ell=1}^{m} C_{ij\ell} \; A_{ij\ell} \; (\Delta p_{ij})^{n_\ell} = 0 \qquad (1)$$

where:

n - number of zones

m - number of boundary elements in zone i

$C_{ij\ell}$ - flow coeficient, defined as the volume air flow rate per unit area (or linear unit of length of crack) and per unit pressure difference between both sides of the component [$m^3/s.m^2.Pa$] or [$m^3/s.m.Pa$]

$A_{ij\ell}$ - area or crack length of component ℓ [m^2] or [m]

ΔP_{ij} - pressure difference between zones i and j [Pa]

n_ℓ - exponent between 0.5 and 1, usually about 0.65 for cracks.

For each of the n zones in a building, an equation of the type of eq. (1) can be established, thus resulting in a system of n simultaneous equations. It should also be noted that, given the dependence of the density of air upon temperature, all flowrates must be referred to the same temperature level.

Flow measurements of infiltration air through cracks are difficult if not impossible to make with enough accuracy because the pressure differences between the sides of any component and the resulting air flow rates are very small. Thus, rather than measuring the flow itself, indirect forms of measurement are usually employed, such as the tracer-gas method, the blower-door test method, and the component pressurization method, e.g., the method specified by ASTM standard E 283.68 for measuring window leakage. While the tracer-gas determines air leakage by measuring the changes in concentration of a gas, the other methods amplify the pressure difference between both sides of a component or building envelope, thus increasing the air flow rate and making its measurement easier.

MEASUREMENT OF FLOW COEFFICENTS IN PITCHED ROOFS

The element pressurization method was chosen in this case. It consists of sealing off a portion of the roof with a plastic sheet and pulling a vacuum between this sheet and the roof. The pressure difference and air flow are then measured and the flow coefficient deduced from the measurement of leakage rates at various pressure differences.

Due to the difficulty in completely sealing off a section of an actual roof in a building and to the little mobility possible in most attics, in-situ measurements were not made. Rather, a model was built in a laboratory and the measurements then taken under completely controlled conditions. Pressure measurements were taken with an electronic micromanometer having a resolution of 10^{-5}mm of water gauge and air flow was measured with two rotameters, one for flowrates up to 27 m^3/hr and the other for flows up to 175 m^3/hr. The rotameters had a 2 % precision.

The air flow is driven by an air pump with 700 W, capable of drawing a flow of 70 m^3/hr, which is much larger than the leakage possible through the element under study. The flow rate is then regulated with two valves.

The experimental facility is schematically show in Fig. 1, while Fig. 2 shows a detail of the evacuated space between the roof and the plastic sheet, including the connection between the plastic and the tube through which the air is aspirated.

Prior to studying the roof itself, the equipment and method were used to measure the leakage rate through windows. These values are known and have been tabulated (ASHRAE, 1977), and it was thus possible to compare the measured and tabulated values to check the validity of the procedure.

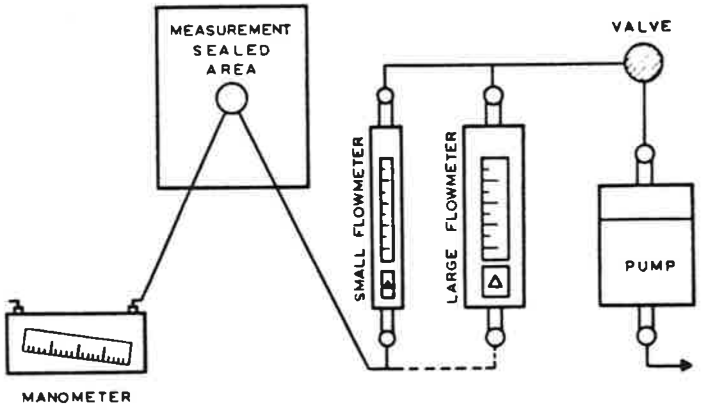

Fig. 1 - Schematic representation of the leakage measuring equipment.

Fig. 2 - View of an experimental model.

RESULTS

The most common types of roofs in Portugal (Abrantes, 1980) are shown in Fig. 3

The measurements for each type of roof were then correlated to an equation of the type

$$Q = C \Delta p^n \qquad (2)$$

and a least squares fit was found. The results are shown in Fig. 4 and are summarized in Table 1, which lists the values of C and n for each roof type, as well as the statistics that were obtained.

In Table 1, the values of the flow coefficient C and flow exponent n are shown for a variety of roofing materials, and two values obtained from ASHRAE (1977), one for windows and the other for a wall, are given for comparison.

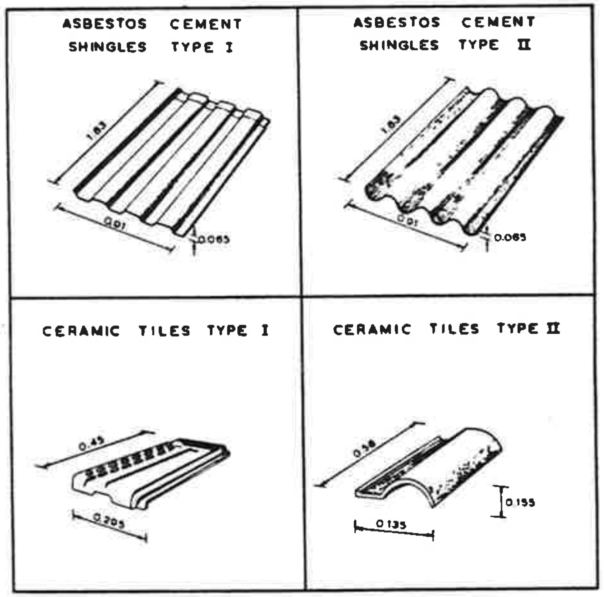

Fig. 3 - Common types of roofs in Portugal.

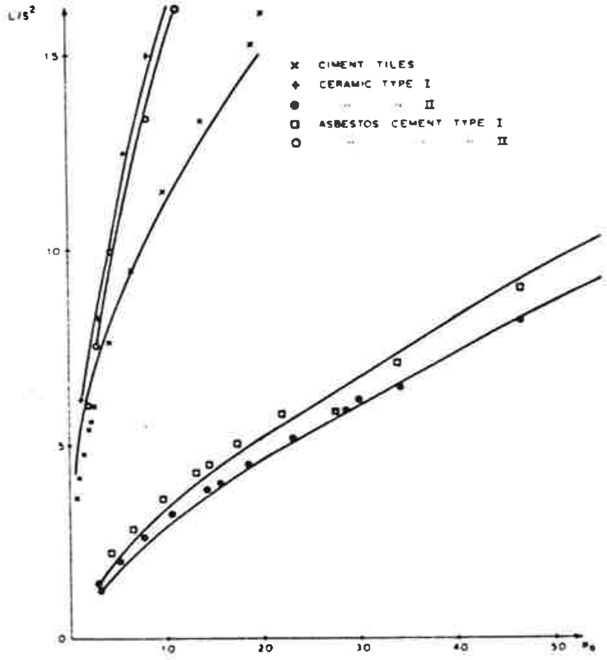

Fig. 4 - Leakage characterics of the studied roofs.

TABLE 1 - Experimental Values of Flow Coefficients

Type of roof	Flow Coefficients C [ℓ/sm^{2}Pa]	Flow Coefficients n	Statistics[1] N	Statistics[1] r^2
Ceramic Tiles				
- Type I	4,593	0,537	11	0,999
- Type II	3,970	0,595	12	0,997
Cement Tiles	4,642	0,385	12	0,976
Asbestos Cement Shingles				
- Type I	1,076	0,936	12	0,933
- Type I[2]	0,670	0,688	14	0,972
- Type II	0,642	0,668	14	0,997
Window[3],[4]	0,29	0,65	-	-
Loose Wall[4]	0,18	0,65	-	-

[1] Number of experimental points and correlation coefficient.

[2] Weatherstripped

[3] Non weatherstrippes loose fit with around frame in masoney wall not caulked.

[4] From ASHRAE (1977).

CONCLUSIONS

The pitched roofs that are traditionally used in Portugal are characterized by large leakage rates. This contributes significantly to the large infiltration rates that occur in typical Portuguese buildings.

The flow coefficients of roofs with ceramic tiles are much greater than those made of asbestos-cement shingles. This results in larger ventilation rates in attics below the former type of roof, which is a favourable situation during the summer. Conversely, if there is an opening to the main portion of the building, ceramic tiled roofs will also result in larger air exchange rates in the building itself.

The availability of flow coefficents for these roofs will allow the simulation of the global air exchange in buildings, treating the attic as a separate zone (Abrantes and Galanis, 1981, and 1982).

Finally, the equipment and method that were used in this project are simple tools that can and have been used in energy-audit procedures to verify "in-loco" the leakage characteristics of building components and locating possible energy conservation opportunities.

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