AIR QUALITY IN PORTUGUESE SCHOOL BUILDINGS: SOME RESULTS

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1. Introduction

Most Portuguese school buildings have no mechanical ventilation, the air renovation being therefore made by natural means. Hence the frequent situation of discomfort during winter as, even in the mild Portuguese climate, it isn't usually possible to associate good thermal comfort conditions with satisfactory air quality levels without incurring into excessive energy consumption.

In view of the persistence in the non-utilisation of mechanical ventilation in our buildings, it was suggested to resort to natural ventilation means with air preheating in solar collectors installed on south-facing walls.

This paper shows the results of a small survey on air quality in school buildings carried out in the mildest climatic region in Portugal - the centre-south coast; these results translate various discomfort situations ensuing from the low air change rates in the school period.

With a strategy of air quality control in control by dilution, the behaviour observed by resorting to solar collectors installed on the south façade is simulated. The simulation has been carried out in two ways:

. numerical way, using simplified algorithms deduced from the dimensional analysis and resorting to numerical integration of the Navier-Stokes equations;
. experimental way, using a small simplified model and extending it to the analysis of collectors installed on a prototype building. However, this analysis was rather limited, both by the type of model used and also by the fact that the school building where the collectors were installed was not yet completed (the building is expected to be completed in August 1987 and to be functioning in the next school year).

2. Survey on air quality in portuguese school buildings

As stated above, most school buildings in Portugal are not equipped with means of controlled ventilation and, in the mildest climatic regions, auxiliary heating is not contemplated. Therefore it is logically admissible that minimum conditions of air quality and of thermal comfort are not met. As regards the latter aspect, previous studies (1) had already been conclusive. It is now attemped to make a survey with a significant dimension allowing the confirmation of our suspicious as far as the former aspect is concerned.

For this purpose, our choice was limited to buildings located in the mildest climatic region in the country (mean temperature in January ~ 10° C, 900/1200 DD_{18}) and that could be considered as paradigmatic of the most current type of school buildings (the observation was also limited to preparatory and secondary schools).

Measurements were made only for CO_2 contents and it was resorted to the simple method of "test-tube" using the "Dragger" detector.

Observations were made in wintertime, by mid-morning and in class-rooms with windows partly open or completely closed (although windows were opened in the 10 minutes' intervals between classes).

In some schools measurements were made during a whole morning to allow the detection of the evolution of carbonic gas concentration during the whole period and simultaneously the assessment of the corresponding renovation rates.

Figures 1 and 2 show the results of the survey.

The ventilation rates observed in some class-rooms of those schools - deduced from the evolution of carbonic gas contents - can be estimated as follows:

- with closed windows (typical situation during classes): ach ≈ 0.5, i.e., values between 0.4 and 1.0 l/person.second;
- with open windows (typical situation during class intervals, and in some classes in Lisbon schools): ach ≈ 2 to 4, i.e., values between 1.6 and 10 l/person.second.

Despite the limited number of observations (less than 100 in ten different schools) it can be inferred that, as a rule, minimum air quality requirements - CO_2 at 0.12-0.25%, as standard parameters - are not met and that therefore the adopted ventilation strategy is unsuitable.

As the buildings when the observations were made generally correspond to type-projects spread throughout the country, and considering that in the remaining climatic regions the roughness of winter tends to limit the opening of windows, it is believed not to be exaggerating when applying that statement to most school buildings in Portugal.

3. Natural ventilation by resorting to air solar pannels integrated in the façades

The correction of the present situation implies the increment and regularisation of ventilation rates allowing good hygienic conditions. This can be achieved in two ways: (i) active way, be resorting to mechanical ventilation, and (ii) passive way, where, although by natural means, it is attempted that the ventilation rates attain the values usually recommended (2).

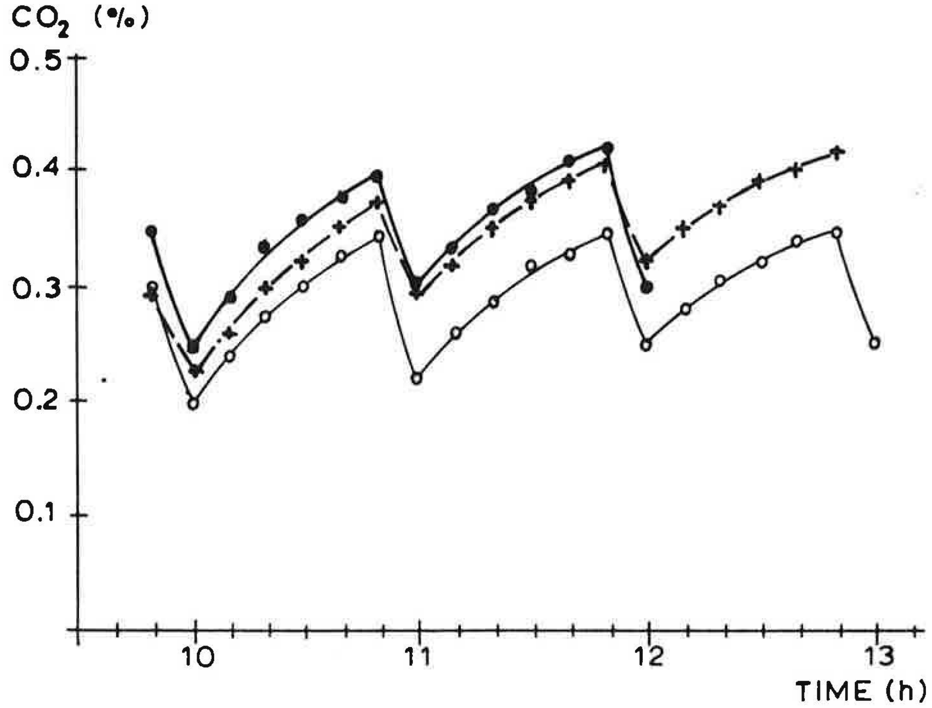

Fig. 1 - Evolution of CO_2 contents in class-rooms in three different schools

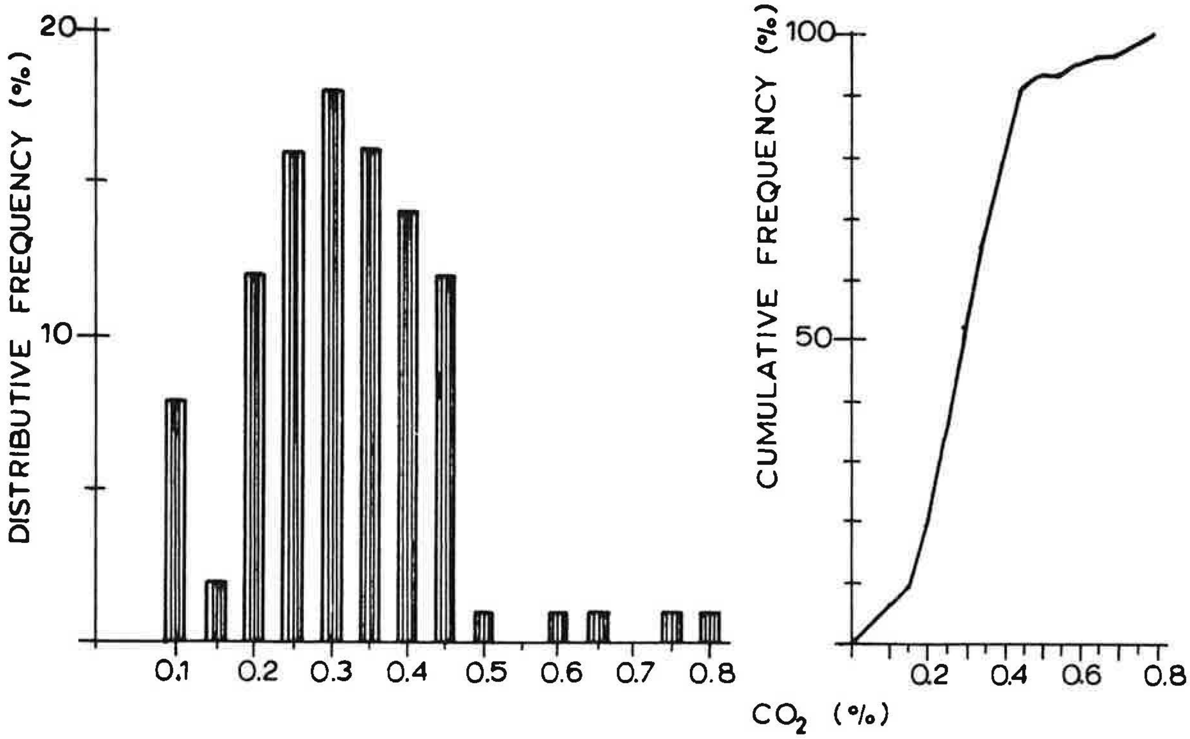

Fig. 2 - Distribution of CO_2 contents in the class-rooms under observation

In both cases a problem arises: the increase of ventilation rates causes greater thermal losses and, consequently, a higher final energy consumption to meet the comfort requirements. A possible solution could be preheating the air to be admitted, by using cost-free energy (recovery of lost heat or solar energy). However, considering that the entities promoting the building of school are generally reluctant to resort to active installations - especially because of maintenance problems - recourse to solar collectors integrated in the south façades was contemplated.

This solution has been the object of a study by resorting to both the numerical and the experimental simulation and, assuming its viability, it is being used in a medium-size school building (about 400 pupils) that is expected to open next September.

3.1 - Numerical simulation using simplied algorithms

A first approach to the study of the adopted solution consists of its consideration in the thermal balance of the place where it is installed, by resorting to a numerical simulation model of the "nodal network" type, as shown in Figure 3.

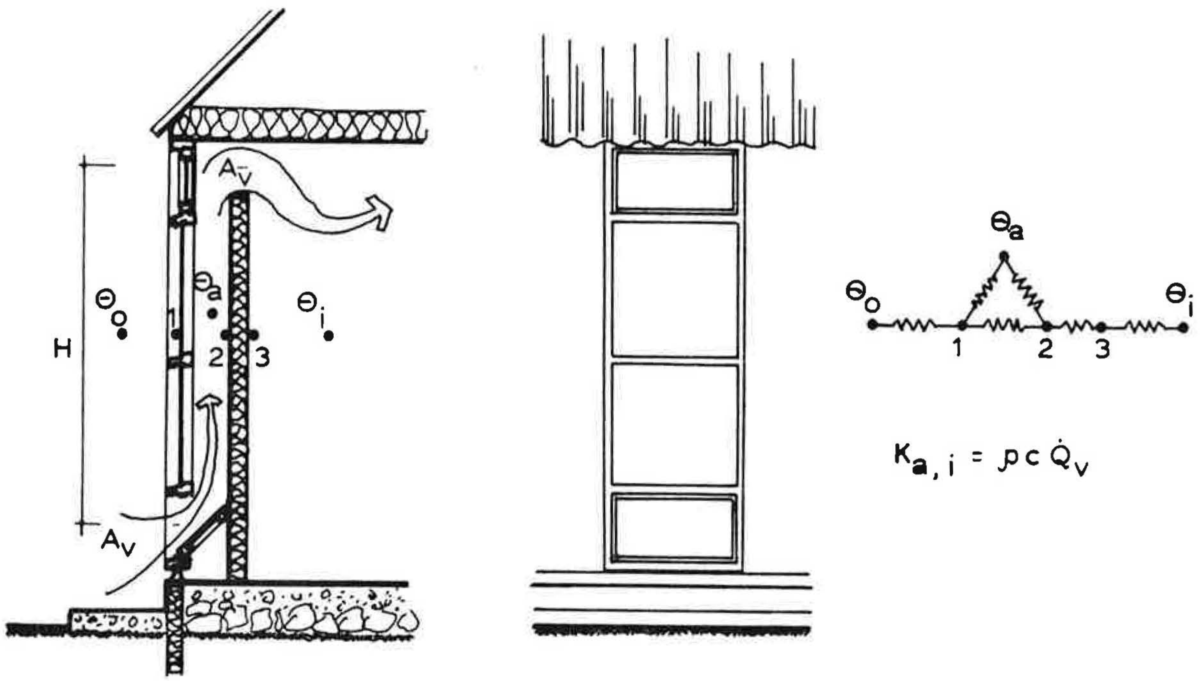

Fig. 3 - Network model for solar air-collector integrated in an ordinary classroom

It is thus considered that the air renovation flow is due to the "stack effect" assuming the value of:

$$Q_V = 0.12\ A_V \sqrt{H\ \Delta\theta}$$

where: A_v - area of openings;

H - height between the medium lines of the openings;

$\Delta\theta$ - difference between air temperatures in the outside and in the pannel.

For the simulation, a normal class-room was considered, i.e., a class--room corresponding to the class-rooms of the school being built (2,3), with an area of approximately 50 m2 and a height of 3.10 m. The solar pannel has a glass zone of approximately 2 m2, with a flow are adjustable between 0.18 and 0.24 m2. The location that was considered was that of an intermediate climatic zone in the country, which is characterised by a mean temperature of 11.5°C in the cold season; mean temperature in January of approximately 8°C and ~ 1800 DD_{18} .

It was assumed that the school day would be from 9 a.m. to 5 p.m. and that there would be no auxiliary heating (as usual). For the simulation a characteristic sequence was also used (six representative days per month), and an infiltration rate of 0.5 ach was assumed.

Figure 4 shows the results corresponding to the two roughest months in the period considered.

This simplified method shows that, for the whole period and under the said conditions, the air change rates are, as a rule (in over 95% of the school hours), higher than the minimum recommended values, and the collector shows a positive energetic balance and allows a significant energy saving in maintaining the comfort requirements or, without resorting to auxiliary heating, inside temperatures are still acceptable:

. in the cold season during the school period (October through April, from 9 a.m. to 5 p.m.), the likely temperatures - according to the simulation - would be $\geqslant$18°C in 75% of the time and $\geqslant$16°C in 95% of the time, respectively;

. under similar conditions, without the air solar collector and aiming at an air change rate of 5 l/s.pupil during the occupancy period, the corresponding values would be: temperatures equal to or higher than 18°C in 47% of the time and higher than or equal to 16°C in 78% of the time, respectively.

3.2 - Analysis of the flow by direct integration of the Navier-Stokes equations

The method described above allows only the "stack effect" to be taken into account. This effect, however, can be seriously opposed by the action of the wind. It was therefore attempted to study the collector behaviour in view of the double contribution of ventilation due to action of the wind against the façade (action that can be of suction and consequently invert the flow direction) and to the thermal draught.

The approach to the problem is then made by the direct integration of the Navier-Stokes equations (mass conservation, energy conservation and momentum conservation), the numerical method described by Patankar (4) being used.

Difficulties, however, still subsist in establishing the pressure field in the collector opening zone, due namely to its dependence on the shape of the building, the rugosity of the soil, etc., besides the countless parameters of difficult control.

This study is still in an exploratory phase, only a few simulations having been made to control the main parameters; one of these simulations is shown in Figure 5 and it is believed to translate the complexity of the problem.

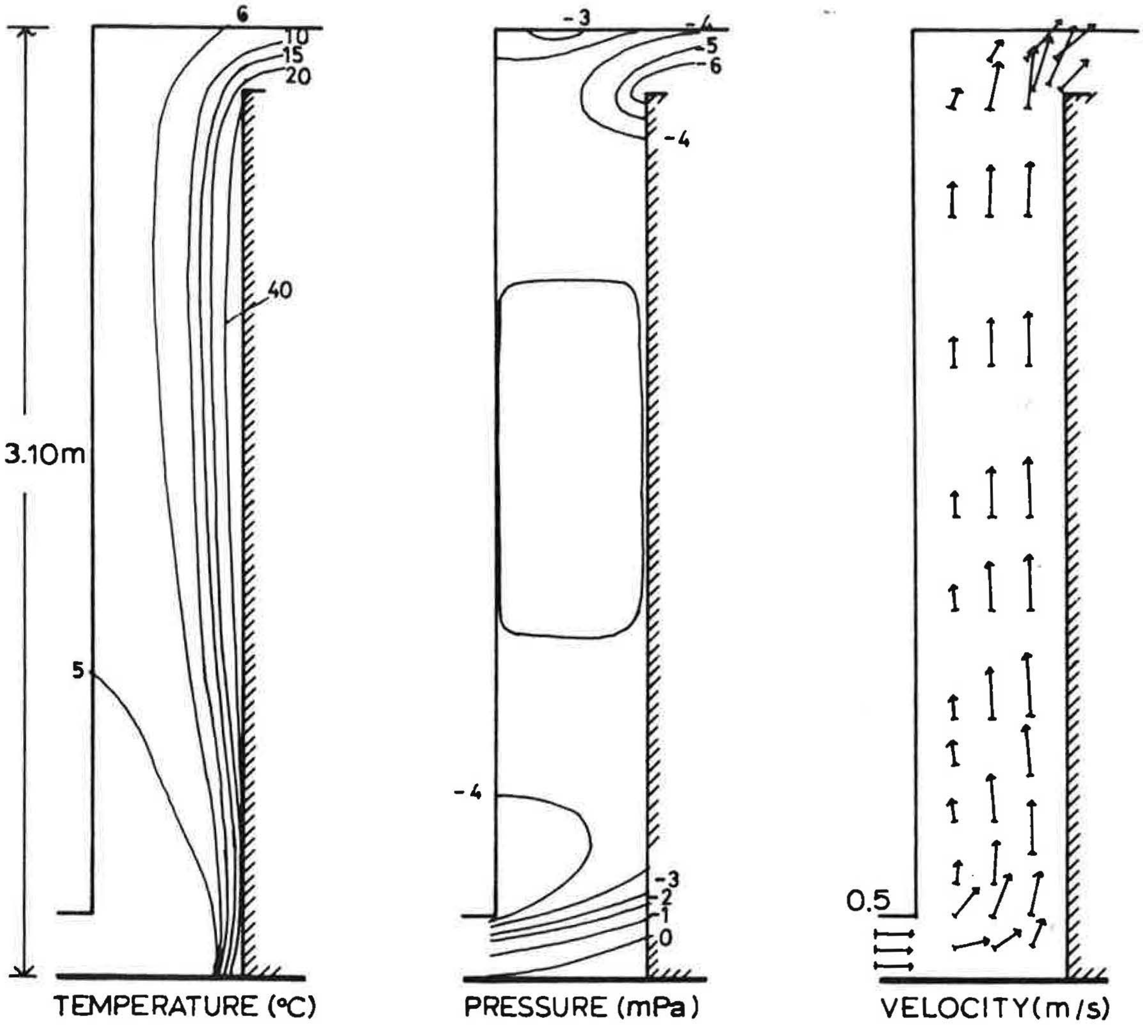

Fig. 5 - Distribution of pressures, temperature and velocity for a given situation of the simulation

3.3 - Experimental study

For the experimental study of the behaviour of this element (the solar air collector), a model with characteristics similar to those of the model proposed for the prototype school (3), which is shown in Figure 6, was built.

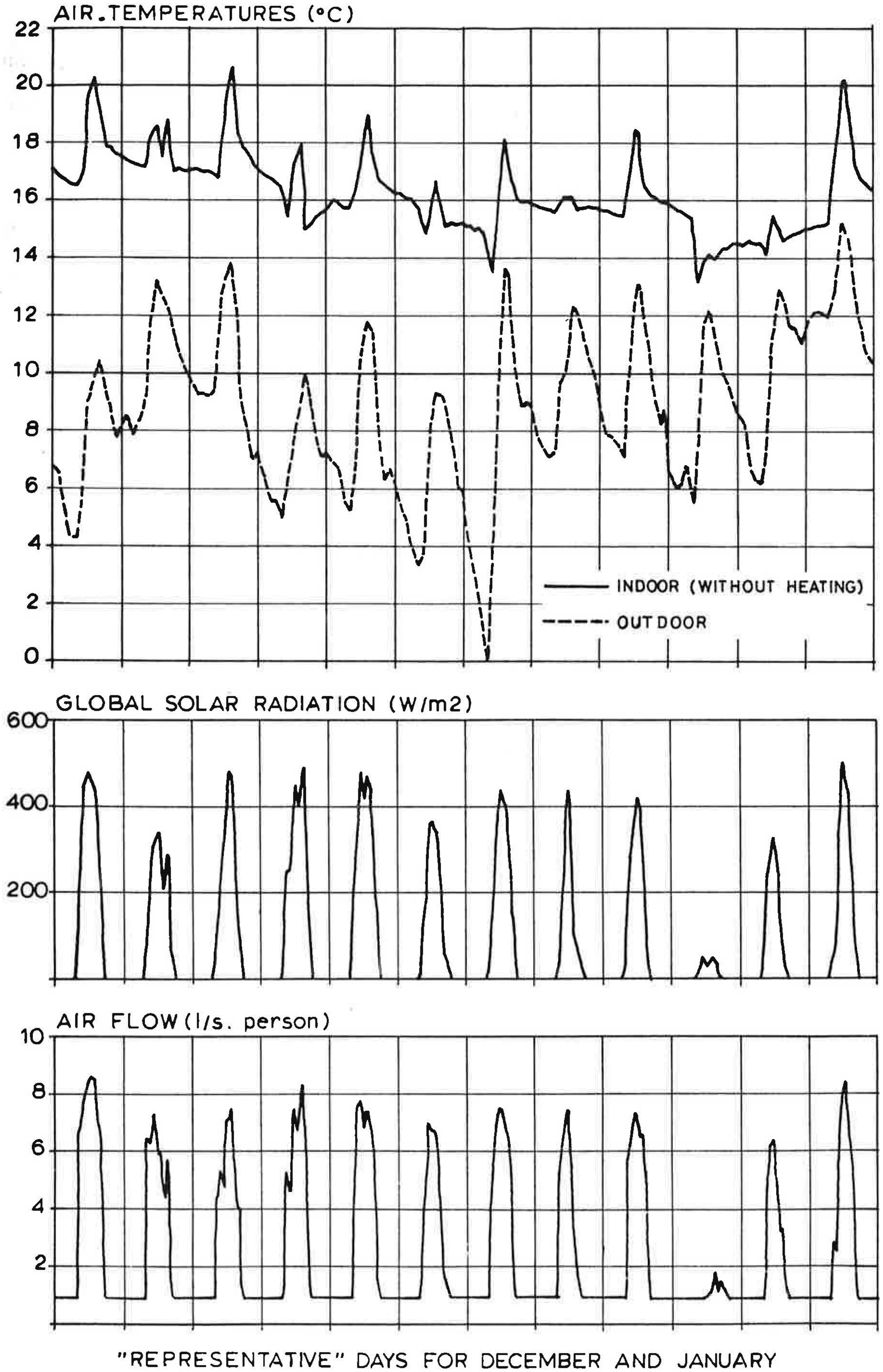

Fig. 4 - Simulation results corresponding to the two roughest monts in winter

Some months of observations were lost because of an accident suffered by the measuring equipment; consequently, the only data available at present are the data used for testing the measurement programmes.

As an example, Figure 7 shows the evolution of temperatures in two consecutive winter days as observed in the outdoor air and in the collector model (metal sheet and renovation air).

Velocities at various points of the pannel outlet were also measured with hot wire anemometers (the problem of monitoring the measurement of velocities and flows in the model is not yet properly solved) and values between 0.10 m/s and 0.90 m/s were observed, but with a strong, instantaneous variation and significant differences in the observation points. (The temperature of the collector metal sheet also shows significant differences depending on the measurement points; consequently, to consider a uniform outlet throughout the collector width, in the model, may be rather controversial).

It is believed that these results, although rudimentary, allow us to face with a certain optimism the values obtained in the simulation by resorting to simplified algorithms (the values of both air temperatures in the pannel and velocities are in agreement with the values obtained experimentally, in spite of the reservation mentioned above).

It is, however, necessary to develop the experimental analysis, which is expected to occur next winter, and not only on the model used (where the parameters referring to the pannel may be controlled), but also on the school itself where they will be built (in which the user's factor will nodoubt signify).

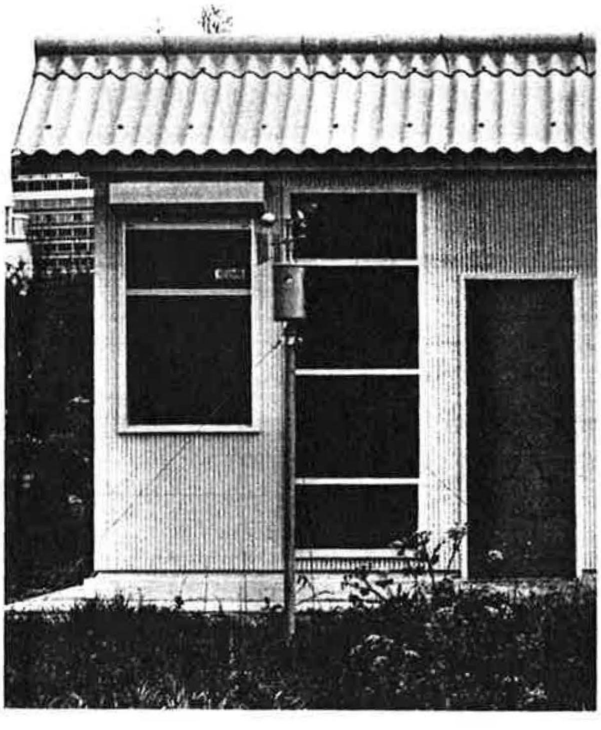

Fig.6 - General view of the experimental solar air-collector

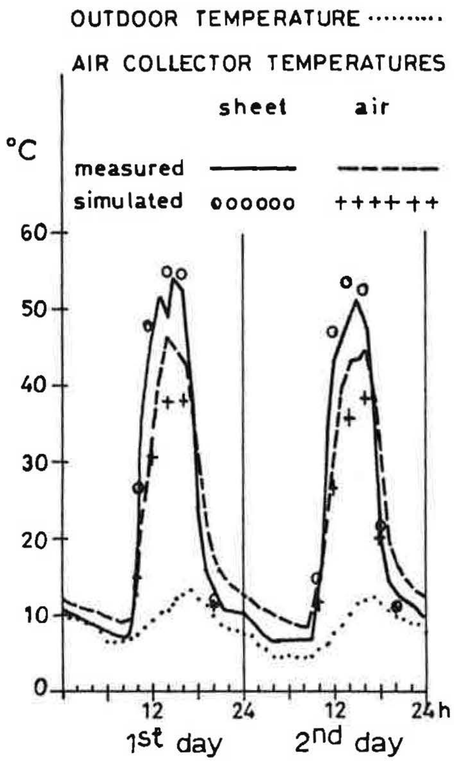

Fig. 7 - Solar air collector data examples

4. Conclusions

Based on the work presented in this paper the following may be inferred:

. air quality requirements, as per values of CO_2 lower than 0.25%, are not, as a rule, met in portuguese school buildings during wintertime;

. improving such conditions requires a significant increase of the buildings ventilation rates, which can be achieved by resorting to mechanical ventilation or to induced natural ventilation;

. because of the objections usually raised in Portugal against installations - objections being due to maintenance problems - natural ventilation will be the most suitable (ventilation) process; for this purpose, the use of solar pannels integrated in the south façade is being projected;

. based on simplified numerical simulation studies it can be inferred that the recommended air quality standards or a considerable improvement of the thermal comfort conditions are possible with significant energy savings, as compared with what is usually observed; the resulting additional costs are irrelevant and may be amortised in periods of 5 to 9 years, depending on the alternative solution and on the profitability rates;

. this solution is being the object of an experimental study on a model and, although the results obtained so far are not conclusive, they point towards the same direction as the numerical studies performed; this solution is going to be put into practice in a prototype building to be completed in August, where a careful analysis of its validity will be made in the course of next winter.

5. Aknowledgments

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