PREDICTION OF THE INDOOR AIR QUALITY TREND IN A DWELLING IN THE MEDITERRANEAN CLIMATE

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ABSTRACT

The purpose of this study was to evaluate the indoor air quality parameters in a residential dwelling using information from the field. The subject was a typical example of the modern Italian dwelling stock, built in the 1980s in a residential area in the northern part of Rome. The dwelling was constructed from pre-cast panels using industrial building techniques. The windows were steel-framed and painted. Airtightness was measured to obtain the ACH (air changes per hour) at 50 Pa pressure difference, and ELA (equivalent leakage area). Other parameters which were also measured to predict the behaviour of the dwelling during natural ventilation the influence of the urban environmental conditions. The data were used as input to simulations using the NIST multizone model CONTAM96 to predict the contaminant distribution within the dwelling during normal activities such as cooking, smoking etc. The combined use of field measurements and computer simulation produces a better evaluation of the pollutant trends than previously available, since quantities such as airtightness of windows and frames previously had to be estimated from background literature, based mainly on factory tests, which ignore quality of workmanship during construction.

INTRODUCTION

A three year research programme funded under contract by MICA (the Italian Ministry for Industry Commerce and Craftmanship) started in 1995 and is currently under discussion for extension. This programme has led to remarkable results in terms of knowledge and confidence with the environmental and energy issues relevant to indoor living spaces. The importance of these studies is highlighted by the fact that one third of the primary energy consumed in Italy is used in the domestic sector and that, until now, no extensive investigations of the Italian stock of about 30 million dwellings have been available. For instance, airtightness measurements are not yet common in the Italian dwelling stock and records of the aerodynamic and energy performance are not contractual documents among the parties involved in either the construction or use phases. The majority of the dwellings in Italy still rely on natural ventilation. Standardisation relates only to specific aspects of particular individual components.

The opportunity to use the various tools which are currently available (analysers, blower doors, computer codes etc.) synergistically to study indoor air quality (IAQ) and other related issues was of considerable interest to ENEA, particularly in providing satisfactorily answers to interested organisations (industries, public bodies, professionals) which now require more extensive knowledge and capability than in the past.

FIELD MEASUREMENTS

Equipment

Airtightness was measured using a Minneapolis Blower Door mod-3 [1] installed in the entrance doorway of the dwelling under test. The blower door consists of four components:

- blower door fan
- door frame (aluminium model)
- Data Acquisition Box (DAB) - 8 channel data logger plus portable computer in which APT (Automated Performance Testing System) ver 1.0 software was installed
- accessory case.

The blower door fan consists of a precision-moulded fan housing with a 550W AC motor capable of moving up to 10,900 m^3/h of air. Air flow through the fan is determined by measuring the pressure difference created by the air flowing through the fan inlet. The fan meets the flow calibration specifications of both CGSB Standard 149.10-M86 and ASTM Standard E779-87. The fan may be used to generate flow either into or out of the house resulting respectively in an over- or under-pressure respectively relative to the ambient air. This pressure difference causes a flow of air through any openings (cracks, holes etc.) in the external envelope. This flow is referred to as infiltration if the flow is from outside and exfiltration if it is to outside.

The doorframe and the associated nylon panel are used to seal the fan into an exterior doorway. The arrangement is adjustable to fit any size opening. Final adjustment and sealing are achieved by means of cam levers on the side of the assembly.

The DAB contains 8 pressure channels, along with 8 analogue voltage input channels. Each pressure channel consists of a calibrated differential pressure transducer connected to a pair of 1/8" OD taps. Each pressure channel is switchable between two ranges, ± 400 and ± 1000, with resolutions of 0.1 to 0.5 Pascals respectively, and has a built-in auto-zero capability. When operating in the automated airtightness testing mode, two channels are used. Channel P1 is used to measure the pressure difference across the building envelope, while channel P2 is used to measure flow through the fan.

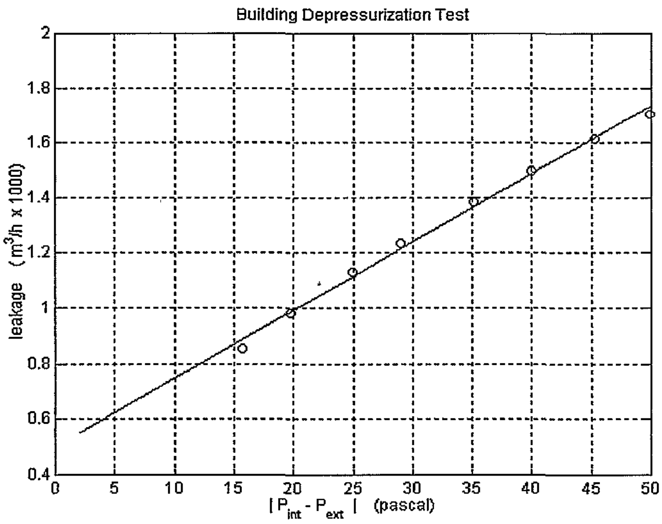
RESULTS

Since greater confidence was placed in depressurisation than in pressurisation or 'cruise' testing, it was decided to start with this first and reserve other approaches for a later stage. Sunny days having negligible wind velocities were chosen. To minimise pressure fluctuations and reading uncertainties, openings for hoods were sealed.

Multi-point depressurisation tests were undertaken, as shown in Figure 1. The supplied software installed in the computer controlling the blower door automatically produces the best fit line and the coefficients of the 'building leakage curve' which can be used to estimate the leakage of the building at any pressure. The building leakage curve is defined by the coefficient *c* and exponent *n* in the following power law equation [2,3]:

$$Q = c(\Delta p)^n \qquad (1)$$

where Δp is the pressure difference between the inside and outside of the building. From Figure 1, it was found $c = 0.00456$ $m^3/(s.Pa^n)$, $n = 0.597$ (dimensionless).



Date: 22 – APR - 98
Address:
District Nuovo Salario
City: Rome - ITALY
Volume: 245.9 m^3
Floor: 90.8 m^2
Surface: 101.7 m^2

	ΔP (Pascal)	FLOW (m3/h)	F LOW (l/sec)
1	50	1703	473
2	45	1617	449
3	40	1500	417
4	35	1387	385
5	29	1236	343
6	25	1132	315
7	20	982	273
8	16	855	238

Figure 1. Results of depressurisation test

Other important quantities were provided by the output of the code, i.e.:

Equivalent Leakage Area (EqLA) = 723 cm^2 @ 10 Pa
Effective Leakage Area (ELA) = 406 cm^2 @ 4 Pa

Where: EqLA is defined (Canadian National Research Council) as the area of a sharp-edged orifice that would allow the same air flow rate as the building envelope at a pressure difference of 10 Pa,

ELA is defined (Lawrence Berkeley Laboratory, USA) as the area of a special nozzle-shaped hole (similar to the inlet of the blower door fan) that would allow the same airflow rate as the building envelope at a pressure difference of 4 Pa.

By means of these measures, and using equation (1), the characteristics of the leakage of the building were assessed. It should be noted that no cracks or other discontinuities in the envelope of the dwelling were recorded.

EVALUATION OF INDOOR AIR QUALITY

Evaluation of the indoor air quality IAQ was considered principally as the study of the variation of the concentrations of two to three important pollutants. To calculate air flows and pollutant distribution, CONTAM 96 was used [4]. This code uses a multi-zone network approach to airflow analysis. The building is treated as a collection of zones connected by airflow paths. These zones may represent groups of rooms, individual rooms, or even a part of a room, as well as shafts and components of the building air handling system. Within each zone, the temperature and contaminant concentration is considered to be uniform. The airflow paths include doorways, small cracks in the building envelope, fans and windows and a simple model of the air handling system (AHU).

The main problems to be solved to perform the simulations were:

- identification and emission rates of pollutant sources
- airflow path modelling
- time schedule for occupancy, operation of ventilation system.

The use of computational fluid dynamic (CFD) codes such PHOENICS was considered. However, this approach requires complex models and is in general used to investigate specific situations in detail. For engineering and research purposes, multizone models are particularly useful for their immediate and impressive outputs and, also, because they allow groups of simulations to be undertaken in a reasonable period of time.

Identification and emission rate of the sources

These values were obtained from the literature [5]. Emissions from tobacco smoking were initially not considered. Only emissions from cooking activities were studied to obtain confidence with the whole procedure. The following values were used, assuming a gas cooker:

Rates: CO_2 = 51 000 μg/kJ, CO = 65 μg/kJ, NO_2 = 10 μg/kJ
Times: 06:40 to 07:10; 11:30 to 13:00; 19:30 to 20:00.

Airflow path modelling

A critical issue was to identify the best way to enter the field results in the model. Since the dwelling had windows all in the same condition, from the same manufacturer and installed at the same time, the airflow rates at the various pressures were proportionally allocated according to the glazed area. This is not an unknown procedure, since UNI (the Italian Standardisation Committee) gives the values of window airtightness in $m^3/h/m^2$ @ 100 Pa [6]. Thus, for each window and the entrance door (named in the code as 'flowpaths'), flowrate values at two different outdoor-indoor pressure differences, 20Pa and 45Pa, were attributed using the 'building leakage curve' obtained from the field measurements. The entrance door provides an additional leakage of $0.073\Delta p^{0.6}$ [7]. A constant flow 100 l/s exhaust fan installed in the kitchen canopy operating from 11.30-13.00 and 19.30-20.00 was also simulated. The code requires a meteorological data file. Readings from the weather station at Urbe Airport, Rome situated less that 1km due west of the test site, were used.

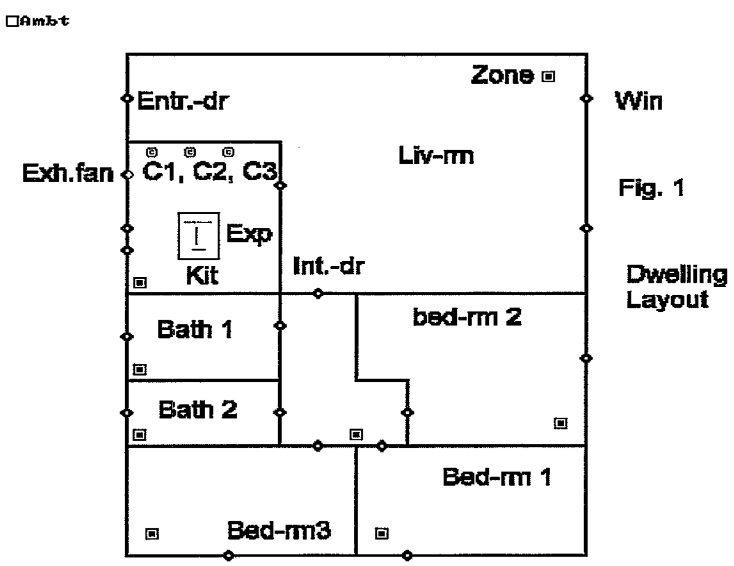


Figure 2 Schematic layout of dwelling for computational purposes

Occupancy and ventilation system schedules

The household includes three people, of which two are in the living room during the preparation of the meals while the housekeeper is in the kitchen. These parameters are important to study the exposition of the occupants to the concentration of the pollutants varying during the time. Figure 2 shows the layout in schematic form as set out on the 'sketchpad' appearing on the screen of the computer.

PREDICTED EXPOSURE

Figure 3 shows the predicted concentration variation for a specific day (22 April 1998) and shows that the maximum daily potential dose for a 65 kg adult female housekeeper inhaling 1.6 m^3/h air, is for CO_2 - 7.523 g; for NO_2 - 1.505 mg; and for CO - 9.78 mg.

DISCUSSION

- The study and identification of the trends of the pollutants in the residential sector is much harder than in offices or other cases where occupancy pattern is much better defined.

- The contribution to the leakage due to the entrance door had to be estimated from literature. A cross test might be arranged placing the blower door in another position, but no other openings were available in the current case.

- IAQ parameters (i.e. concentrations and exposures) were significantly below the risk thresholds provided proper ventilation is provided [5].

- The field assessment of critical parameters like the 'building leakage curve' can add confidence and provide the starting point for more complete analysis to be undertaken through computer simulations, allowing different environmental situations to be considered.

- A increased knowledge of the characteristics and emission behaviour of appliances and building materials should be developed.

- The interaction of between airborne pollutants, currently considered separately, needs further investigation.

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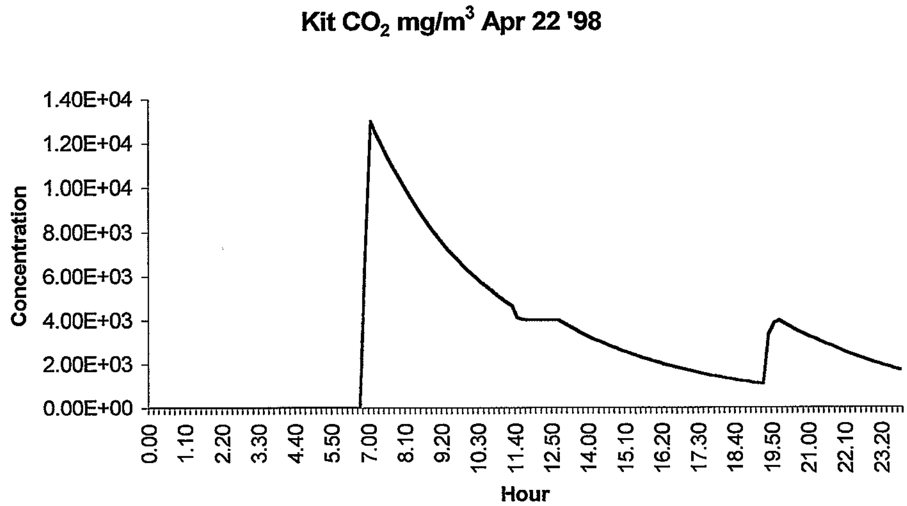

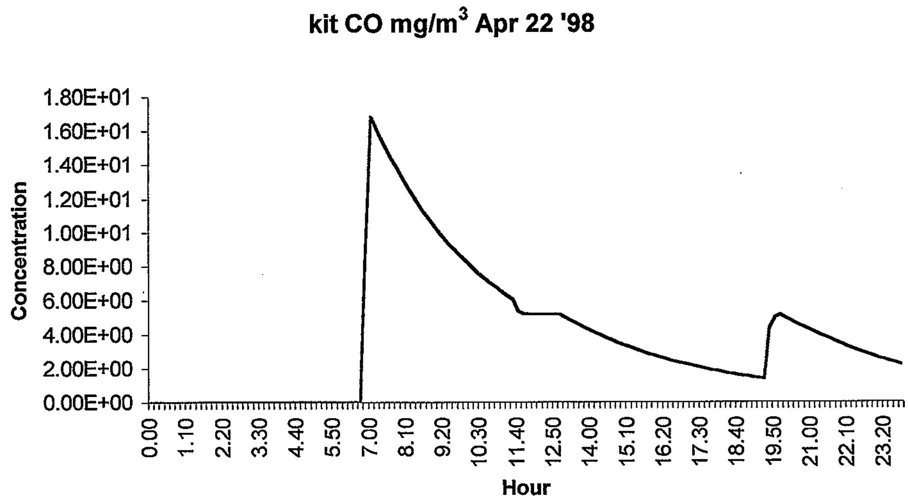

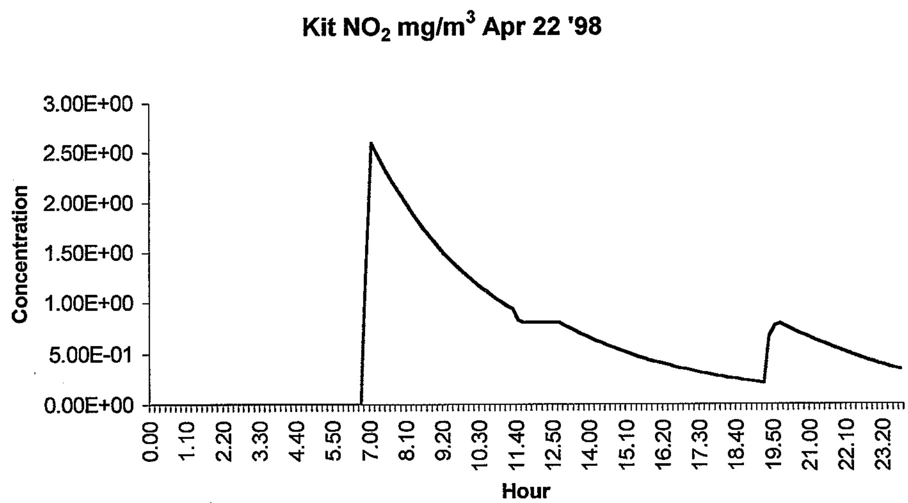

Figure 3. 24-hour variation in concentration (mg/m^3) of CO_2, CO and NO_2 in the dwelling kitchen, predicted using CONTAM 96