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MINIMUM VENTILATION RATES TO PREVENT CONDENSATION: A CASE STUDY

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SYNOPSIS

Moisture and mould in buildings have become fairly common problems in Italy, particularly since regulations aimed at energy conservation have been enforced in the seventies.

Results of a case study conducted within IEA Annex XIV are presented in this paper. Two flats belonging to the same building (one with and the other without moisture problems) have been monitored during the winter 1987-88. Indoor temperature and air humidity, wall surface temperature and weather parameters were recorded for several weeks using two automatic data loggers. Airchange rates were measured using the tracer gas technique.

Processing of the experimental data indicates that the moisture problems in one of the flats are probably due to insufficient airchange rates in a building which presents some noticeable thermal bridges. Differences between the two flats can be attributed primarily to occupants' behaviour (airing habits, retrofits performed on the windows, etc.) and, to a lesser extent, to orientation.

The paper also shows that a good insight on condensation phenomena can be derived from fairly straightforward simplified analyses of temperature and humidity data.

The importance of incorporating guidelines on thermal bridge correction and ventilation strategies into building codes is pointed out.

LIST OF SYMBOLS

D = Indoor water vapour production (kg/h)
h_i = Inside surface heat transfer coefficient (W/m^2K)
N = Airchange rate (1/h)
RH_i = Indoor air relative humidity (%)
RH_e = Outdoor air relative humidity (%)
T_i = Indoor air temperature (°C)
T_e = Outdoor air temperature (°C)
T_s = Inside wall surface temperature (°C)
U = Thermal transmittance of the wall (W/m^2K)
X_i = Indoor humidity ratio (g/kg)
X_e = Outdoor humidity ratio (g/kg)
τ = Temperature factor of the wall (-)

1. INTRODUCTION

During the second half of the past decade, compulsory regulations were introduced in Italy, aimed at promoting energy conservation with regards to space heating, primarily in residential buildings [1].

At that time, the dependence of the Italian energy market on imported oil was extremely high. Oil, in fact, represented almost two thirds of the total primary energy use of the country. Furthermore, a significant percentage of oil consumption was due to space heating, which was the primary consumer within the building sector (accounting, as a whole, for about 30% of global consumption).

Limitation of heating energy consumption, in order to reduce dependence on oil imports, was therefore a high priority goal for the legislator.

The code for energy conservation in space heating, which came into effect in 1977, is based on the following approach. For any new building, as well as for buildings undergoing major renovation work, a maximum permissible *heat loss coefficient* is calculated. Such coefficient is the sum of two terms, one related to envelope thermal losses, the other to air infiltration and ventilation.

In practice, the code poses a limit on the installed power of the heating plant, by setting requirements concerning minimum thermal insulation levels and ventilation strategies. With respect to ventilation, the code makes a distinction between naturally- and mechanically-ventilated buildings:

- For mechanically-ventilated buildings, airchange rates are specified by the designer, but heat recovery is required if the fresh air flow rate, or the number of annual hours of operation of the ventilation system, exceed a threshold value depending on local climate.

- For naturally-ventilated buildings, the code states that the air infiltration heating load must be computed assuming an ACH value which, for residential buildings, is conventionally taken equal to 0.5.

The main limit of such regulation is that no guidelines are specified concerning either envelope airtightness, or provision for mechanical ventilation. Another limit is that minimum insulation levels are specified, but no indication is given on how to avoid thermal bridges.

Changes in construction practice which took place in response to these regulations have often had negative effects on the quality of the internal environment, particularly with respect to condensation and mould growth problems. The occurrence of such problems can be attributed primarily to incorrect thermal insulation solutions, coupled to a lack of ventilation.

In traditional, pre-energy crisis buildings, moisture was usually not a problem because buildings were quite leaky (windows had no weatherstripping) and walls were poorly insulated. Infiltration rates were normally sufficient to prevent condensation, even in the most critical areas of Northern Italy, where winters are fairly cold, humid, and almost windless.

New constructions, on the contrary, were based on different design criteria. The adoption of a national code on air permeability rating of windows [2] allowed the designers to select the appropriate class of window according to building height and windiness of the area. Airtight windows became popular because designers feared that otherwise excessive ventilation heat loads would cause boiler undersizing; however, the absence of controllable air inlets and of effective mechanical ventilation systems was often cause of insufficient airchange rates.

Insulation of walls and roofs was imposed by law, but lack of experience was often the origin of serious thermal bridge problems, particularly in buildings with prefabricated or site-constructed concrete bearing walls.

The final consequence was that moisture problems became very common in new residential buildings, such as the one which is the object of this case study.

2. OBJECT AND GOAL OF THE CASE STUDY

Within the framework of IEA Annex XIV "*Condensation and Energy*", an experimental survey was conducted on a ten-storey, tower-shaped block of flats, owned by Istituto Autonomo Case Popolari (IACP) of Turin [3].

The building, which was constructed in the seventies, is a good example of social housing of the period. Even if its construction is traditional (i.e.: concrete structure, uninsulated masonry cavity walls, metal frame single-glazed windows), moisture and mould growth problems of varying intensity are evident in some of the dwellings, as a consequence of different orientation and occupants' habits.

The floor plan of the building is shown in Fig. 1. In the measurement campaign, attention was concentrated on two flats located at the fifth floor. The two flats are identical in size, but have opposite orientations and a totally different situation with respect to moisture problems: the flat oriented towards NE/NW, which will be identified as "IACP One", showed serious moisture and mould related decay, while the flat oriented towards SE/SW ("IACP Two") revealed no problems at all.
All flats in the building have individual gas-fired boilers for space heating and service hot water; none has mechanical ventilation. Windows weatherstripping and insulation of the rolling shutter box was performed by the inhabitants of IACP One.

Primary aim of the case study was to get a better understanding of moisture-related problems which are fairly common in recently constructed low-cost housing. In particular, the following issues were addressed:

- to identify and quantify the main causes of moisture and mould problems in the North oriented "IACP One" flat;
- to understand why two flats, almost identical in size and occupation pattern, are in such different condition;
- to evaluate the reliability of the experimental procedure.

3. EXPERIMENTAL PROCEDURE

Experimental data were collected using two programmable multi-channel data loggers; the first unit was installed in the flat being monitored, the second was located on the roof of a nearby three-storey building to gather weather data. The following quantities were measured [4]:

- indoor air temperature in each room
- indoor air relative humidity in each room
- inside wall surface temperature at selected locations
- outdoor dry-bulb temperature
- outdoor air relative humidity
- global horizontal solar radiation flux
- wind speed and direction.

Data were collected every two minutes; time trends and hourly average values were stored on magnetic tape for subsequent processing. Altogether, 55 days of measurements were performed for IACP One, and 10 days for IACP Two during the period November 1987 to February 1988.

Two tracer gas measurements of airchange rate were performed in IACP One, using the decay technique and N_2O as the tracer. Values of 0.32 and 0.47 ach were obtained. Such values are consistent with theoretical estimates and are comparable with other experimental data obtained in similar buildings in the Turin area.

A mycological analysis was also performed, in order to characterise the type of mould formation that occured in the dwelling [5].

4. DATA ANALYSIS

Condensation of moisture and mould development in buildings are caused by excessive air humidity levels in the vicinity of the wall surface. In fact, mycological studies quoted in the literature [6] have revealed that spore germination and growth is likely to develop when relative humidity exceeds the values of 70% and 80% respectively.

High relative humidity at the wall surface, in turns, is due to the combined effect of high indoor air moisture content and low surface temperatures: the former phenomenon is normally due to high indoor vapour production or infiltration of warm-moist air, coupled to insufficient ventilation with dry outdoor air, while the latter is usually caused by localised cold spots in the building structure (thermal bridges).

4.1 Air moisture content

Starting from the measured values of air temperature, Ti, relative humidity, RHi, and wall surface temperature, Ts, the time trend of relative humidity at the wall surface, RHs, was computed assuming that the partial pressure of water vapour in the air is uniform within the room. Such hypothesis is reasonable within the approximation of the study [7]. A sample of RHs trend is shown in Fig. 2.

Figure 3 shows the frequency of occurrence of RHs exceeding the threshold values of 70% and 80%, or reaching 100%, for the various rooms of IACP One; on the contrary, the 70% threshold was never exceeded in IACP Two.

In order to understand how the humidity values measured in IACP One can be rated, a comparison was made with a set of experimental data collected in Belgium. In the graph of Fig. 4, the difference between indoor and outdoor humidity ratio (Xi-Xe) is plotted versus outdoor temperature Te: the data points indicate the weekly average values measured in each room of IACP One, while the solid line represents the 95th percentile of weekly average data according to the Belgian survey [8]. This result indicates that the situation in IACP One is indeed quite exceptional.

4.2 Surface temperatures

The value of indoor surface temperature of a given wall, Ts, is linked to air temperature outdoors, Te, and indoors, Ti, by a parameter called the "temperature factor" of the surface τ [7]:

$$\tau = \frac{Ts - Te}{Ti - Te} \qquad (1)$$

For one-dimensional, steady-state conditions, τ would be a constant given by the equation:

$$\tau = 1 - U/hi \qquad (2)$$

where U is the thermal transmittance of the wall and hi is the indoor surface heat transfer coefficient.

In reality, τ varies in space and time for a number of reasons, such as the presence of two- or three- dimensional heat fluxes in the building structure, or time varying conduction, convection and radiation heat transfer within the wall and at the wall boundaries. A sample of time trend of τ is shown in Fig. 5.

Nevertheless, if values averaged over a sufficiently long period of temperature difference (Ts - Te) are plotted against (Ti - Te), a linear correlation between the data points can still be detected, as indicated in Fig. 6. Such result is very useful beacause the slope of the regression line gives a estimate of the mean value of the temperature factor at a given point of the wall surface.

For IACP One, values on the order of 0.7 (the minimum suggested value according to Belgian recommendations [8]) were found for the bathroom and one of the bedrooms.

4.3 Airchange rates

The indoor humidity ratio, X_i, can be related to outdoor humidity ratio, X_e, indoor vapour production, D, and airchange rate, N, by writing a steady-state water vapour mass balance equation for the room. The resulting expression can be more or less complicated, depending on whether condensation on cold surfaces occurs [8].

In our case, time trends of X_i and X_e are known, while airchange rates can be estimated on the basis of the tracer gas measurements. Moisture production is virtually impossible to measure, but can be derived from the mass balance equations if X_i, X_e and N are known; alternatively, D can be estimated on the basis of literature values.

Assuming a constant airchange rate of 0.4 ach (the average of the two experimental values), the maximum vapour production rate for IACP One was estimated on the order of 1 kg/h, a reasonable value for the type of occupancy of the flat.

As a further step, the minimum ventilation rate necessary to prevent condensation (i.e., to keep RH at the wall surface below 95%) was computed for each hour of the survey. Results for one bedroom of IACP One are shown in Fig. 7; values exceeding 0.4 ach (corresponding to 83.5 m^3, i.e. the assumed value of airchange rate) only are shown in the graph.

These results indicate that for about 30% of the time of the survey, the airchange rate was probably insufficient to prevent condensation in that specific room, thus explaining the occurrence of serious moisture and mould problems.

5. CONCLUSIONS

Some general remarks can be made as a final comment to the case study.

Firstly, the methodology adopted in the case study, based on continuous field measurements of temperatures and relative humidities, provided reasonable results within the accuracy limits of the model describing the physics of the problem.

Secondly, a building like the one that was examined in the case study has a limited "safety margin" with respect to condensation and mould growth, partly because of two specific reasons: the external envelope has a large extension compared to the volume, because of building shape (square plan) and height, and the number of occupants is high (six) in relation to floor area (100 m^2).

In the presence of thermal bridges, which tend to reduce the temperature ratio of the external walls, fairly high airchange rates (of the order of 0.7 ach) are necessary to avoid the risk of condensation. Such an airchange rate cannot be guaranteed by natural ventilation in a climate characterised by very low wind speed, and would be unacceptable in terms of heat losses. Mechanical ventilation, possibly with humidity-actuated regulation of outdoor air flow rate, would probably solve the problem.

The fact that the occupants of IACP One have retrofitted the windows indicates that comfort conditions in the flat were probably unsatisfactory. This may not have been the case in IACP Two, which has a better orientation (SE/SW instead of NE/NW). Care should therefore be taken in order to achieve a draught-free outdoor air inlet.

These comments suggest that more precise guidelines with respect to thermal bridges correction and ventilation requirements should be specified in the building codes, in order to reconcile the apparently conflicting goals of achieving comfort and acceptable indoor air quality in an energy-wise manner.

REFERENCES

1. Legge 30-04-76
   "Norme per il contenimento dei consumi energetici per usi termici negli edifici".

2. Norma UNI 7979
   "Edilizia - Serramenti esterni verticali - Classificazione in base alla permeabilità all'aria, tenuta all'acqua e resistenza al vento".

3. C. Lombardi et al.
   "A case study: IACP Torino"
   Report n. PT-DE-FT 139, Dipartimento di Energetica del Politecnico di Torino, 1988.

4. Aghemo, C. and Lombardi, C.
   "Condensation and mold: a case study"
   Proc. ASHRAE-DOE-BTECC Conference Thermal Performance of Exterior Envelopes of Buildings IV, Orlando (Florida), December 1989.

5. Sampò, S. and Luppi Mosca, A.M.
   "Fungi from the walls of a flat in Turin"
   Allionia 28, 1987/88, pp 175-184.

6. Magan, H. and Lacey, I.
   "Effect of temperature abd RH on water relations of field and storage fungi"
   Trans. British Mycological Society *82*, pp71-78.

7. Hens, H.
   "Annex XIV - Condensation and Energy"
   Proc. 10th AIVC Conference, Espoo (Finland), September 1989.

8. Centre Scientifique et Technique de la Construction
"Problèmes d'humidité dans les bâtiments"
Note d'information technique 153, 1984.

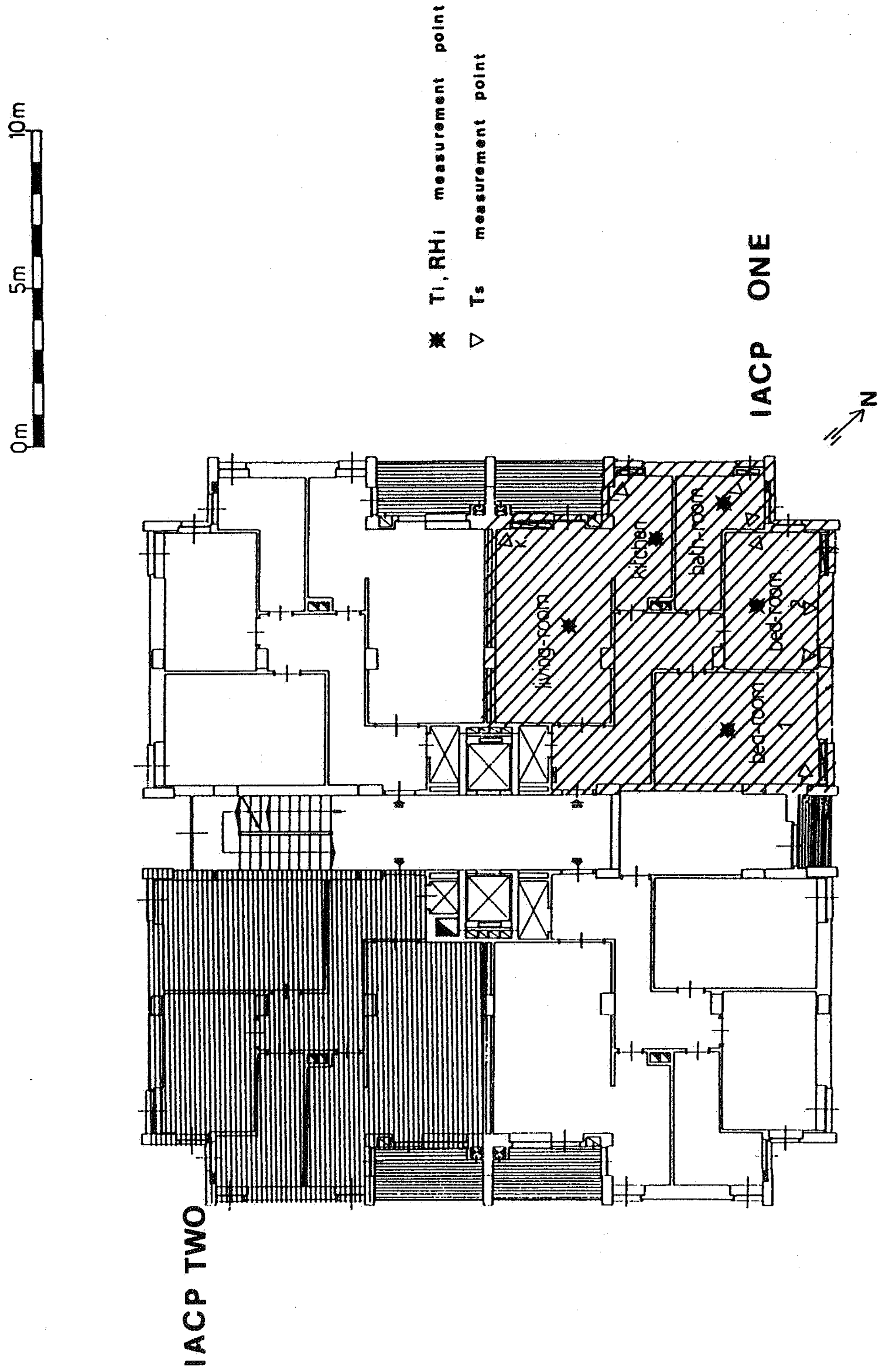


Fig. 1 - Floor plan of the building

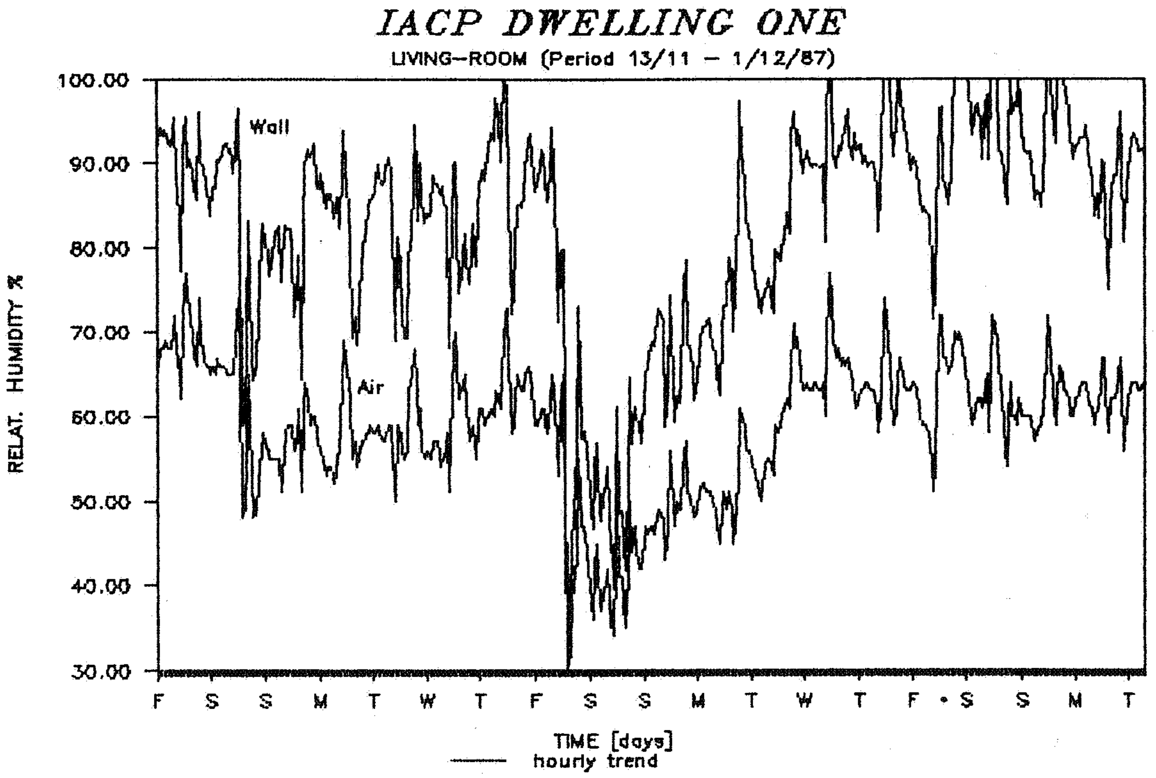


Fig. 2 - Relative humidity (RH) trends in indoor air and at the wall surface.

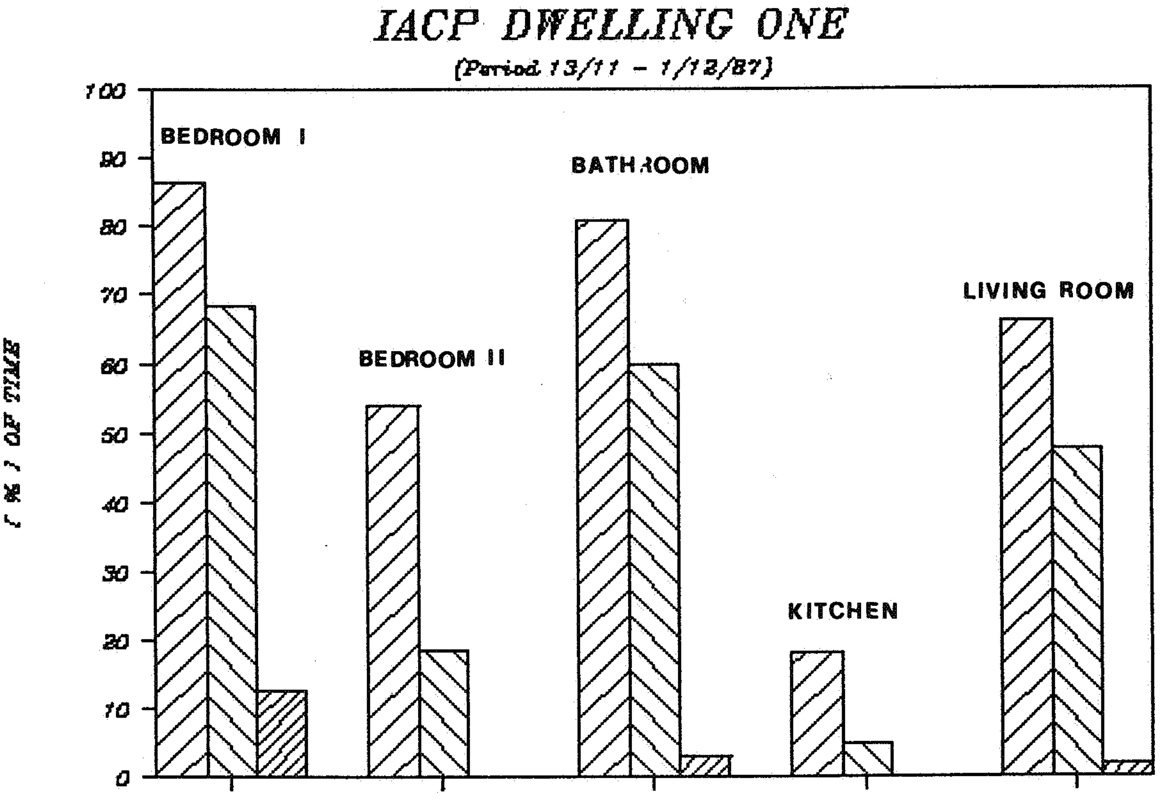


Fig. 3 - Frequency of RH exceeding the threshold values (70%, 80%) or equalling 100% in IACP One.

▨ RHs > 70 % ▨ RHs > 80 % ▨ RHs = 100 %

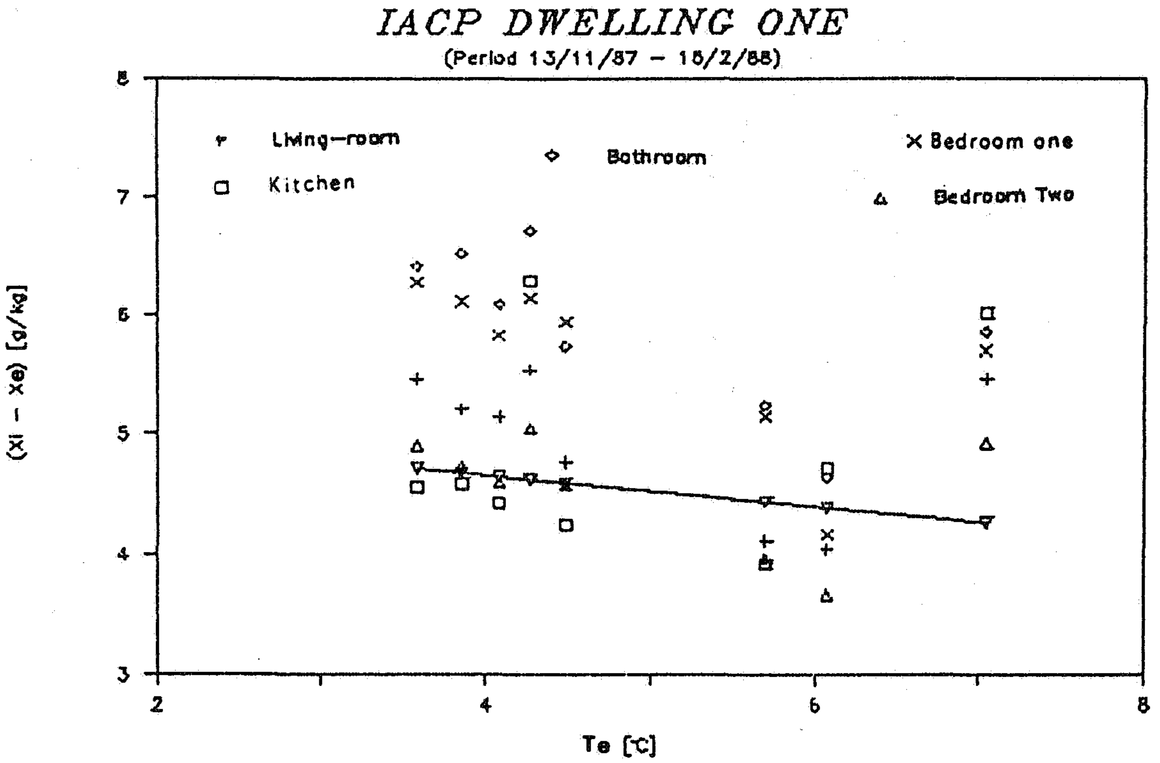
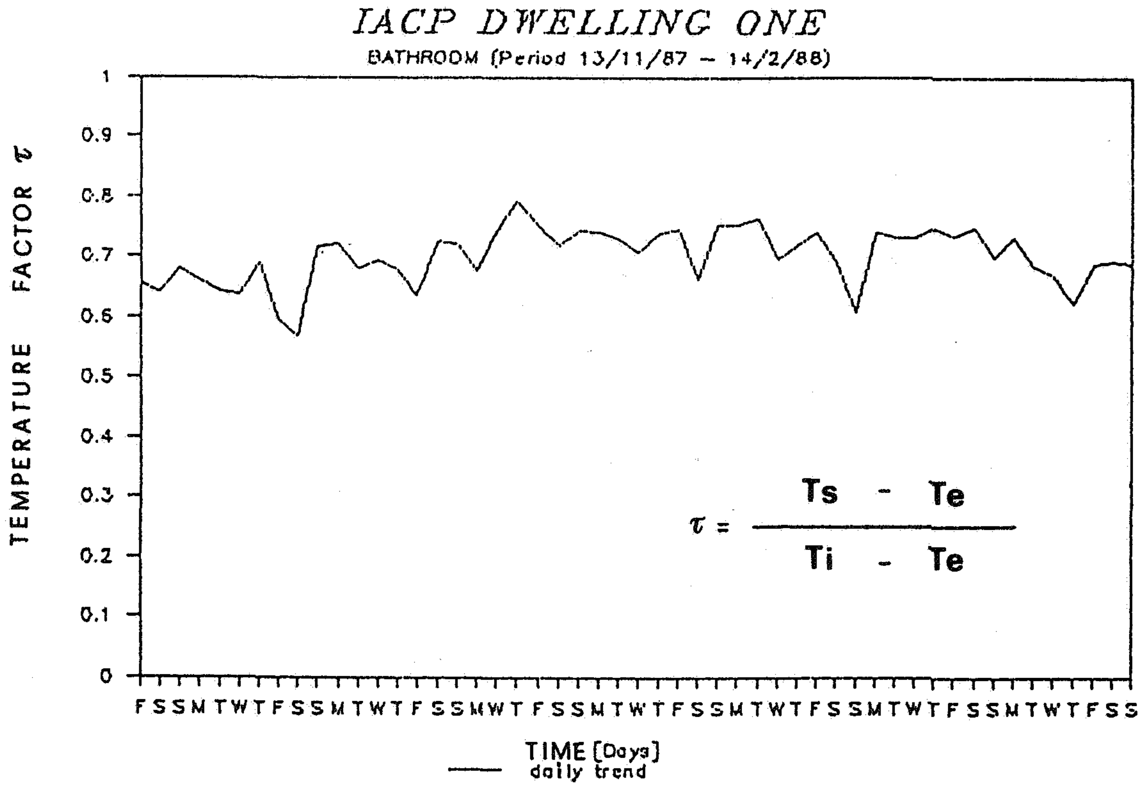


Fig. 4 - Indoor - outdoor humidity ratio vs. outdoor temp.
Comparison of experimental values with statistical data collected in Belgium (solid line indicates the 95th percentile of weekly average data in Belgium).



$$\tau = \frac{Ts - Te}{Ti - Te}$$

Fig. 5 - Daily average values of wall temperature ratio .

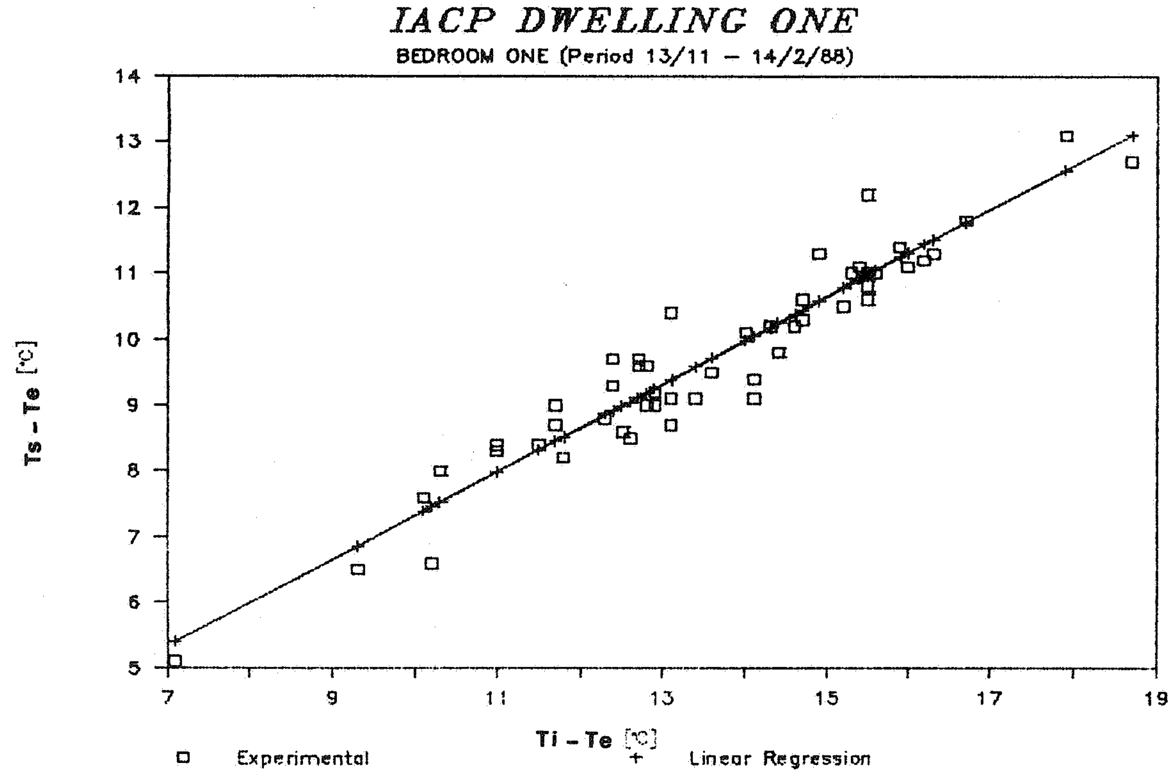


Fig. 6 - Linear regression between daily average values of (T_s - T_e) and (T_i - T_e).

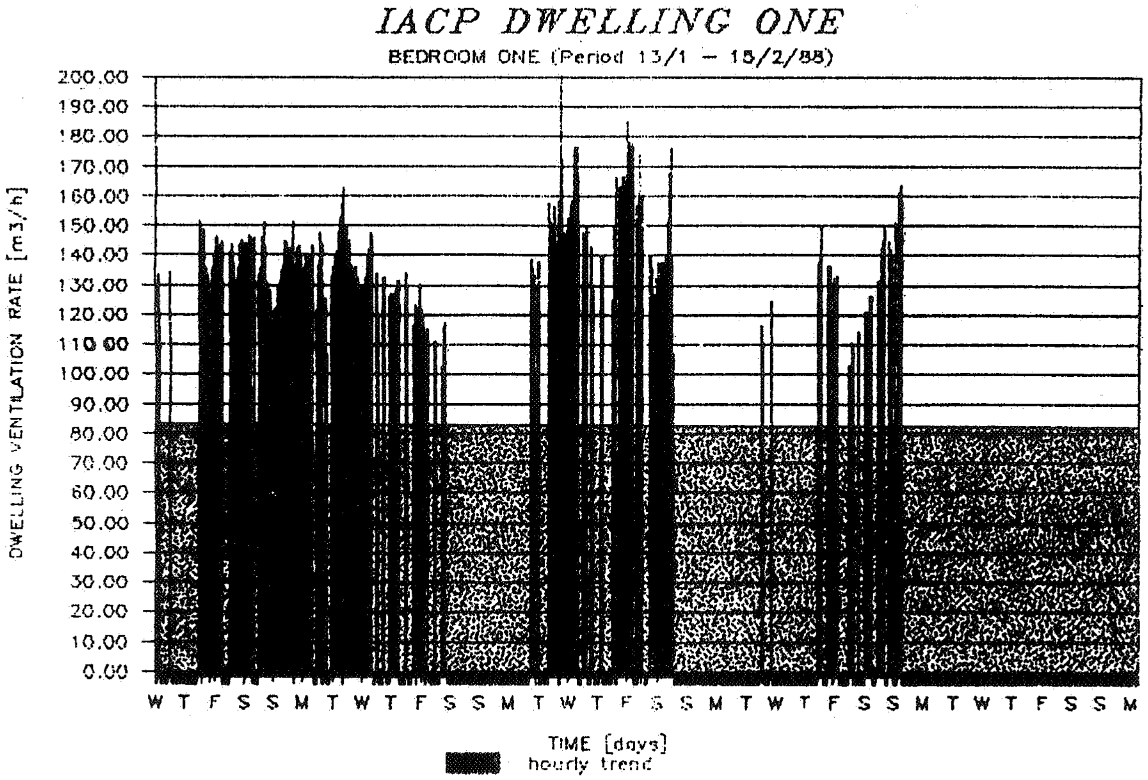


Fig. 7 - Minimum airchange rate to prevent condensation.