Setting up a database of indoor climate measurements in recently built Belgian dwellings

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ABSTRACT

One of the major sources of problems in dwellings -if not the main source- is moisture, especially due to surface and interstitial condensation on walls and roofs. For this reason, it seems important to evaluate the current standardisation and reference documents dealing with moisture and eventually to develop new assessment methods. This is the goal of the Belgian project "Moisture problems in roofs", carried out by BBRI, KUL, RUG and W&K. The first step is to collect a large number of indoor climate measurements in recently built dwellings built.

A monitoring program is currently carried out. Temperatures and relative humidity levels are measured every 10 minutes in 5 rooms (as well as outside) of 41 dwellings, during several months. CO_2 is monitored in 3 dwellings, in the same rooms and at the same frequency. Pressure differences across the roof are measured in 1 dwelling, at a frequency of 1 measurement every minute. All these collected data are gathered in a database that is presented in this paper. It is intended to make this database available to the scientific community.

KEYWORDS

Indoor climate, dwellings, database, temperature, moisture, humidity.

INTRODUCTION

One of the major sources of problems usually met in Belgian dwellings -if not the main source- is moisture, especially due to surface and interstitial condensation in walls and roofs. The existing standards and reference documents related to moisture in dwellings are mainly based on researches dating from 1974-1980. In the meanwhile, construction techniques and standardisation/regulation have changed a lot. Firstly, most dwellings were not yet properly insulated at that time. Secondly, dwellings were not yet equipped with any kind of ventilation systems. Thirdly, buildings usually were much less airtight; especially the air tightness of window and door joineries has been improved since the 80's. Consequently, dwellings became more energy efficient and more comfortable. The indoor climate is much better controlled than before when ventilation systems are used. On basis of these considerations, it seems necessary to evaluate if the reference documents related to moisture in roofs are still relevant and, if not, to develop additional evaluation methods.

This is the objective of the project "Moisture problems in roofs: impact of the present boundary conditions and construction techniques in Belgium", carried out by the Belgian Building Research Institute (BBRI), the Katholieke Universiteit Leuven (KUL), the Ghent University (RUG) and the Hogeschool voor Wetenschap & Kunst (High School for Science

& Art – W&K), and funded by the Belgian Government. In order to achieve this goal, it is necessary to collect data about the actual indoor climate in dwellings built since 1980; this is one of the project tasks. This paper presents the monitoring that has been set up, the database and some preliminary results.

SETTING UP A DATABASE OF INDOOR CLIMATE IN RECENT DWELLINGS

In order to collect a large number of data, 41 dwellings have been selected all over Belgium. Attention was paid in order to select various types of dwellings. The dwelling stock consists of 19 social houses, 18 single family houses of moderate size and 3 houses with a swimming pool. Other characteristics that were taken into account during the selection are the presence of a ventilation system and the type of structure (heavy versus lightweight constructions).

Until now, measurements are available for 28 dwellings, for periods varying from about 6 months up to 24 months. Measurements will go on until the expected end of the project (April 2005).

In each dwelling, temperature and relative humidity are measured every 10 minutes, at six different locations: outside, in the living room, in two sleeping rooms, in the kitchen and in the bathroom. The measurements are done with HOBO® H8 Pro-dataloggers. The accuracy of these dataloggers is ± 0.2 °C (at 21°C) and ± 3% RH (at 25°C).

Several parameters are calculated from the measured values (formulas are given at the end of the paper):

- for each location: the saturated vapour pressure p_{sat} and the vapour pressure p_v,
- for each indoor location: the indoor/outdoor vapour pressure difference, the critical temperature factor $f_{Rsi,crit}$ (which is a temperature factor with the dew point temperature taken as the indoor surface temperature) and the indoor surface temperature θ_{si} corresponding to a temperature factor f_{Rsi} equal to 0.7,
- and average values for the building.

The database contains therefore 46 parameters by dwelling, for each 10 minutes interval.

This database would not be complete if there was no information available about the dwellings. For this reason, the occupant has to answer a questionnaire. This questionnaire includes questions about the dwelling (type, location, insulation level…), its equipments (heating and ventilation systems…), the occupant's behaviour (number of occupants, time of occupancy …) and humidity (humidity related problems, source of humidity as aquariums…).

As the project team considers that the database could be useful for other research projects, at both Belgian and international levels, it is foreseen to make it available to the scientific community (the precise format has still to be decided). The database could be used for researches related to humidity in dwellings, for building simulations, etc…

FIRST ANALYSES OF MEASUREMENTS

Internal humidity classes

Several methods can be used to assess the internal humidity class on basis of the outdoor temperature and the indoor vapour pressure. A first method is described in the informative annex A of EN ISO 13788 and is based on monthly mean values. Two other methods have been developed by Hens H. (1992) and have been adopted in BBRI Technical Notes (which are considered as reference documents for the Belgian building sector). These methods are respectively based on monthly and annual values for temperature and vapour pressure. Based on the measurements available at the time of writing this article, the internal humidity class has been determined with both monthly methods. An example is given in Figure 1 for one building.

TABLE 1
Humidity class descriptions, according to Hens H. (1992) and EN ISO 13778.

Class	Hens H. (1992) (monthly average)		EN ISO 13778	
	Description	$(p_{v,room} - p_{v,out})$	Description	$(p_{v,room} - p_{v,out})$
1	Buildings with a low humidity production	$< 159 - 10*\theta_{out}$	Storage areas	$< 270\text{-}13.5*\max(0, \theta_{out})$
2	Well ventilated buildings with a limited humidity production	$< 436 - 22*\theta_{out}$	Office, shops	$< 540 - 27*\max(0, \theta_{out})$
3	Moderately ventilated bldgs with a higher hum. production	$< 713 - 22*\theta_{out}$	Low occupancy dwellings	$< 810\text{-}40.5*\max(0, \theta_{out})$
4	Buildings with a high humidity production	$> 713 - 22*\theta_{out}$	High occ. dwellings, sport halls, kitchens…	$< 1080\text{-}54*\max(0, \theta_{out})$
5	–	–	Special buildings	$> 1080\text{-}54*\max(0, \theta_{out})$

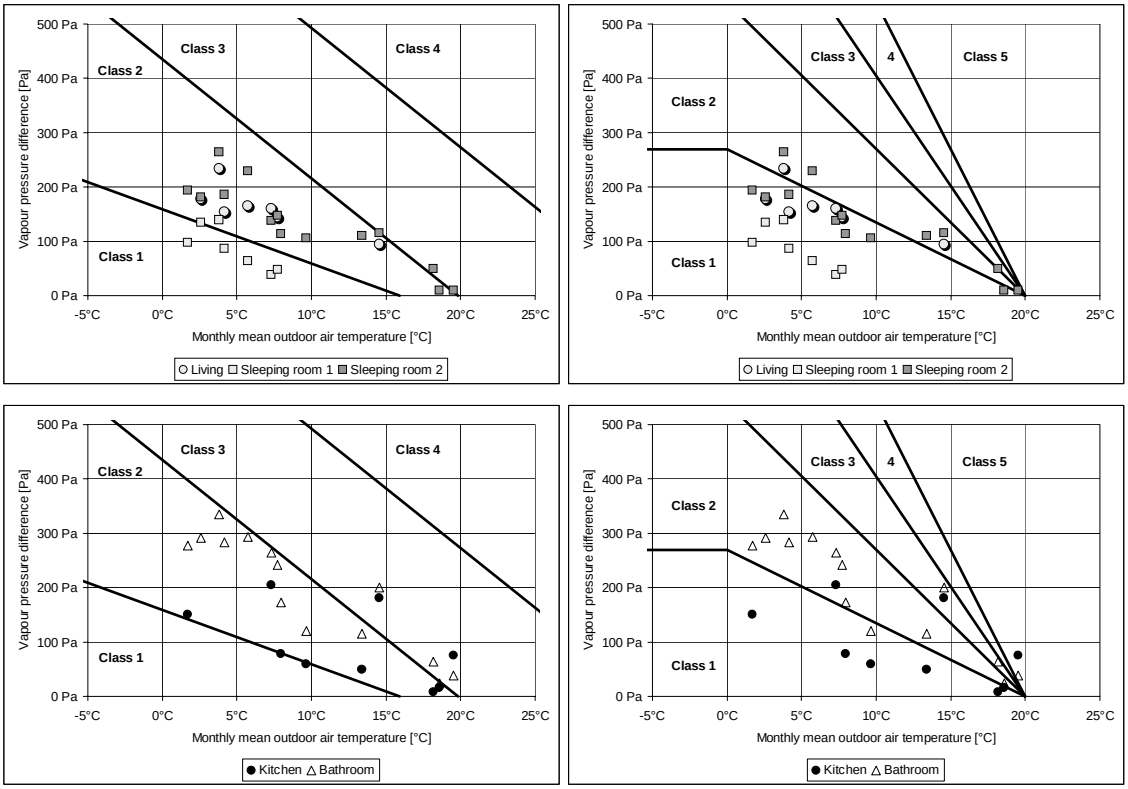

Figure 1: Assessment of the internal humidity class for a building, with methods given in
(left) BBRI Technical Note (Hens H. (1992)) (right) EN ISO 13788

The method proposed by Hens H. (1992) considers 4 classes, whereas the method proposed in EN ISO 13778 considers 5 of them. In the case of the particular dwelling presented in Figure 1, it can be noticed that the sleeping room 1 usually belongs to the internal humidity class 1/1[1], whereas the living and the sleeping room 2 belong to class 2/1 and the kitchen to the class 2/1, and even higher during some time intervals. In this building, the bathroom is the most humid room (mainly class 2/2 but sometimes class 3/≥3).

The impact of some parameters, like for instance the presence of a ventilation system (as far as it is efficiently used by the occupants), could be identified by performing similar analyses on different sets of dwellings. Unfortunately, there are not yet sufficient data available to perform such analysis at this time.

The data will also be used in order to answer some questions: Which method seems to be the most relevant to assess the moisture risk in a dwelling? As the humidity class is different in each type of room, what is a representative procedure for characterising the humidity conditions of a whole building?

Air temperature, relative humidity and critical temperature factor

Measurements from 01/12/2002 (beginning of the monitoring) to 30/04/2003 (end of the heating season) are available for 8 dwellings. From Figure 2a, it appears that the median temperature in the living rooms is about 19.5°C, in the bedrooms 17.5°C, in kitchens 20°C and in bathrooms 19°C. During a small time period, the bathroom is the warmest room of the dwelling.

[1] The first number corresponds to the class given by the method developed by Hens H. (1992) and described in BBRI Technical Notes and the second number to the class described in EN ISO 13778.

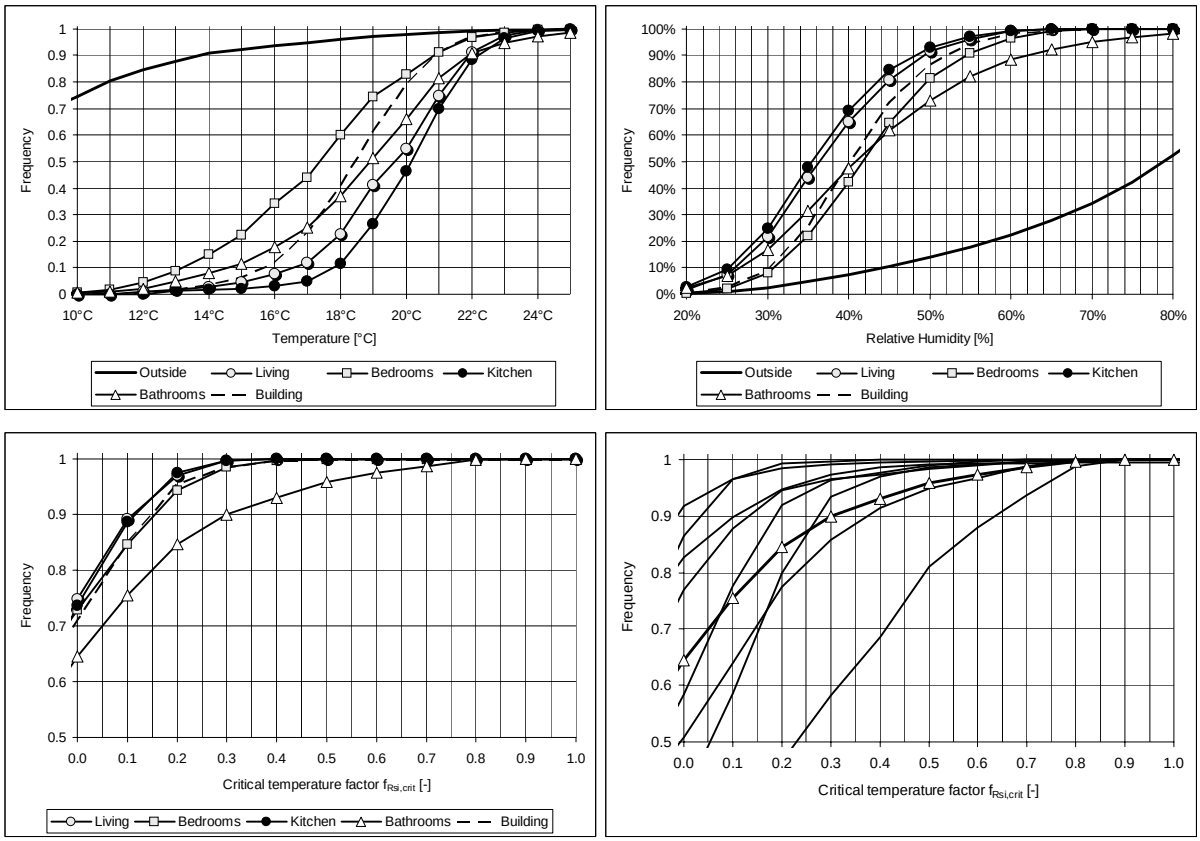

Figure 2: Indoor climate in 8 dwellings, from 01/12/2002 to 30/04/2003
(a) Average temperature and (b) relative humidity by type of room
(c) Average $f_{Rsi,crit}$ by type of room (d) $f_{Rsi,crit}$ in the bathrooms of each dwelling

Figure 2b shows that during 10% of the time, the relative humidity is higher than 49% in the living rooms, higher than 54% in the bedrooms, higher than 48% in the kitchens, and higher than 62% in the bathrooms.

Figure 2c shows that during the major part of the time (±65% of the time in bathrooms, ± 75% of the time for all other rooms), there is no risk of condensation, as the critical temperature factor $f_{Rsi,crit}$ is lower than zero. This means that, if the indoor air temperature θ_{room} is higher than the outdoor air temperature $\theta_{out,}$ the inside surface temperature leading to condensation is lower than θ_{out}, which is of course impossible (in steady-state conditions). Figure 2c also shows that in bathrooms $f_{Rsi,crit}$ is only during 1% of the time higher than 0.7. This of course may vary considerably from one dwelling to another, as can be seen in Figure 2d, according to the building characteristics and the occupant's behaviour. The database, when completed, will allow to evaluate if the criterion $f_{Rsi} \geq 0.7$ is the most appropriate to prevent condensation risk.

It is important to mention that the condensation risk may only be assessed with the help of the temperature factor in steady-state conditions. However, bathrooms are usually only heated just before usage (as illustrated in Figure 2a). The temperature of the wall contacting the outside climate will not rise up as fast as the indoor air temperature. Consequently, the wall surface temperature will be lower than the value calculated in the database and the condensation risk will be higher. It is the intention to study this issue more into detail in the framework of this project.

Indoor air quality based on CO_2 levels

In order to evaluate the indoor air quality and to obtain a better idea of the flow pattern in dwellings, CO_2 measurements have been started in a few dwellings. Five sensors have been installed, in the same rooms as the temperature and humidity sensors.

Pressure differences across the roof

It is commonly stated that dwellings or individual rooms should not be put in overpressure in order to reduce the risk of moisture transport in the building envelop. For this reason, fan assisted supply air ventilation systems (called "system B" in Belgium) are not recommended. However, this statement does not consider that important pressure differences across a roof can also be due to the sole effect of stack and wind, even in the absence of a mechanical supply. This is shown by the measurements carried out in one of the dwellings. The principle of this monitoring is given in Figure 3(a): two manometers are measuring respectively the air pressure differences across the roof (ΔP_1) and between the two external surfaces of the roof (ΔP_2), at a frequency of 1 measure every minute.

Figure 3(b) shows that pressure difference across the roof ΔP_1 was lower than 0 Pa during 4% of the time, higher than 10 Pa during 6% of the time and higher than 20 Pa during 1% of the time. ($\Delta P_1 - \Delta P_2$) gives more or less an indication of the pressure difference due to the thermal effect only. Figure 3(b) shows that $\Delta P_1 - \Delta P_2$ varies between 0 Pa and 5 Pa during 80% of the time, with an average of 2.4 Pa. During this period, the average temperature difference[2] $\theta_{building} - \theta_{out}$ was 8.7°C. As the height of the building is about 15 meters and assuming that the cracks are equally distributed over the building envelop, the pressure difference across the roof due to the stack effect can be roughly estimated to $\Delta P = (0.04*\Delta H*\Delta\theta)/2 = (0.04*15*8.7)/2 = 2.6$ Pa, which is in line with the measurements.

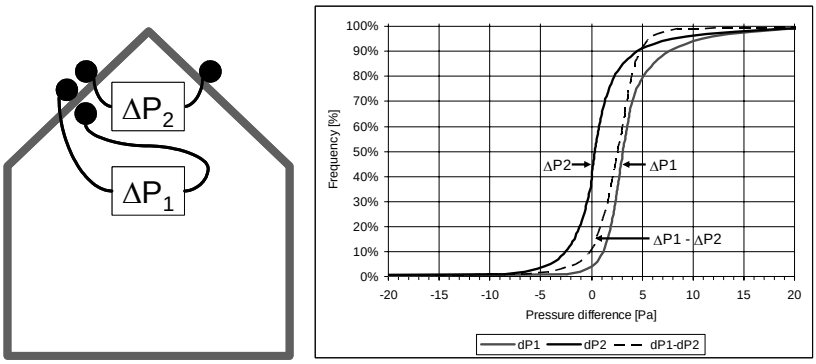

Figure 3: Pressure differences across a roof
(a) Principle (b) Distribution of ΔP_1 and ΔP_2 for the periods
from 29/02/2004 to 20/03/2004 and from 11/06/2004 to 20/06/2004

CONCLUSIONS

In the frame of the "Moisture problems in roofs" project, the indoor climate has been extensively monitored in 41 Belgian dwellings. This monitoring includes temperature and humidity measurements outside and in five rooms of each dwelling. Moreover, CO_2 is

[2] As the measurements were not yet available at the time of data, measurements of 2003 were used for this calculation.

monitored in five rooms of 3 dwellings and 2 pressure differences across the roof are measured in 1 dwelling. The monitoring period varies from 6 to 24 months.

These measurements give a better overview of the indoor climate of Belgian dwellings. In particular, they allow to evaluate the internal humidity classes typically met in dwellings and to select the most appropriate method to assess the moisture risk in a dwelling.

These data could also be used in other researches, both at Belgian or international levels, as the measurement database will be made available to the scientific community.

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FORMULAS USED FOR THE CALCULATIONS

The formulas used for the calculations in the database are given below:

$$p_{sat} = \exp\left(65.8094 - \frac{7066.27}{(\theta + 273.15)} - 5.976 * \ln(\theta + 273.15)\right)$$

$$p_v = RH / 100 * p_{sat}$$

$$f_{Rsi,crit} = \frac{(\theta_{dew,room} - \theta_{out})}{(\theta_{room} - \theta_{out})} = \frac{\left(\left(\frac{\ln(p_{v,room} / 611) * 234.18}{17.08 - \ln(p_{v,room} / 611)}\right) - \theta_{out}\right)}{(\theta_{room} - \theta_{out})}$$

$$\theta_{si,room} = \theta_{out} + 0.7 * (\theta_{room} - \theta_{out})$$

where θ is the measured air temperature in °C, RH is the measured relative humidity in %, p_{sat} is the saturated vapour pressure in Pa, p_v is the vapour pressure in Pa, $f_{Rsi,crit}$ is the dimensionless critical temperature factor, θ_{dew} is the dew point temperature in °C and θ_{si} is the surface temperature corresponding to a temperature factor f_{Rsi} equal to 0.7. Note that the temperature factor is commonly noted τ in Belgium.

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