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The Use of Tracer Gas Methods for Detailed Airborne Moisture Transport Study in Buildings

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THE USE OF TRACER GAS METHODS FOR DETAILED AIRBORNE MOISTURE TRANSPORT STUDY IN BUILDINGS

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SYNOPSIS

Three different examples illustrate the possibilities offered by the use of tracer gas methods for detailed airborne moisture transport studies in buildings. The first one concerns an individual dwelling with severe condensation problems, the second one gives an example of statistical data collection of humidity related parameters in 18 apartments and the last one focuses on the evaluation of the amount of water evaporating from the building materials of a recently built low energy dwelling and on the energy consumption required for drying the construction.

The paper deals on the one hand with the methodology employed for the measurements, on the other hand with the practical results that were obtained.

LIST OF SYMBOLS

V	volume of the space	[m^3]
S	source/sink in the space	[kg/s]
w_{inside}	absolute humidity inside	[kg/m^3]
$w_{outside}$	absolute humidity outside	[kg/m^3]
Q_{air}	air flow rate	[m^3/s]
$Q_{condensation}$	condensation rate	[$kg/m^2.s$]
β	vapour transfer coefficient	[s/m]
$p'_{surface}$	saturation vapour pressure on the surface of the profiled sheets	[Pa]
p_{cavity}	vapour pressure in the cavity	[Pa]
θ	temperature	[K]

1. INTRODUCTION

In the framework of three different projects, quite unique methods were used and data collected in relation to airborne moisture transport in buildings. This paper focuses on the one hand on the methodology employed and, on the other hand on the practical results obtained. It does not deal with humidity levels in spaces or with humidity transport in materials or constructions.

After a short discussion on the relevance of airborne moisture transport studies, available measurement techniques and schemes are presented. Then follow three applications.

The first one concerns an individual dwelling with severe condensation problems in the pitched roof structure. The combination of tracer gas techniques with accurate water vapour measurements permitted to qualify and quantify the causes of the problem and to propose appropriate solutions.

The second project [1] gives a good example of statistical data collection concerning the water vapour transport. Humidity and air change rate were measured during about 2 months in 18 apartments situated in Namur, Belgium with the specific aim of estimating the moisture production.

The third project focuses on the detailed evaluation of the overall energetical performances of a new low energy building. Detailed measurements were carried out during two periods of about one month. The recorded data permitted to accurately estimate the air change rates as well as the amount of water drying out from the construction.

Finally, some conclusions are given.

2. RELEVANCE OF AIRBORNE MOISTURE TRANSPORT MEASUREMENTS

2.1 MOISTURE PROBLEM

Moisture problems in dwellings often find their origin in an insufficient air renewal leading to high water vapour levels which provokes condensation on cold surfaces (single glazing, thermal bridges,...). These problems can generally be simply detected by humidity measurements possibly combined with surface temperature measurements.

However, other more complex problems require more than a simple humidity measurement to be understood. This is the case when there is a doubt on the origin of the water vapour which condenses. The use of tracer gas combined with humidity measurements can be the only way to understand the source of a problem and determine appropriate remedial actions.

2.2 STATISTICAL DATA

Nowadays, there are many simulation tools on the market that allow to simulate pollutant spreading in buildings (COMIS, CONTAM,...). These tools should be used by designers in order to evaluate the impact of different strategy (heating, ventilation,...) on the indoor climate (air quality and thermal comfort). However, the problem is as usual to feed the simulation tool with sufficiently representative/accurate input data so as to end up with valuable simulated values. In particular, the pollutant sources and sinks must be known as well as typical outside concentrations.

In this context, the collection of statistical data on water vapour is of high relevance since humidity is a major parameter for qualifying the indoor climate.

2.3 ENERGY CONSUMPTION FOR DRYING OUT CONSTRUCTIONS

New constructions contain important amounts of water stored in the building materials (plaster, concrete,...). The required energy to dry constructions and the time it can take are not well known. Humidity measurements combined with air flow rate measurements allow to follow the evolution of the water evaporation and to derive the energy consumption that it requires.

3. MEASUREMENT TECHNIQUES

3.1 BASIC EQUATIONS

The water vapour source/sink (production, condensation, evaporation, adsorption,...) in a building considered as a single zone is given by:

Eq. 1 $$S_{H_2O} = Q_{air} \cdot \left(w_{inside} - w_{outside}\right) + V \cdot \frac{dw_{inside}}{dt} \qquad \text{[kg/s]}$$

where the first term represents the water vapour flow rate extracted/supplied by the ventilation, that is:

Eq. 2 $$Q_{H_2O} = Q_{air} \cdot (w_{inside} - w_{outside})$$ [kg/s]

and the second term represents the variation of inside absolute humidity.

Thus, the study of airborne water vapour transport requires measurements of absolute humidities and air flow rates. The latter can be determined thanks to tracer gas techniques [2].

It must be noted that absolute humidities appear in the form of differences in those equations which implies that the measurement error on the absolute humidity strongly impacts the accuracy of the calculated results. This is for example shown by the next formula giving the error on the calculated water vapour extraction rate as a function of the measurement errors on the air flow rate and on the absolute humidity.

Eq. 3 $$\left|\frac{\Delta Q_{H_2O}}{Q_{H_2O}}\right|^2 = \left|\frac{\Delta Q_{Air}}{Q_{Air}}\right|^2 + 2 \cdot \left|\frac{\Delta w}{w_{inside} - w_{outside}}\right|^2$$

Equations 2 and 3 can easily be extended to multi-zone building models.

3.2 Sensors

3.2.1 Classical humidity sensors

One of IEA Annex18 reports [3] provides a good overview of existing humidity sensors and their performances. The most commonly used are: the hair and polyethylene-strip hygrometer, the capacitive hygrometer, the conductance-film hygrometer and the lithium chloride sensor.

3.2.2 Infrared gas analysers

The measurement is based on the absorption of infrared light by the molecules of gas (water vapour or tracer gas) contained in the analysed air sample. The absorption can either be detected by the decrease of the light intensity after it has gone over a long path in the air sample (photometric type) or by the acoustic field created in a closed cavity filled with the gas when it is submitted to a pulsating light source (photoacoustic type).

By way of example, the accuracy of the Brüel&Kjaer type 1302 (employed for the first and the third project) is about 1% and a range drift of 2.5% over a 3 months period. This equipment permits to measure the concentrations of up to 5 different gases and the absolute humidity in a few minutes.

3.3 Measurement schemes

To study the airborne humidity transport necessitates to measure absolute humidities at several places, at least one point inside and one point outside. Two schemes are possible: either a humidity sensor at each measurement point or a central sensor to which air samples collected at the different points are brought.

The use of an individual sensor for each point has the disadvantage that the unavoidable drifts affecting the measurement can be different for each of them. Accordingly, they have to be taken into account in the humidity measurement error (Δw in Eq. 3).

On the contrary, using a common sensor allows to eliminate (for a zero drift) or reduce (for a range drift) the drift error on the difference of two humidities and accordingly increase the accuracy on the calculated result. This point may be essential when absolute humidity differences are small which can be due to high ventilation rate (in summer for example).

4. EXAMPLE OF THE EXAMINATION OF A MOISTURE PROBLEM

4.1 DESCRIPTION OF THE PROBLEM

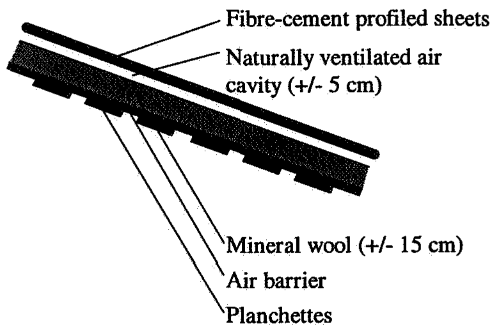


Figure 1: Structure of the pitched roof

The investigated dwelling is situated in Wommelgem, Belgium. It has a pitched roof made up of fibre-cement profiled sheets.

Often, water is dripping out of the roof structure into the dwelling. Usually this happens after a period of frost.

Figure 1 shows a sketch of the roof structure.

4.2 PERFORMED MEASUREMENTS AND OBJECTIVES

The main objective of the performed investigations was to determine where the water vapour condensing in the naturally ventilated air cavity was coming from. Indeed, it could originate from the dwelling where the absolute humidity is higher than outside and therefore could condense on the cold profiled sheets or it could come from the outside and, in this case could condense because of a supercooling effect on the profiled sheets (due to radiation exchange with a clear sky the temperature of a surface can be lower than the air temperature).

Pressurisation measurement, smoke visualisation and tracer gas measurement were performed.

The purpose of the tracer gas measurement is to determine the amount of indoor air leaving the house through the air barrier to the roof structure. Therefore a tracer (SF_6) is injected in the dwelling (constant concentration) and its concentration is measured continuously on different places in the air cavity. At the same time the temperature and the absolute humidity are measured on different places (inside, outside, in the cavity, on the profiled sheet).

4.3 RESULTS AND DISCUSSION

4.3.1 PRESSURISATION AND SMOKE VISUALISATION

The pressurisation gave an n_{50}-value of about 10 h^{-1}. This is not very good, but not extremely high for a Belgian dwelling. The smoke visualisation showed that the most important leakages are situated in the roof structure and at the windows.

4.3.2 TRACER GAS MEASUREMENT

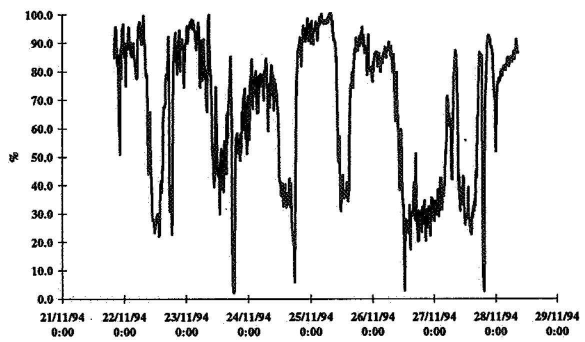
Figure 2 shows the evolution of the ratio of the SF_6 concentrations in the air cavity and in the dwelling. This value directly indicates the proportion of inside air in the cavity. As one can see this is a rather fluctuating value (due to changing weather conditions). The average of the ratio is about 67%; this means that over the whole period the air in the cavity includes on average 2/3 of inside air and 1/3 of outside air. It is clear that the air barrier is far to be airtight.

The following step was the examination of potential condensation. One knows that the air in the cavity will condense against the profiled sheets if:

Eq. 4 $\theta_{surface} < \theta_{dew,cavity}$ [K]

The temperature on the surface is measured and the dewpoint in the cavity can be calculated from the measurement of the absolute humidity. The measured data showed that some condensation occurred during the measurement period.
To know the importance of this condensation the following equation can be used:

Eq. 5 $Q_{condensation} = \beta \cdot (p_{cavity} - p'_{surface})$ [kg/m^2.s]



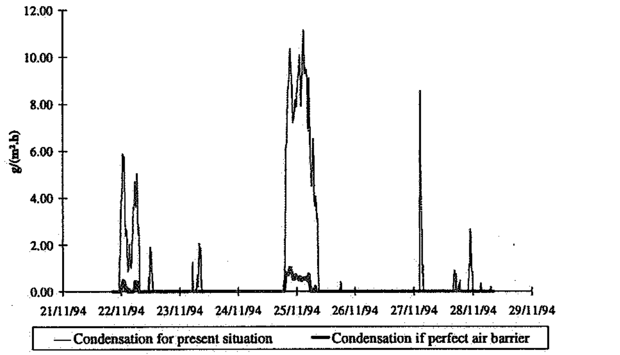


Figure 2: Ratio between the SF_6 concentrations in the cavity and in the dwelling
Figure 3: Condensation rates in present situation and for a perfect air barrier

This calculation has been made with the measured data (Figure 3) assuming a value of 22.10^{-9} s/m for the vapour transfer coefficient. The total amount of condensed water vapour over the considered period (6 days) is about 13 kg.
The reason why the problem mostly occurs after a period of frost, is that a buffer of frozen water is formed. When the roof surface temperature rises (because of the sun), this ice is melting very quickly and cannot be dried by the air in the cavity. As a consequence a large amount of water will be released in a short period, which causes the dripping of water into the dwelling.
The outside air flow rate to the air cavity can easily be determined from the tracer gas measurements if the assumption is made that all the air exfiltrating from the dwelling (measured) passes through the roof. The improvement brought by a perfect air barrier can then be evaluated. The result is also shown in Figure 3. The remaining part of condensation is caused by the effect of supercooling and is rather small compared to the present situation.
The problem is clearly due to the very bad airtightness of the air barrier and could be solved either by strongly improving the present air barrier or by placing a new airtight air barrier.
As conclusion it can be said that the studied problem clearly shows the relevance of airborne moisture transport study not only to find the origin of the problem, but also to simulate the effect of possible improvements.

5. Example of statistical data collection

5.1 The context

In the framework of an EC demonstration project [1] devoted to the field-testing of humidity controlled natural ventilation, a large amount of data was collected in 18 apartments situated in Namur, Belgium during about 70 days. Various parameters were continuously monitored (temperatures, air flow rates, CO_2 concentrations, absolute humidities,...) in the "humid spaces" (toilets, bathrooms and kitchens) in which natural extraction is taking place. One of the specific aims was to evaluate the water vapour extraction rate due to the natural ventilation.

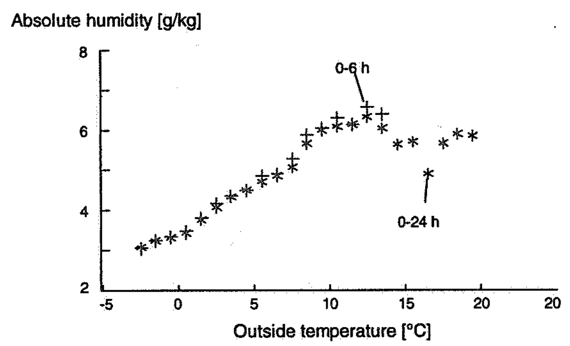
5.2 THE MEASUREMENT TECHNIQUE

The MATE (Multi Purpose Automated Tracer Gas Equipment) system [2] was used to measure the extraction flow rates. Air samples were drawn successively from the different rooms and their tracer gas concentrations measured using infrared gas analysers as well as their humidity.

5.3 THE RESULTS

The next figures show some humidity related results from this project. Figure 4 shows the average outside absolute humidity as a function of the outside temperature. As one can see, the dependency is almost linear in the range -5 to 10 °C. Figure 5 shows histograms of the extracted water vapour rates through the ventilation ducts for 9 apartments with humidity controlled ventilation (hygro) and for 9 apartments without humidity controlled ventilation (reference). The average value is about 5 kg of water per day.

More information on the results of this study can be found in [1].



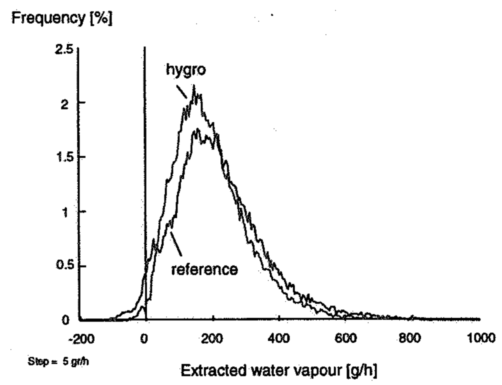


Figure 4 - Average outside absolute humidity as a function of the outside temperature
Figure 5 - Histogram of total extracted water vapour rates

6. EXAMPLE OF DETERMINING ENERGY CONSUMPTION FOR DRYING OUT WATER FROM CONSTRUCTION

6.1 THE OBJECTIVE OF THE STUDY

The PLEIADE dwelling is a low energy building situated in Louvain-La-Neuve, Belgium, recently built in the framework of IEA Task XIII, "Advanced Solar Low Energy Building".

An extensive monitoring was carried out in order to identify the performances of the dwelling (thermal performances, building airtightness, ventilation, air heating system...).

As part of it, detailed moisture measurements were performed with the objective to evaluate the energy consumption for drying out construction water in order to be able to make the heat balance of dwelling and to derive its thermal characteristics. On the other hand, it was also the intention to measure the amount of water that can be evaporated from a new construction during the first heating periods.

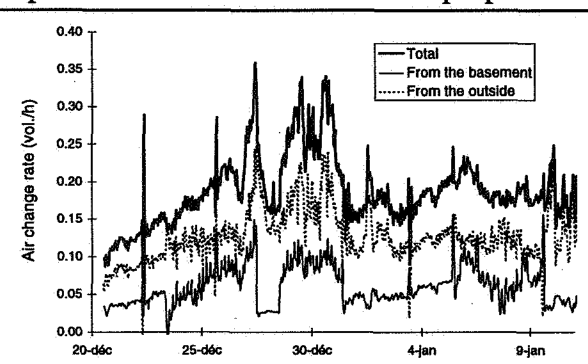
6.2 THE MEASUREMENT TECHNIQUE

As previously mentioned, a Brüel&Kjaer gas analyser type 1302 was used. The tracer gas concentrations were measured at 11 different places in the building as well as the absolute humidities (also measured outside). A two tracer gas technique was used so as to be able to differentiate the air coming from the outside and from the basement to the dwelling.

6.3 THE RESULTS

Figure 6 shows the evolution of the total air change rate of the dwelling. It should be noted that the mechanical ventilation system of the dwelling was switched off which explains the rather low values, only due to air infiltration.

The measured absolute humidities in the dwelling (average of 10 measurement points), in the basement and outside are shown on Figure 7. The higher inside values are due to the evaporation of construction water (no other source of water in the building). The variation of the humidity in the basement is due to the strong changes of its ventilation rate mechanically imposed for thermal identification purpose.



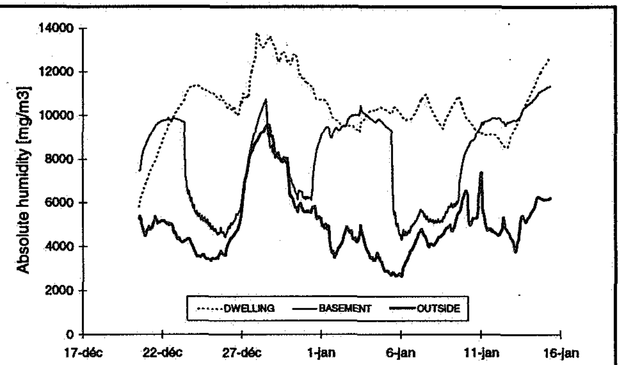


Figure 6 - Air change rate in the dwelling (from the outside and from the basement)
Figure 7 - Evolution of the absolute humidities (basement, dwelling and outside)

Knowing the air flow rates and the humidities in the time allows to derive the water vapour source in the building which is given in Figure 8.

Figure 9 gives the average air flow rates and absolute humidities during the measurement period (from 20-12-94 to 15-1-95).

In total, 312 kg of water were evaporated during a period of 25 days which corresponds with an energy consumption of about 700 MJ. On average, 500 g of water per hour evaporates from the construction which is equivalent to a cooling power of 300 Watt.

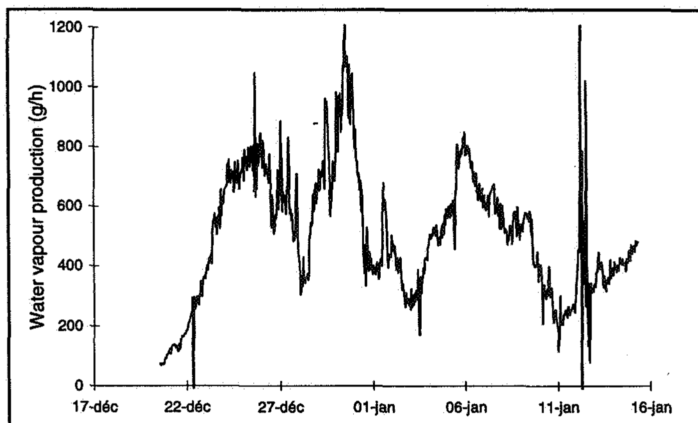
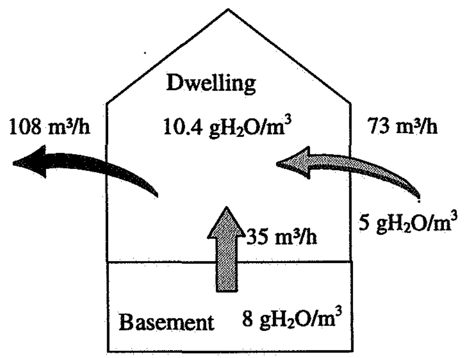


Figure 8 - Evolution of the water vapour production in the dwelling

Figure 10 gives, the distribution of thermal losses in its three components: the losses by transmission, the ventilation losses and the energy consumption due to the evaporation of the construction water. As it can be seen, about 10% of the whole heating energy injected in the building was consumed to evaporate construction water. It should be added that the building was protected from solar gains during this period.



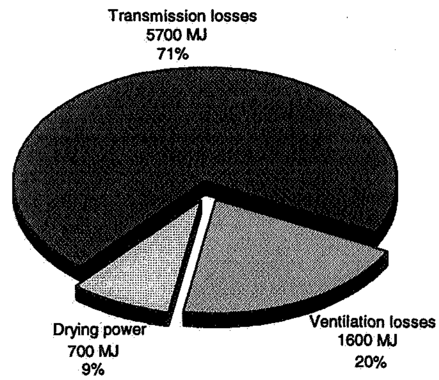


Figure 9 - Average air flow rates from 20-12-94 to 15-1-95
Figure 10 - Distribution of thermal losses

7. GENERAL CONCLUSION

This paper demonstrates by means of three examples that the combination of accurate absolute humidity measurements (with a common sensor for drift avoidance) and air flow rate measurements (by means of tracer gas) provides quite unique results for airborne moisture transport related problems.

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