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Humidity Controlled Exhaust Ventilation in Moderate Climate

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1 Introduction

Born with the energetic crisis, humidity controlled ventilation has been introduced in regions with a moderate climate[1] as a means to fight condensation problems induced by tighter building construction and lower heating temperatures.

This paper develops the means and goals of humidity controlled ventilation in the framework of the building energy reduction. Why have a variable airflow? Why chose humidity as the driving parameter? How does humidity controlled ventilation work? How to test the performances of such sophisticated products and what standard for the industry? How to evaluate the related energy gains? Those are the questions addressed in this paper.

2 A drastic reduction of the energy consumption of buildings is required

The Kyoto protocol and the required drastic cut by 4 into the greenhouse gas emissions before 2050 are the two strong commitments taken to protect the earth from extreme global warming and the exhaustion of fossil energy sources in the medium term. Although the implementation of regulatory and incentive tools since the first oil crisis has significantly reduced the average energy consumption per square meter of new dwellings, the effort must be sustained to meet the most recent targets.

Indoor air renewal can represent up to 50% of the dwelling's energy consumption, and is therefore a key parameter in the buildings' energy need reduction. As a consequence, ventilation is thus a trade-off between indoor air quality and energy efficiency. A variable airflow adapted to the need is an ideal answer to those seemingly contradictory requirements and demand-controlled ventilation can be adapted to the various local (national) markets. In new buildings, the ever increasing thermal insulation reinforces the weight of ventilation on the energy consumption, thus making the control of airflows an absolute requirement. Renovation, on the other hand, requires easy to implement and easy to maintain solutions.

Non occupied dwellings (e.g. 7% of the French[2] building stock) emphasize how relevant demand-controlled ventilation is. Today's ventilation needs to be able to adapt to vacancy periods and to immediately fill the need when the dwelling is occupied again. This is all the more true as the modes of living have evolved thus modifying deeply the occupation of dwellings: more people leave their homes to go to work and more and more families are single-parent ones, which leads to a reduced average daily and hourly occupation rate. Variable airflows in response to the needs appear to be one relevant way to conciliate high indoor air quality and energy efficiency.

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[1] This paper is for moderate climate typical of France, Benelux or Poland for example.

[2] Source: Insee, year 2008, France : http://www.insee.fr/fr/themes/tableau.asp?reg_id=0&ref_id=NATFPS05201

3 Demand-controlled airflow

State of the art ventilation proposes two different technologies to save energy in a dwelling: heat recovery and variable demand-controlled airflow.

The first one offers a steady, often fixed airflow, potentially increased to a boost rate in higher pollution cases. Such a system has a double ductwork, one for the extracted air and one for the incoming air. A heat exchanger between the two recovers part the heat from the extracted air and transfers it to the incoming one. Several fans operate the in- and out airflows and have to counteract the pressure drops occurring in the ductworks, filters, and pre-heating device (in some models).

Demand-controlled airflows in exhaust-only ventilation systems provide very low rates of air change when the need is minimum but can increase the airflow to very high levels when needed. The rationale behind it is to set the average airflow to a minimum, and reduce the heat losses accordingly, while ensuring high ventilation rates for very short periods of time when necessary. The ventilation peaks have a very limited impact on the average air change rate because they occur in response to very short and rather rare needs.

For now, no system really combines variable demand-controlled airflows and heat recovery for the whole dwelling, but this would be a very efficient means to conciliate indoor air quality and energy efficiency.

3.1 Why have variable airflows?

In multi-family houses, ventilation based on demand-controlled variable airflows offers a chance to optimize and reduce the ductwork dimensions. Because the needs are spread over time and space, the statistical average airflow is below the sum of all fixed equivalent[1] airflows, which allows reducing the ductwork dimensions. This benefit attached to variable airflow systems is even stronger in case of renovation of a collective building, where changing the fixed for demand controlled ventilation air extract units will not require to modify or to increase the ductwork.

[1] In terms of indoor air quality.

With a much lower mean air change rate, demand controlled ventilation produces significant energy savings, as well as slower dust charge of filters, ducts, extractors and air terminals, thus reducing the maintenance requirements.

4 Humidity: a relevant indicator of indoor air quality?

Demand-controlled ventilation has to rely on a parameter which is indicative of the indoor pollution. The parameter has to be easily detected and measured physically and needs to be reactive enough to adapt the air change in real time.

Sources of indoor air pollution are of three kinds:

- pollutions emitted by the building and furniture materials
- pollutions emitted by human activities
- pollutions emitted by the occupiers' metabolism

Material-emitted pollutions are essentially volatile organic components (VOC), among which aldehydes and hydrocarbons can be a hazard to the occupiers' health. This type of pollutant requires a permanent low ventilation rate, even when the dwelling is vacant.

Human activities include cooking, showering, clothes washing and drying …Those are important sources of humidity as well as various smells.

If those are no danger to the occupiers, they constitute however a threat to the integrity of the building (condensation) and a potential olfactive discomfort. With peak emissions as high as 350 g of water vapour for a 10 minute shower, the boost rate appears to be crucial to limit the presence of humidity in time and rate.

Finally, the pollution generated by the occupiers' metabolism (breathing and perspiration) produces humidity and carbon dioxide, which requires a ventilation rate adapted to the number of persons in the room and to their activities. A single person having 'standard' activities generates 50 g/h of water vapour and 19 l/h of CO_2. Those are significant amounts of pollution among the whole dwelling pollution sources that need to be handled properly.

Among the above mentioned types of pollutants, one appears to be relevant to the amount of pollution generated by occupants: humidity.

The three opposite graphs (Figures 1 to 3) show the results of an in situ experiment which included 60 dwellings equipped with passive stack humidity controlled ventilation in 3 countries: France, Belgium and the Netherlands. The study was led by CSTB, TNO, BBRI and Aereco [Ref. 5].

The graphs demonstrate by a real and statistical experiment the correlation between absolute humidity and carbon dioxide in the various 'wet' rooms. CO_2 is usually recognized as a relevant indicator of the indoor pollution generated by human metabolism. Each point reflects the simultaneous record of absolute humidity and CO_2. What appears here is a direct correlation between CO_2 and H_2O in toilets[1], while, in kitchens and bathrooms, we see that the highest CO_2 increases are always followed by even higher H_2O rises. This means that handling H_2O is a way to handle CO_2 properly at the same time. Moreover, humidity-driven ventilation protects the building by maintaining reasonable amounts of indoor water vapour, which would not apply with CO_2-driven ventilation. The official report of this experiment states that "*indoor humidity is a relevant parameter (...) to automatically change the air renewal rate in response to the pollution created by human activity and metabolism*".

The question of 'dry' rooms (living- and bedrooms) was addressed during another experiment performed in Paris[2] in 2008, based on dwellings equipped with humidity controlled mechanical extract whole house ventilation.

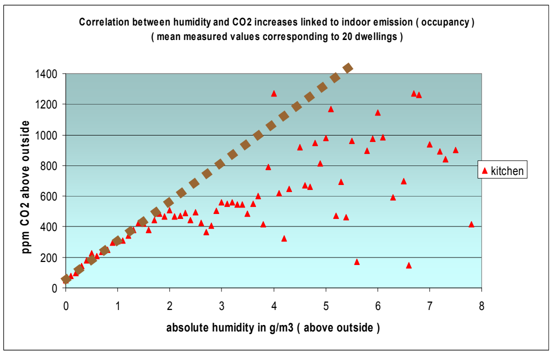

Figure 1: Correlation between absolute humidity and CO_2 in kitchens

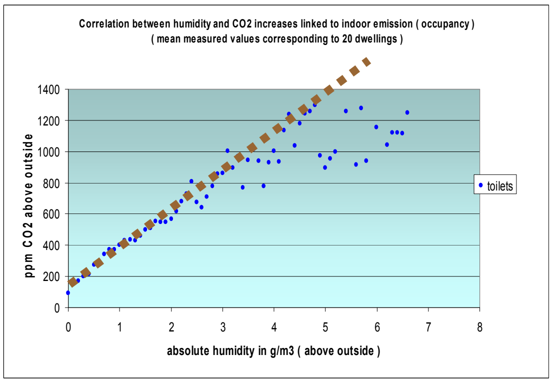

Figure 2: Correlation between absolute humidity and CO_2 in toilets

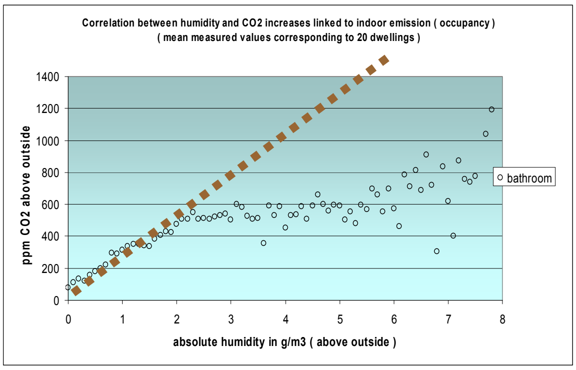

Figure 3: Correlation between absolute humidity and CO_2 in bathrooms

[1] The case of toilets ventilation, where the main pollution is odours, can be solved by adding presence detection control to the extraction terminals.
[2] Project ADEME PREBAT "Performance".

Figure 4 shows simultaneous measurements of relative humidity in the dwelling and carbon dioxide over a period of one week in a bedroom occupied by a single person. Occupied periods, corresponding to night-time, are shown in light grey.

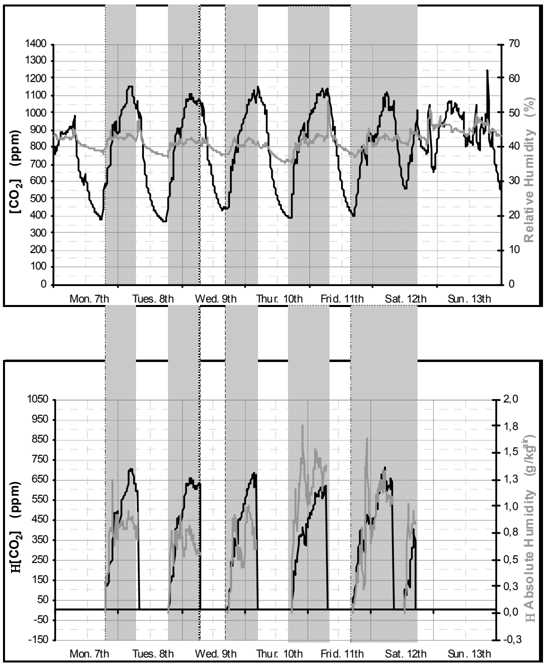

Figure 4: CO_2 and H_2O changes in a single room. Top: continuous measurements of CO_2 and relative humidity. Bottom: measurement of CO_2 and absolute humidity during occupied periods only (nights)

At first sight, the top graph shows higher variations for CO_2 than for relative humidity. However if we focus on occupied periods (light grey areas) and calculate the changes in absolute humidity[1] as compared with the beginning of the night and the corresponding changes in CO_2, we get the second graph. The correlation between CO_2 and H_2O increases is then clearly seen.

A calculation shows that about 50% of water vapour was absorbed by the surrounding materials, but the correlation with the CO_2 increase was nevertheless observed.

Note that the air inlet cannot rely on the measurement of the indoor relative humidity only. In case of cold weather, the outdoor relative humidity would be very low and consequently the indoor relative humidity would go down. An increase in indoor humidity might not be significant enough to trigger the opening of the air inlet. Therefore, the temperature of the sensor integrated into the air inlet has to be adapted to the outdoor temperature [Ref. 8]. This is controlled by the specification of a thermal coefficient for the air inlet.

5 Humidity controlled ventilation and VOCs

Besides pollutants emitted by the human activity and metabolism, VOCs also have a direct impact on the indoor air quality. However, it is very complicated to control their presence by ventilation only due to their occurrence, nature, composition, time-dependent concentration (higher when the material is new) as well as their temperature and humidity dependency. The best and most economical way to maintain VOCs at reasonable levels is certainly to control their sources, by a careful choice of the materials incorporated into the dwelling. It is indeed more cost-effective to initially select low emission materials than ventilate for several years after the construction at a high rate to extract the VOCs. Humidity controlled ventilation however contributes to VOC reduction: it sets a minimum air change rate even when the dwelling is vacant, and it treats humid and warm air conditions, which are known to be favourable to VOC emissions (as demonstrated by several studies). Formaldehydes and other compounds are not specifically handled by a humidity sensitive ventilation, but the operation of such a system is consistent with the treatment of VOCs.

[1] Taking into account the absolute humidity instead of the relative one, we cancel the impact of temperature changes on the readout.

6 Principle and applications of humidity controlled ventilation

6.1 Principle:

Humidity sensitive air terminals modify the airflow depending on the indoor relative humidity. Several technologies have been implemented among which electronic humidity sensors, wood chips and nylon strips.

The market has evolved towards nylon-only products because of accuracy and reliability issues with the other technologies.

The sensor is made of a set of nylon strips (Figure 5) and it uses the hygroscopic properties of the fabric in two ways: first the natural changes in the strips' length are used to measure relative humidity; second the shortening of the nylon with dryer air is used as a recall force, and the force of a spring is used when air humidity increases. The hygroscopic module including the set of nylon strips can thus be seen as a natural "motor" with an integrated humidity sensor.

The sensor mechanically drives a shutter which defines the free opening area of the terminal, which sets the admitted airflow in reference to a given pressure. In order to avoid dirt and grease collection, the sensor is protected from the airflow. The indoor relative humidity is read thanks to micro-convection and osmotic pressure balance.

This technology operates without electricity and does not require any wiring or batteries. Based on a natural physical process, it offers an intrinsic reliability. Tests performed on a sample of installed air terminals after 10 years of operation have shown that there had been no change in their hygro-aeraulic performances. The very simple mechanism actually prevents drifting behaviours or failure.

Moreover, the nylon strip technology provides a graduate and more accurate answer to the relative indoor humidity (Figure 6), whereas other technologies such as hygrostats or electronic humidity sensors offer binary or intermittent operation.

6.2 Products:

Humidity controlled technology can be applied to natural (passive stack), mechanical or hybrid ventilation, by the combination of dedicated components: air inlets, air extract grilles (Figure 7), and fans. Today, this technology is used in extract-only ventilation devices, but a combination with double-flow heat recovery systems could benefit from both techniques in the future.

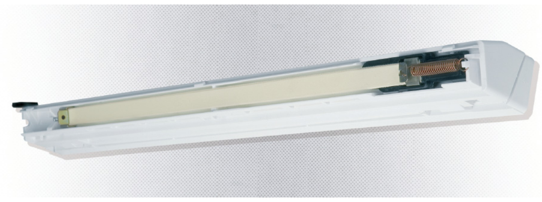

Figure 5: Nylon hygroscopic sensor of an air inlet

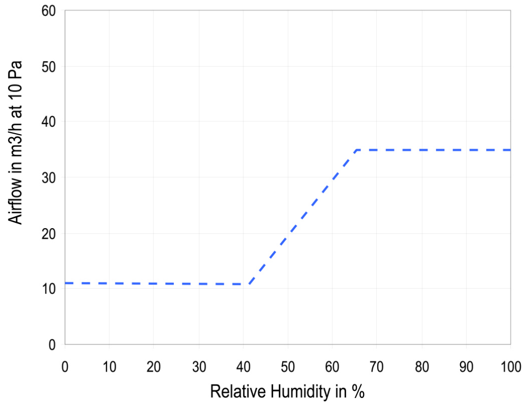

Figure 6: Airflow as a function of relative indoor humidity in a humidity controlled air terminal (e.g. air inlet)

Figure 7: Humidity sensitive extract units

Figure 8 details the parts of a humidity sensitive air extract unit: detachable grille (2), front cover (4), removable shutter box (3), humidity sensitive motor module (6), base (1). The connection to the extraction duct can be done with an adaptor (5). The shutter is directly driven by the humidity sensitive module.

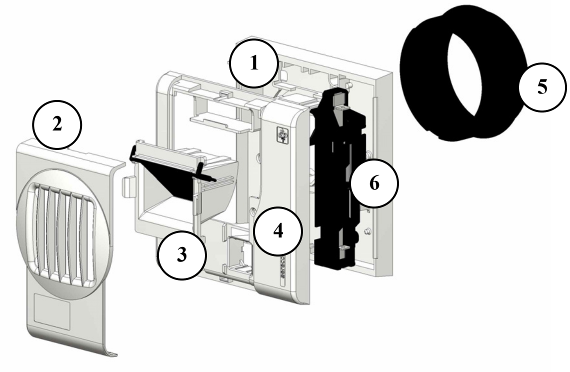

Figure 8: Parts of a humidity sensitive air extract unit

6.3 Operation of the humidity sensitive terminals

As shown on Figure 9, the airflow extracted by the extract units (2) from the wet rooms (kitchen, bathroom and toilets) defines the air change rate of the whole dwelling. The air extract units adapt the airflow in response to the amount of humidity in each wet room. An additional boost rate -either manual or automatically triggered by presence detection- can complement the humidity-driven airflow. The extract units dispatch the available airflow generated by the fan's (3) pressure in the various wet rooms. Humidity sensitive air inlets (1), in turn, dispatch fresh air in the various dry rooms (living room, bedrooms) according to their amount of relative humidity.

Such a setup constitutes a typical extract-only system, where fresh air enters into the less polluted rooms (dry rooms), and is extracted from the more polluted wet rooms. As a result, the pollution generated into the wet rooms does not spread into the dwelling. Besides, the same air is used to ventilate the dry rooms and then the wet ones, which limits the amount of energy required to heat the incoming "cold" air.

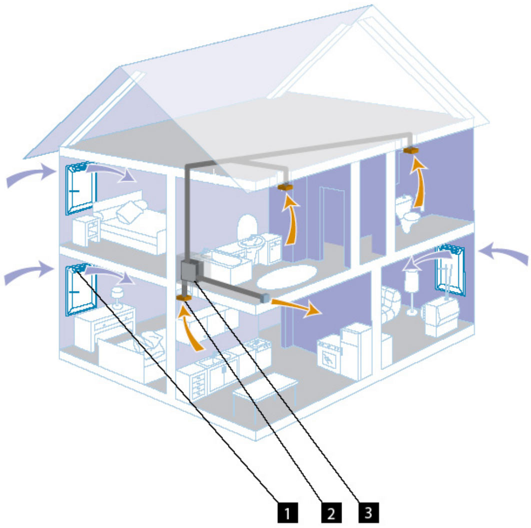

Figure 9: Airflows and humidity sensitive components in a single-house mechanical ventilation system.

7 On-demand airflow dispatching within and between dwellings

A humidity controlled ventilation system provides a regulated dispatching of air inside the dwelling. The air is provided in relation to the needs thanks to the humidity sensitive air inlets and outlets. Heat losses are thus limited in vacant rooms and occupied rooms are ventilated as needed. During day time (Figure 10), air inlets in the living room (occupied) provide more air than those in bedrooms (vacant). At nigh time (Figure 11) the reverse happens.

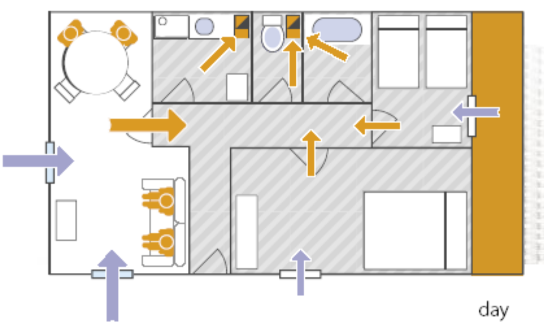

Figure 10: Typical day-time dispatching of airflows within the dwelling

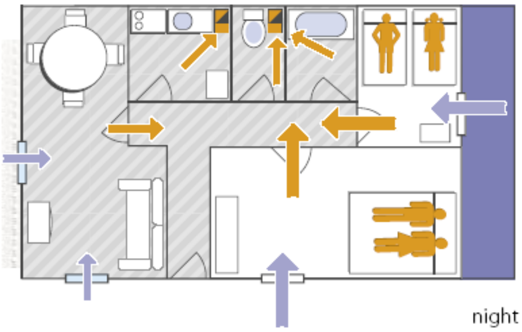

Figure 11: Typical night-time dispatching of airflows within the dwelling.

A humidity controlled system manages the needs in all rooms and dispatches the flow as required. If the need for ventilation increases in the kitchen for example, the extract unit will open up, thus increasing the whole dwelling air change rate[1]. Part of the pressure will then be transferred from the extract unit[2] to the inside of the dwelling, thus increasing the airflow admitted through the air inlets, until the extracted and incoming[3] airflows are balanced.

On the other hand, if the demand (humidity) increases in a 'dry' room, the air inlet will go from a standard minimum free section of e.g. 5 cm² (required to ventilate VOCs) to a higher free section. A partial transfer of pressure will occur from the air inlets towards the extract units. This, added to the humidity coming from the dry rooms, will increase the total air change rate of the dwelling. The dispatching of airflows between the kitchen, bathroom and toilets will depend on their respective states of pollution. The whole system is therefore able to manage the whole dwelling in a consistent and combined way, from air supply to air extract.

The various rooms inside a dwelling have different needs that are handled by the humidity sensitive system. Similarly, different dwellings have different needs and these needs are time-dependant. In a multi-family house (Figure 12), the humidity rise in the most occupied dwellings induces the opening of the air inlets and extract units, thus increasing the air change rate. In less active dwellings, smaller openings contribute to energy savings on heating.

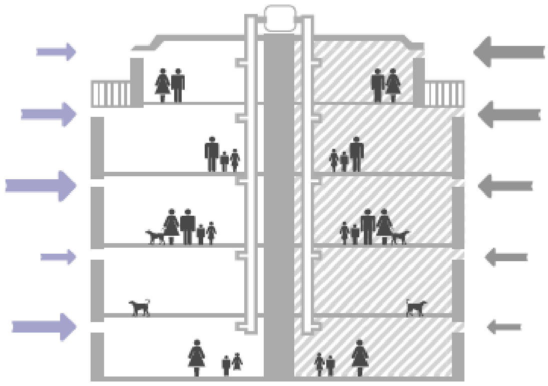

Figure 12 : Dispatching of airflows between dwellings as a function of occupation in Mechanical Extract ventilation

Mechanical ventilation systems installed in multi-family houses are not always able to avoid the generation of higher pressures close to the fan than further away, whatever the care in the design and installation of the system. In passive stack ventilation configurations, the thermal draughts tend to create more pressure in lower dwellings whereas higher ones can suffer from insufficient pressures. Humidity control of ventilation will reduce the pressure differences between floors. Where the pressure is higher, humidity will be extracted more rapidly, and the extract units will go back to low/normal opening. More pressure will then be available to the other dwellings.

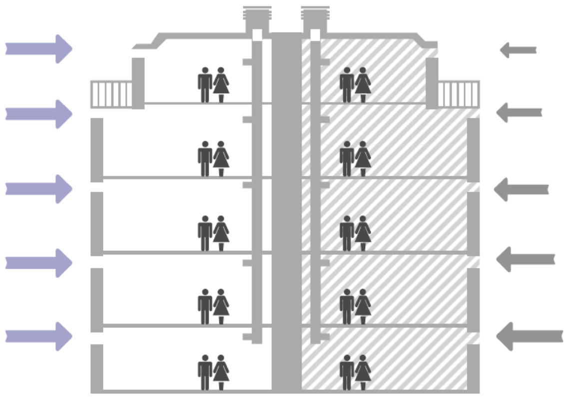

Figure 13: Humidity control of ventilation balances the airflows across floors in passive stack ventilation

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[1] Note that fans for humidity-controlled systems operate at constant pressure.
[2] When the extract unit located in the kitchen is wide open, the pressure drop there goes down and the pressure is transferred to the rest of the dwelling, down to the air inlets and the building envelope.
[3] Airflow coming in through the air inlets and the building envelope.

8 Benefits of humidity controlled ventilation

8.1 Better control on heat losses

Depending on the type of dwelling, its air-tightness, the type of ventilation involved (passive stack or mechanical) and the benchmark reference, humidity controlled ventilation can save up to about 60% on heat losses.

The Technical Assessment (Avis Technique) delivered in France to humidity controlled mechanical ventilation systems defines the energy gain in comparison with a self-regulated system, and for the regulatory airflow. Depending on the dwelling size and configuration (number of dry rooms, number of bathrooms and toilets), the gain ranges from 27% to 57%. Those results are computed by a dedicated software, named SIREN and developed by the CSTB.

The in situ experiment called "Demonstration project EE/166/87" [Ref. 15] was performed on multi-family houses equipped with passive stack ventilation. The measured gains were about 30% as compared with the standard fixed ventilation system. The indoor air quality was equivalent.

A humidity controlled ventilation system induces low extra investment costs in comparison with similar technologies without airflow variation (fixed or self-regulated systems). The return on investment is achieved after a small number of years of use[1].

The energy gains mentioned are due to a reduced mean airflow as compared to a fixed or self-regulated airflow defined by the regulations.

As mentioned earlier, the reduced mean airflow does not impact the quality of the indoor air, as long as the systems is able to provide a high airflow in response to a time-limited need. The air quality obtained with such a statistically reduced airflow is even better, in some cases, than with a fixed airflow system, since the peak airflow can be higher. This however does not significantly change the air heating requirements since peak airflow occurs rarely and in a very time-limited way. Besides, peak airflow is very seldom simultaneous in rooms or in dwellings.

8.2 A better air renewal and a better protection of the envelope

The efficiency of humidity controlled ventilation has been evaluated both with computer simulations (CSTB Technical Assessment) and in situ experiments.

In the project "HR-VENT" [Ref. 4] the values of pressure, airflow, temperature and humidity were monitored in 55 dwellings equipped with humidity controlled fan-assisted passive stack ventilation. Run over a period of 2 years, this monitoring has provided very precious results on passive stack and hybrid ventilation performances.

"HR-VENT" has demonstrated the ability of a humidity controlled system to adapt the airflow to the amount of humidity with very brief occurrences of peak airflows (Figure 14).

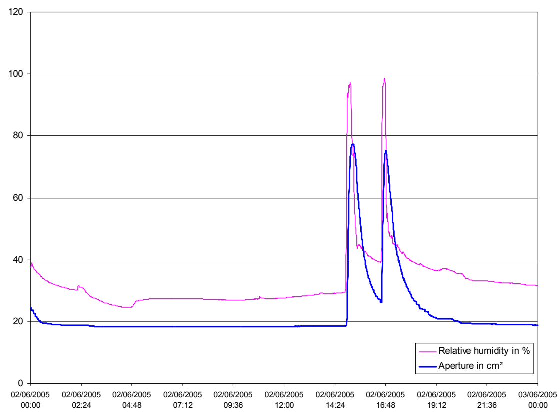

Figure 14: Opening of the humidity sensitive air extract grille (blue, in cm²) and indoor relative humidity (pink, in %) over one day, in a bathroom.

Figure 15 plots the daily minimum, maximum and mean airflows in a bathroom over one year (one point per day). The graph demonstrates the ability of the extract grille to adapt the airflow, with a mean daily amplitude of 80 m^3/h, and very high peak airflows.

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[1] Return on invest not only depends on the price of the systems but on the application: envelope (insulation, leakage, etc.), use (occupants behaviour), configuration as well as weather conditions influence the results.

The mean airflow is very close to the minimum one, which ensures a low energy impact and reinforces the results presented in the previous paragraph.

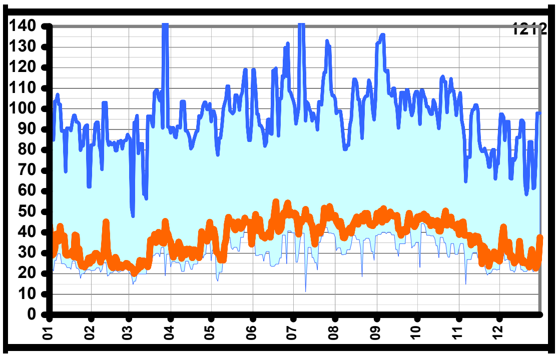

Figure 15: Range and mean daily airflows in a bathroom over one year. Blue: minimum and maximum airflows. Red: mean airflow.

8.3 Protection of the walls against condensation

HR-VENT project has also shown that a humidity controlled system contains condensation phenomenon on the colder parts of the internal envelope walls.

A calculation based on the temperature and humidity recording inside the dwelling has shown that there was no condensation on the internal envelope walls over the whole year and in all dwellings (Figure 16).

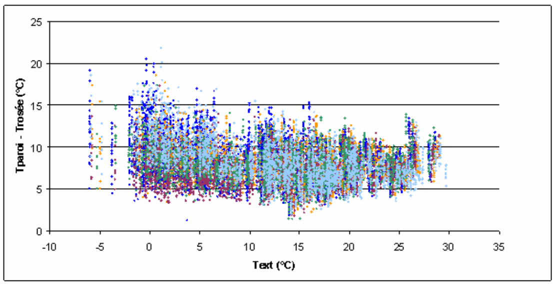

Figure 16: Difference between the wall temperature and dew-point for all dwellings over a year.

The graph shows that at all times the wall temperature was higher than the dew temperature of the indoor air. A good handling of humidity by the ventilation system thus allows preventing condensation.

9 Quality criteria for humidity controlled ventilation

It has to be emphasized that it is not enough to drive a shutter relatively to humidity to ensure a good control of the airflows and of the indoor relative humidity.

The European test standards EN 13141-9 and 13141-10 specify how to characterise humidity sensitive air terminals in order to guaranty good performances.

The air inlet's thermal coefficient C determines the humidity sensor's temperature as a function of the indoor and outdoor temperatures. This coefficient is a key characteristic for the good operation of the terminal since the 'reading' of the relative humidity by the sensor depends on its own temperature.

$C = (T_{in} - T_{sens}) / (T_{in} - T_{out})$

Where

T_{in} is the indoor temperature

T_{out} is the outdoor temperature

T_{sens} is the sensor temperature

It is also crucial to have a low hysteresis, i.e. similar behaviours during the opening and closing of the shutter. <u>This requirement excludes some technologies such as wood and other materials.</u>

The responsiveness (i.e. the time to react to a strong rise of humidity) must be high to avoid spread and deposit of the pollution. The HR-VENT experiment has shown that the humidity sensitive extract grilles could react in less than 2 minutes.

Reliability is also a key criterion. In situ experiments as well as tests conducted on products with several years of operation have shown that the products maintain their hygroscopic performances over more than 10 years.

Last but not least, humidity controlled mechanical systems require specific fans with constant pressure operation, in order to provide a direct conversion of the free opening area into a value of airflow.

This non exhaustive list of criteria emphasizes the need to manufacture and characterize the components of humidity controlled systems with great care. The European test standards are a first step, but demand-controlled ventilation, as a technology, would benefit from even more standardized quality criteria.

10 Simulation of performance

The lack of evaluation software tools has been and still is a barrier to the introduction of dynamic ventilation systems in some countries.

Designed by the CSTB (France) to assess the energy requirement and indoor air quality of humidity controlled systems, the SIREN software offers a calculation method to characterize the aeraulic behaviour of buildings as well as the occupants' exposure to pollutants. It computes the thermal losses and the cumulated CO_2 values in ppm.h. The input data are: the type and configuration of the model dwelling, occupation scenarios, the ventilation system and the local weather data. Today the software is designed to assess mechanical ventilation systems, but complementary modules are planned to include natural and hybrid ventilation in multi-family houses.

Another software, named CONTAM, and designed by the US National Institute of Standards and Technologies (NIST) also offers assessment tools for dynamic ventilation.

11 Worldwide development of humidity controlled ventilation

Since 1980, more than 2 millions dwellings worldwide have been equipped with humidity controlled ventilation.

In situ experiments and tests have shown that it can offer an improved indoor air quality as well as energy savings as compared with constant airflow extract only technologies. Humidity controlled ventilation relies on two complementary approaches: a statistical approach regarding the energy performance with significantly reduced mean airflows over the year, and an occasional high ventilation rate to maintain a high indoor air quality. The characterization of such dynamic systems influenced by numerous parameters is certainly a hard task, but tools are appearing, and national regulations progressively adapt to this technology.

Humidity controlled ventilation is easy to implement, especially during the renovation of multi-family houses – a sector which is a large potential of energy reduction. Where heat recovery systems cannot be implemented, or when installation and maintenance costs matter, humidity controlled ventilation offers an alternative, in line with the rational use of energy.

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The Air Infiltration and Ventilation Centre provides technical support in air infiltration and ventilation research and application. The aim is to promote the understanding of the complex behaviour of the air flow in buildings and to advance the effective application of associated energy saving measures in the design of new buildings and the improvement of the existing building stock.