Annex 41
Whole building heat, air and moisture response

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ABSTRACT

Combined heat, air and moisture (HAM) simulation at the envelope level and building simulation have been two separate activities for many decades now. In HAM-models, inside temperature and inside relative humidity are handled as known boundary condition, while all building simulation tools predict inside temperatures and net energy demand without any consideration for relative humidity.

Things started to change when airflow modeling became doable. That step not only allowed a better quantification of ventilation related energy consumption but it also permitted a refinement of the humidity balances in the building. However, at least two linkages between the building and the indoor environment remained poorly explored: (1) the fact that many adventitious air flows enter and leave the building across the envelope causing a complex pattern of indoor air washing, wind washing, air looping, infiltration and exfiltration in it and (2), the fact that moisture buffering in indoor finishes and furniture delays and dampens the inside relative humidity. Both phenomena have an impact on the energy consumed for heating, cooling and air conditioning, on durability and on perceived indoor air quality. Analyzing those linkages which are at the basis of whole building heat, air and moisture transport and studying the impact on energy consumption, durability and perceived indoor air quality are at the core of the annex 41 activity.

KEYWORDS

Combined heat, air and moisture transport, moisture buffering, air leakage, energy, durability, perceived indoor air quality

INTRODUCTION

Although it is well known that the heat, air and moisture flows (called HAM) generated by building use and entering from outside, that the HAM flows that traverse the enclosure and the HAM flows that are injected by the HVAC system are in permanent and mutual balance, simulation tools and the designers that use them do not currently consider that reality. Building designs are scrutinized on the heat needed, while HVAC-systems are dimensioned as to deliver that heat with as main goal to keep the indoor temperature at comfort level. Yet, indoor relative humidity is typically kept free floating, except when full air conditioning is applied, as it is perceived to be less important. Few designers detail the envelope taking into account the full hygrothermal load from inside and from outside, while hardly anyone considers the whole heat, air and moisture balance that develops between the building's interior, its envelope and the outside environment. This is a pity as air pressure differences inside the building and between the building and the outside for example may generate airflows that change the heat, air and moisture response of the envelope and the building drastically, while buffering effects could dampen relative humidity fluctuations significantly. Resulting air ingress, possible rain penetration and the moisture deposits both cause in the envelope could not only negatively affect energy consumption but also trigger the envelope's durability. Simultaneously, inside relative humidity, if not well managed, may affect perceived indoor air quality and become a driving force for mold infection and dust mite multiplication.

Clearly, the whole building heat, air moisture response has impact on human comfort, indoor air quality, energy consumption and envelope durability. Enough reasons to start an Annex on the subject, termed as Annex 41, Moist-En (Hens, 2003)

STATE OF THE ART

Building modeling started in the fifties. From the beginning, the goals were quantifying the net energy demand, analyzing the ways that demand could be reduced by building related measures and getting information on the temperature without heating and cooling as this allowed to evaluate overheating. Later-on, HVAC-models were added and energy consumption became the quantity quantified. Hardly any model, however, was able to model the air and humidity balances in the building. Instead rough estimates on infiltration and ventilation air flows were used and humidity remained untouched (ASHRAE, 2001)

During the same period, the research effort on heat, air and moisture transport focused on the envelope. In the sixties, a few simple evaluation tools became popular. They scaled reality down to two steady state transport modes: heat flow by conduction and water vapor flow by diffusion (Glaser, 1958, Glaser 1958, ASHRAE, 2001). Today highly sophisticated one- and two-dimensional full heat and moisture models are available that allow modelling vapor and liquid flow, that are transient in nature, that consider moisture sources such as wind-driven rain, rising damp, initial moisture, sorption and desorption, interstitial condensation and surface condensation and that allow to quantify some of the consequences of unfitted moisture tolerance, such as hygrothermal stress and strain, mold infection, corrosion and frost damage (Pedersen, 1990)(Carmeliet, 1992)(Künzel, 1994)(Grünewald, 1997)(Sedlbauer et al., 2003). Examples of such models are: Match, Wufi, Latenite and HygIRC. In Europe, the one-dimensional full models are even in the process of becoming standardized procedures. All envelope models, however, take the indoor climate (temperature, relative humidity, air pressures) as known boundary condition. This of course is fiction, except in case of full air conditioning, when the indoor is completely uncoupled from the outdoor. Also a correct implementation of wind driven rain and its impact on the building envelope remained a weakness. In fact, although wind and wind driven rain has been a research topic for many decades, one had to wait until CFD became a commonly used tool before a turn could be made from experiment and simple calculation to full simulation and prediction of the rain load on the envelope (Lacy et al., 1962)(Blocken et al., 2004)

As already said, the analysis of the airflow patterns within a building was an important step on the road to whole building HAM analysis. Basic work on inter-zonal flow has been done by the Comis group and Annex 23 (Allard et al., 1990). The last decade, large numbers of researchers use CFD to analyze intra-zonal flow (Baker et al., 1994). The linkage between the flows in the building and those in the envelope, however, is hardly established, although the study of air flows in and through envelope parts has underlined their importance for a correct evaluation of the hygrothermal response (Kronvall, 1982)(Trechsel ed., 1994).

Finally, the last years, we saw a renewed interest in indoor moisture buffering by finishing layers and furniture (see figure 1) (Svennberg et al., 2004). A few software packages have been developed, which allow evaluating the effect. Measurements on buffering capacity of finishing materials and furniture are performed in several laboratories. Nordtest initiated a research program on the subject, included a round robin on buffering (Rode, 2003).

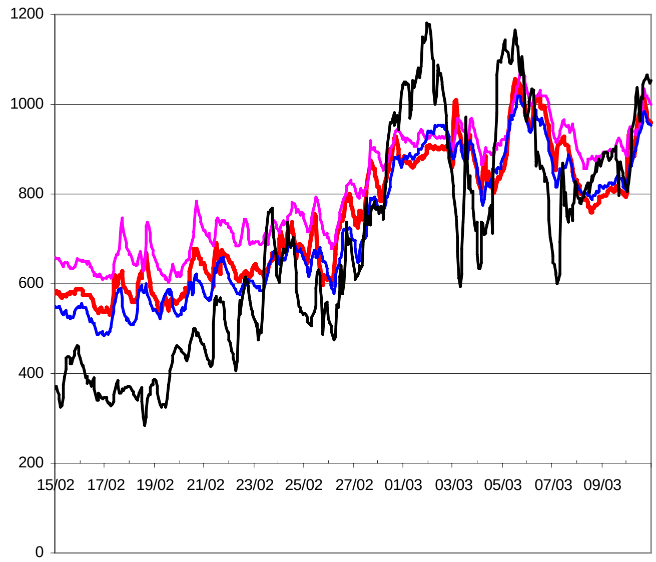

Figure 1 Inside vapor pressure in a naturally ventilated office. Black shows the outside vapor pressure, purple, red and blue the inside vapor pressure. Hygric inertia dampens the swings and causes the inside excess to turn negative when the weather changes from cold to moderate

ANNEX OBJECTIVES

The annex is meant to establish a holistic view on the overall HAM transfer in buildings and their envelopes. The specific objectives are:

1. Exploring the physics involved in whole building HAM response. That includes basic research, a further development of models, measuring the moisture storage function of finishing materials and furniture, mock up testing and field testing. Test results will be used to verify and validate models by inter-comparison and confrontation with measured data. Objective 1 should establish a basic understanding of the overall HAM-flows that come from inside and outdoors under different weather conditions (cold, warm and dry, warm and humid and maritime) and their effect on the building's overall hygrothermal response.

2. Analyzing the effects of whole building HAM on comfort, indoor air quality, on energy consumption and enclosure durability. Good comfort and good indoor air quality are part of overall users satisfaction. As everyone spends up to 80% of her/his time in buildings, the whole society is benefiting when comfort conditions are optimal. Avoided energy consumption helps sustainability. From that point of view, humidity changes, termed as latent energy, are very significant in warm moist regions, where latent heat often makes over 50% of the annual cooling load. Optimal moisture storage solutions may reduce that percentage. The result is a net saving in energy resources and less CO_2 produced, not only now but even more in the future when the desire for well-controlled indoor environments will further increase. Better durability finally also means more sustainability. A long service life in fact economizes on material use, embodied energy and embodied pollution. Damage statistics learn that bad moisture management is the most important cause of shortened service life. Objective 1 should translate itself in original research, damage case evaluation and literature reviews. Simultaneously, measures must be studied as to moderate possible negative impacts of combined HAM transfer with air- and rain-tightness, correct moisture management, optimal thermal insulation, well balanced humidity storage and lower energy demands as some of the focal points.

ANNEX ORGANISATION

The work is structured in four subtasks:

Subtask 1: modeling principles and common exercises

Subtask 1 concentrates on whole building HAM modeling with special emphasis on HAM-transfer between the surroundings and the outside surface of the building envelope, HAM transfer in the envelope, HAM transfer between the inside surface of the envelope and indoors, HAM transfer from outdoors to indoors and vice versa through leakages, purpose designed ventilation grids and HVAC-coupled in- and outlets, HAM transfer between the building envelope and the interior partitions, HAM transfer between the indoor air and furniture and HAM transfer between the different zones in a building. Models that result from the subtask will take into account parameters such as location and orientation of the building, the heating, ventilation and air conditioning systems, adventitious and user defined air flows, moisture response by hygroscopic and capillary-active materials in the building enclosure and furniture, the type of room (bathroom, living room, etc.) and user's behavior (number of people, activities (moisture and energy production, etc.), frequency and duration of window ventilation). Numerical codes that integrate the above mentioned elements will be verified and validated and their applicability demonstrated, using common exercises as the main vehicle. The actual schedule of common exercises looks as follows:

Exercise 0	Dry BESTEST for validating the thermal part of the models (done)
Exercise 1	Wet BESTEST. Generating vapor in the BESTEST building, predicting of the inside relative humidity in isothermal and transient conditions (done)
Exercise 2	Simulating experimental results at room level under isothermal conditions
Exercise 3	Simulating experimental results at room level under non-isothermal conditions
Exercise 4	Simulating a coupled room configuration under isothermal conditions
Exercise X	Real world case, evaluating the impact of adventitious ventilation flows that traverse the envelope on durability and energy consumption

Exercise 2, 3 and 4 are meant as validation steps. In all three cases experiments have been done and the objective of the exercise is to simulate the experiments, to compare the calculated with the test data and to judge the agreement between both

Subtask 2: experimental investigation

Subtask 2 primarily considers the impact of moisture buffering in finishing materials and furniture on the relative humidity in the indoor environment. For that purpose material property data, surface film coefficient values and design parameters required for modeling will be generated. More specific goals of the subtask are to collect material property data needed for modeling and characterizing buffer effects, to study the parameters affecting moisture transfer between the air and a material surface both in steady state and transient conditions, to provide the data for validation of the models through well monitored benchmark mock-up cases and to generate concepts and practical applications of moisture buffering systems. For that purpose, the Annex 24 material database will be extended by adding more data on vapor permeability, specific moisture capacity and air permeance. Also a round robin on measuring vapor permeability, specific moisture capacity and buffering ability of unpainted and painted gypsum board is going on and well monitored mock-up tests are performed.

Subtask 3: boundary conditions

Subtask 3 concentrates on outdoor and indoor climatic conditions, on the heat and moisture loads, on air pressures generated by wind, stack and fans as parameters to be used in whole building HAM model(s). The subtask has as specific objectives to characterize wind and wind driven rain patterns around buildings, to analyze absorption and runoff properties of exterior cladding, to quantify the moisture load due to condensation on exterior building surfaces by clear sky radiant cooling, to collect data on interior heat and moisture release, on interior temperature and interior relative humidity in different types of buildings and to come to a usable classification of indoor climates

Subtask 4: long term performance and technology transfer

Subtask 4 starts from a clear fit for purpose concept. Buildings should provide required indoor environment and comfort at low energy costs during an economically feasible service life, what the exterior climate and usage pattern may be. Special attention will go to the effects of moisture on the indoor environment, on durability and energy consumption with problems in buildings caused by a high indoor humidity as specific topic. Predicting long term performances, of course, demands a frame of reference. That may for example involve extending the limit state approach to durability assessment. Within subtask 4, this will be done for some types of decay, mould being one of them. In such limit state approach, two levels intervene: risk assessment at the design stage and prevention methods for use during the building's service life.

Also an effective communication with practitioners, building services engineers, project managers, administrators and educators is of importance. Subtask results should be accessible to everybody outside the scientific community. Because of different priorities and training, end-users have different perspectives. That means, it is necessary to put the results into a form which is easy to understand and to use by the following groups: (1) private industry, (2) practitioners, (3) educational establishments. Of course, this cannot be realized globally within subtask 4. The report of subtask 4 will anyhow focus on it.

ANNEX PRODUCTS

The products of the annex will be designed for use by the building research community, by engineering offices that focus on building physics, energy, HVAC and sustainable construction, by material and building system developers, by corporations with an interest in high performance systems, by building designers and by educational institutions. These products will include

In general	An internet site. The site contains all meeting proceedings, all annex papers and common exercise results and the drafts of the final reports (http://www.kuleuven.ac.be/bwf/projects/annex41/).
Subtask 1	Final report on whole building HAM modeling with an appendix discussing the results of the common exercises
Subtask 2	Final report documenting all experimental investigations (round robin on gypsum board, test room measurements) and a database with moisture storage properties of finishing materials and furnishings.

Subtask 3	Final report on indoor and outdoor boundary conditions for whole building HAM simulation with special emphasis on wind driven rain, undercooling, air pressure differences that may exist between the inside and outside and moisture, measured inside climate data and heat and moisture sources within buildings
Subtask 4	Final report on long term performances in relation to comfort, durability and energy, demonstrating the benefits of a well controlled whole building HAM response

All final reports will be published in hard copy form and on CD-ROM.

CONCLUSION

Annex 41 has a huge program to cover. The initiative yet motivated 18 countries and more than 50 experts to participate, underlining the interest in the topic and the expectation people has that the activity will not only generate a better understanding of the whole building heat, air and moisture response but also establish ways how to benefit from that knowledge in the design and construction of buildings and HVAC-systems in terms of better comfort, better indoor air quality, better durability and less energy consumed. The work started 18 months ago and will proceed for another 30 months.

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