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Building Physics and HVAC: different but complementary

H. Hens, rapporteur
K.U.Leuven, Department of Civil Engineering
Laboratory of Building Physics
Celestijnenlaan, 131, B-3001 Leuven, Belgium

1. INTRODUCTION

A first question attendees from oversees may ask is: what is meant by building physics? In fact, the name is hardly used in the Anglo-Saxon and Roman countries. In Northern Europe instead, the indication ‘building physics’ points to the discipline which covers all physical aspects of influence on building performance and building use. Three main fields of knowledge are involved: (1) heat and mass, (2) sound, (3) light. Energy for example belongs to the first. Room acoustics is part of the second. Day-lighting takes a big share in the third. In Germany, also fire safety is included in building physics. This is less the case in other countries.

The fact that building physics covers heat and mass transfer, creates strong mutual relations with HVAC. In that respect, both disciplines are complementary, though different. Next paragraphs first highlight the differences and common interests, after which a glimpse is given of the actual trends and the way the conference papers fit into it.

2. DIFFERENT

2.1 HVAC

Building physics and HVAC reflect two cultures. HVAC is part of mechanical engineering. Understanding how boilers, fans, pumps, chillers, compressors, etc. work and should be constructed supposes a good knowledge of thermodynamics, heat transport, hydraulics and mechanical construction, four domains wherein mechanical engineers have a strong tradition. Sizing HVAC-components is also quite straight-forward. A boiler has to produce x MW, a pump should displace y kg water per hour against a pressure head of z kPa, a chiller needs a cooling capacity of u MW at a COP w, etc. This fits well within the culture of a mechanical engineer.

The only random variable which intervenes is the load the building causes. This load question is tackled in the design stage with simple, deterministic calculation methods. As a consequence, many HVAC-engineers reduce a building to U-values and ventilation rates. As far as cooling is concerned, also solar and free gains are part of it. For them, the building is a load, not a quality issue. In fact, also bad buildings need a HVAC-system. Bad buildings may even increase the turn over of HVAC-companies, a nice example being the promotion made today for dwelling cooling in moderate climates, such as Belgium. The passive solar lobby, which never felt restrained by a well balanced insight in the complex physical behavior of buildings, first stimulated architects to use more E-S-W oriented glazing. This being done, the tenants detected that even in a cool climate, solar gains may result in overheating from March to October. No problem, HVAC-companies launched the answer: cool. Ridiculous of course in a climate, which is one big cooling reservoir. Call this a bad application of a creative concept, passive solar, conceived to decrease the energy consumption for heating ending in an increase in primary energy use because of cooling.

2.2 Building Physics

Building physics has its roots in applied physics. Originally, the discipline had no intention to interfere with building construction. Physicist analyzed heat and mass flow, they studied acoustics and played with light. The models they developed concerned ideal systems, such as an infinite wall, a homogeneous material, flat composite elements, etc. A body of knowledge anyhow developed, which after a long period of hidden existence moved to building practice. Architects however had not enough scientific basis to use building physics as a design instrument. So, a move towards building engineering started, as was seen with structural design as well, some century ago.

A full application of the rationales, embodied in building physics, implies a shift in the building sector, from the ‘art of construction’ to a performance based approach. For many years this was a wish. The evolution of the last decades, however, made it reality. Energy efficiency became an issue after the first energy crisis of 1973. This brought thermal insulation in the picture. Gradually two negative consequences of the insulation reality were experienced: thermal bridges and increased moisture sensitivity. In the eighties, energy analysis highlighted the role of fenestration as a solar collector. Designers however forgot this may be beneficial in winter, but not in summer. Caulking the windows in adventitious ventilated buildings, a measure promoted the first years after the energy crisis of 1973, jeopardized the indoor air quality and increased the risk on visible fungal defacement. Traffic and indoor noise both underlined the benefits of a better acoustical insulation. The high energy consumption coupled to electrical lighting brought day-lighting back in the picture, etc.

The result is that today designers, standardization bodies and builders are convinced that a correctly balanced performance rationale, based on a fitness for use concept, is the right way towards a guaranteed building quality. There-in, building physics is a key discipline, with a strong impact on design and construction.

3. COMPLEMENTARY

HVAC-systems have as first objective to offer the tenant and user a comfortable indoor climate. As long as the air temperature was thought to be the most important comfort parameter, their role was dominant. A better understanding of the humans as thermal system in relation to the environment, however, learned that the radiant temperature is of equal importance. This gave the building its proper role in thermal comfort: offering a radiant temperature, close to the air temperature. As a consequence, thermal comfort became a common building physics-HVAC issue.

As well HVAC as building physics are interested in heating and cooling loads and the building as energy consumer. Prime objective from a fitness for use point of view is a minimum load and a minimum consumption, at least as far as economically feasible and environmentally beneficial. This objective of course changes the type and sizes of all HVAC-systems and the control strategies used. Minimum load is achieved, among others, by an optimal thermal insulation. The lower the U, the more detrimental, though, the effects of poor workmanship, combined heat, air and moisture transport and thermal bridging. All three are seen as building physic’s issues. However, due to the influence on load and consumption, the HVAC-side also shows an active interest in those questions, as proven by the activities of ASHRAE in those fields.

The V in HVAC means ‘ventilation’. In countries with a hydronic heating tradition forced ventilation in dwellings was no issue until tight windows from the seventies on and the move from local stove-heating to central heating reduced adventitious natural ventilation to an unacceptable minimum. As a consequence, correct ventilation became a key concern. Building physicist focused on the air permeability of the envelope, on indoor air quality, on the moisture balances indoors and on fungal defacement, while HVAC-engineers concentrated on the use of balanced ventilation, if possible with heat recovery. The efficiency of those systems however depends of the air-tightness of the building, i.e., again a cluster of common interests.

The last years, new concepts, such as active envelopes are promoted. Architects love it, as the choice reflects high tech. Active envelopes are advertised as energy efficient, highly comfortable, etc. The proof should be their ‘lower’ U-values, higher inside surface temperatures and the superiority in mastering solar gains. Active envelopes may be part of the HVAC-system, for example as a return plenum. Hence, an analysis in depth proves that, if so, the active envelope becomes an energy spender instead of a efficiency measure. Another common concern, isn’t it

One may go on. Building physics and HVAC are different, for sure, but they have so many common interests, that they behave as a twilling. The main difference is the objective. Building physics cares for the building and its tenants, while HVAC focuses on the building services.

4. ACTUAL TRENDS

Building physics today develops along various tracks. To mention three:

1. enhancing the performance concept
2. tightening the gap between research and design
3. advanced building components

As in each field of applied science, there is also a continuous need for (4) knowledge build up, knowledge deepening and knowledge broadening.

4.1 The performance concept

The performance concept should change the traditional ‘art of construction’ habit of the past into a knowledge based quality rationale, which figures as a translation of the interactions between the user and the society at one side and the building and its services at the other side. Performances are best defined as all physical (and functional) properties of a building construction which can be expressed in a numerical or at least exact way, are predictable at the design stage and controllable during and after construction. The definition implies four topics for sustained research work: (1) the needs (comfort, health, durability, economy, environment), (2) their translation into performance requirements, (3) the development of design tools and (4) control methods.

The needs are addressed in other technical sessions at this conference. No papers focuses on the translation of the needs into performance requirements. Still, much work has to be done there. What for example with the impact of LCA on the energy efficient choices of tomorrow? How LCA may change the energy performance standardization? Is it true that zero-energy houses are unacceptable from that point of view?

Five papers instead look to design tools or upgrade control instruments in some way. (Garde et All, 1997) tackles the problem of energy conscious construction in a tropical island climate. Clear prescriptions in relation to shading, thermal insulation and ventilation are formulated, which allow the designer to make choices and the consultant to do a first check. (Ozaki et All) prove that wall designs with a vapor retarder inside, which are developed for cold region applications, do not work very well in a moderate, humid climate, as the direction of the moisture flow reverses in summer, outside to inside instead of inside to outside. A vented cavity behind the exterior cladding gives some relieve, but no guarantee on a risk-free moisture response. The paper also contains specific design recommendations. (Fissore, 1997) compares different rationales used in modeling the heat exchanges between a window and indoors. The conclusion is that the simple approach with a constant surface film coefficient inside and a fixed U-value may predict heat losses which deviate substantially from the results, obtained with a more correct model where convection and long wave radiation are kept apart. (Sarte et all) come to an analogous conclusion as they show that a traditional calculation with constant U-values, including a constant surface film coefficient inside for combined convection and radiation, leads to a serious overestimation of the heating demand in an intermittently heated furnished office building. Convection alone gives more reliable results, although too optimistic, when compared with the outcome of a detailed analysis of the radiant heat exchanges inside. (Corrado et all, 1997) finally treat fenestration in relation to solar radiation. Using an on incidence angle corrected solar transmittance results in lower time averaged solar gains through a window system than when a constant solar transmittance is handled. In the three cases, however, conclusions in relation to design checks and controls are not formulated yet.

4.2 Tightening the gap between research and design

Design has its own rationale. Characteristic for the design process is that the knowledge grows as the process advances. At the start, few things are hardware, most are ifs. Along the line of advancement, decision are taken, loops are made, conflicting performances resolved and decisions refined. These first steps ask for conceptual models (decision trees, handy formulas, double entry arrays, etc.). The farther one progresses in the design process, the more control calculations are needed, a job which demands fully developed control tools. The difference between conceptual models and full control tools is not well understood by researchers. Most in fact concentrate on simulation methods, where the input supposes the design as being finished. All materials known, the sequence of the layers fixed, the geometry as an invariant, etc. Nice, but only useful after the pre-design is finished and fine tuning by control is the activity left. We classified two papers under the heading ‘upgrading control tools’. (Lombard, 1997) analyses the HVAC system dynamics of hot and cold air mixing inside, downstream a diffuser through measurements and CFD-calculations. A simplified model with mixing time constant is proposed as an aid for choosing the best location of the temperature sensor. (Roux et All, 1997) apply model reduction techniques to a floor heating calculation module before implementing it in the Trnsys software environment. The example they treat with the software learns that temperature control policies play an important role in relation to the energy efficiency of floor heating and the stability of the inside temperature.

After construction, things are easier. The design has become hardware and the only thing left, if needed, is checking if the building and the building parts perform as planned. An example of this is (Iwamae et All, 1997), where condensation in a leaky crawl space with vapor retarding ground cover is analyzed. Adding a moisture absorbing layer to the ground cover reduces the problem to some extend. Crawl space ventilation on the contrary is not efficient.

4.3 Advanced building components

The connotation ‘advanced building component’ covers a wide range of ‘new’ developments. To mention a few:

- facades used as active air to air heat exchangers
- TIM-facades turning the envelope into a heat delivering device
- new glazing materials with solar transmittance function of the incident radiation
- PV-facades turning the envelope into an electric generator
- building components constructed with recycled materials

- vapor retarding foils with diode properties
- etc.

Four papers consider new developments. (Hall at All, 1997) describe the use of reconstituted open cell PUR-foam in floating floor applications with as aim to upgrade the impact sound insulation of light- and heavy-weight floors. They report how the research was conducted and the product developed. One of the energy-related advantages they mention is that using reconstituted foam saves on embedded energy. (Hens et All, 1997) discuss the hygro-thermal performances air-tightness, U-and E-value, transient response, hygro-thermal stress and strain, moisture response, thermal bridging for TIM-facades. They underline that TIM may improve energy efficiency but at the price of more overheating, increased cracking risk in the backing massive wall and a delicate moisture behavior. (Corsi et All, 1997) treat the evaluation of electrochromic glazing and related switching control strategies, optimized for both energy efficiency and visual quality, in an office building with the DOE 2.1E software. Apparently, thermal comfort was no part of this optimization. (Russo et all) finally analyze the thermal benefits of attic radiant barriers. They show that the benefits of using them are marginal in cases were a good thermal insulation is in place. When in addition attic ventilation is provided, the effect of both measures together out-ranges radiant barriers completely.

4.4 Knowledge build up

As is the case on many conferences, most papers could be classified under this heading. We nevertheless tried to be somewhat more specific, see above.

Quite new is the attention for the stochastic nature of performance prediction. In fact, boundary conditions in most cases are only known within certain limits. The same holds for the properties of all materials, the starting conditions and even the geometry. The consequence is that only probability distributions can be calculated. Well known examples are the probability that a design will demonstrate moisture problems, or that a cladding may crack within a fixed period of time under repeated moisture and temperature load. (Hokoi et All, 1997) use a stochastic approach to predict the temperature and cooling load in an enclosure as a consequence of varying material properties, random ventilation rate and varying outside climate. They underline that a stochastic approach gives a designer the opportunity to choose ‘safety margins’ with more confidence than a deterministic evaluation does.

Nice examples of broadening knowledge are (Straube et All, 1997) and (Zhao et All, 1997). Straube gives a well documented overview of driving rain on building facades. His measurements show amongst others the beneficial effect of overhangs on driving rain impact. Zhao in turn reports on a new set of Nu-Ra-relations for convection in fenestration glazing cavities, based on extended CFD-calculations, with the temperature difference, the thickness d of the cavity and the aspect ratio h/d with h the cavity height as main parameters. Design information embedded in the study is that even without considering the edge losses, small pieces of double glazing perform thermally worse than big surfaces.

Other papers deepen acquired knowledge. (Matsumoto et All, 1997) refine the calculation of stack induced convection in a mineral fiber insulation by looking to the effects of sorption/ desorption on temperature and relative humidity build up. (Terashima et All, 1997) compare the measured moisture response of two two-layer specimens with the predicted response. They indicate that the hypothesis of a perfect thermal and moisture contact between both layers could not explain the measured results for none of the two combinations they tested. As well a thermal as a moisture contact resistance should intervene. Some doubt however persist on the results of their calculations. How to explain for example a thermal contact resistance as high as 0.2 m².K/W. As each of the two layers in the specimens has a thermal resistance, lower than 0.1 m².K/W, the influence of this contact value is preponderant! Also, the relative humidity at the warm side surface of the specimens is extremely high: ±94%, i.e. close to surface condensation, etc.

5. CONCLUSION

Seventeen papers are part of this session on building physics. They treat a variety of subjects within the broad field of building physics. Most should be classified under the heading ‘knowledge build up’. We however tried to discriminate in a more detailed way. Anyhow, only a few consider design issues and practice. This of course reflects the origin of many papers. Written by researchers at research institutes or universities in the frame of their PhD-work. One cannot blame for that. However, at a conference which aims to inspire practitioners, this is a pity. Much of the information the papers contain is blurred by difficult mathematics and scientific understatements. Too few papers also integrate knowledge or tackle the apparent conflicts which may exist between performance requirements at the design stage. Hence, building physics produces exiting examples of this: daylight versus energy, ventilation versus sound insulation, ventilation versus energy efficiency, passive solar versus summer comfort, etc. Each design again must resolve these opposite demands and expectations. Perhaps, this is key to ‘the art of high quality consultancy, based on practice related research’.

One last remark on research and knowledge build up. Today, everyone uses computer code, which are a numerical transposition of complex physical models. Many people believe these codes replace testing. The use of black box computer tools has at least one big disadvantage: the feeling for the complex physical reality behind a problem is lost. The simple models of yesterday and the need to test on the contrary created a feeling for what could happen if.. Therefore, we should go on testing. Reality in building physics in fact is far more complex than the most extended model may master.

6. REFERENCES

See the list of papers for this session