BUILDING SCIENCE OUTDOOR TESTING - LESSONS LEARNED AND ONGOING RELEVANCE

Prof. Dr. Hartwig M. Künzel& Dr. Cornelia Fitz

Fraunhofer Institute for Building Physics

Abstract:

In the 1950s outdoor testing was the only way to gain more insight in the hygrothermal performance of buildings and their components. Therefore, the German Institute for Technical Physics (later renamed Institute for Building Physics) in Stuttgart decided to establish an outdoor testing field close to the German Alps where 20 test buildings made of different materials were set-up and examined. Investigations at this field test site were so successful and the impact on the German construction sector was judged to be so positive that the originally provisional site soon became a permanent part of the institute. In the following decades more and more test buildings were added and the main research focus changed several times. The field tests have been increasingly used to validate computational simulation tools and to calibrate laboratory tests. However, even today the field tests cannot be completely replace by less costly means, because there are still phenomena that escape the most advanced simulation tools. For this reason, our field test site is still growing not only in size but also in relevance to the building practice. The paper summarizes the most important research topics dealt with on the past and it explains the current and future perspective of outdoor testing for the construction sector.

1.THE BEGINNING: TEST HOUSES SET UP FOR OUTDOOR WEATHERING

Prof. Dr.-Ing. Herman Reiher, the founder of the Fraunhofer Institute for Building Physics proposed in 1950 to Federal Ministry of Transport, Building and Housing to establish an outdoor testing field for building research. Under realistic climate conditions test buildings, with walls consisting of different materials, were to be tested for their hygrothermal performance and long-term behaviour. The ministry financed the construction of six test buildings. The masonry of one of those houses consisted of $1\frac{1}{2}$ brick walls, a standard at that time. Another 20 test buildings were set up on behalf of construction associations and building material manufacturers. In the summer of 1951 the installation of these test houses began on a vacant site at the foothills of the Alps close to Holzkirchen. This location was chosen because of its rather severe climate with cold winters and high amounts of rainfall compared to other German regions. Therefore, the meteorological data were registered right from the beginning of the first experiments which were carried out as early as 1952. In the 1980s the initial manual meteorological set-up was replaced by an automatic weather station that has continuously recorded all relevant weather data until today, providing the institute with very detailed long-term climate data-sets.

***Figure 1**. The 26 test houses seen from the south after their completion in 1952. They are set up on the outdoor testing field like on a chessboard.*

The main goal of the initial experiments was to investigate moisture related characteristics of building materials and their consequences for the building fabric and the interior conditions. It has been consensus that test buildings are more representative for the real life situation than laboratory tests whose practical relevance was largely unknown. The research question of that time dealt with the possibility to reduce the postulated minimum thermal insulation value of vapor absorbing building materials due to their "humidity buffering capacity". From today's point of view a rather unusual question, but building materials were scarce and real insulation materials were hardly ever used for wall construction. Tests carried out and evaluated between 1952 and 1956 showed that the thermal resistance is a suitable parameter for assessing the hygrothermal performance of building components. This means the problem of interior surface condensation and mold growth in winter can only be solved by requiring a minimum thermal resistance for building envelope components. These findings concluded the original test series.

***Figure 2**. Aerial photo taken of the outdoor testing field from the South. A few of the original test houses are still there in the middle part of the picture. Some of them have been altered or converted in the meantime. The voluminous structures in the north-west corner house offices and laboratories. The southern part is entirely dedicated to unoccupied test buildings where the occupants' activities are simulated by controlling the indoor climate to represent either normal or extreme conditions.*

2. FURTHER RESEARCH FOCUS AREAS

As always, solving one task leads to new questions. This is the reason why the field test site still exists today - 67 years after its foundation. With increasing activities, more staff was required and more space became necessary. A recent picture of the institute (Figure 2) shows that the testing site today is about three times as large as it was at the beginning. In Figure 3 the development of the institute's research topics from 1951 to 2001 is shown and summarized. Most information on research from this period can only be provided by request, while information that is more recent can be found online at the Fraunhofer IBP website.

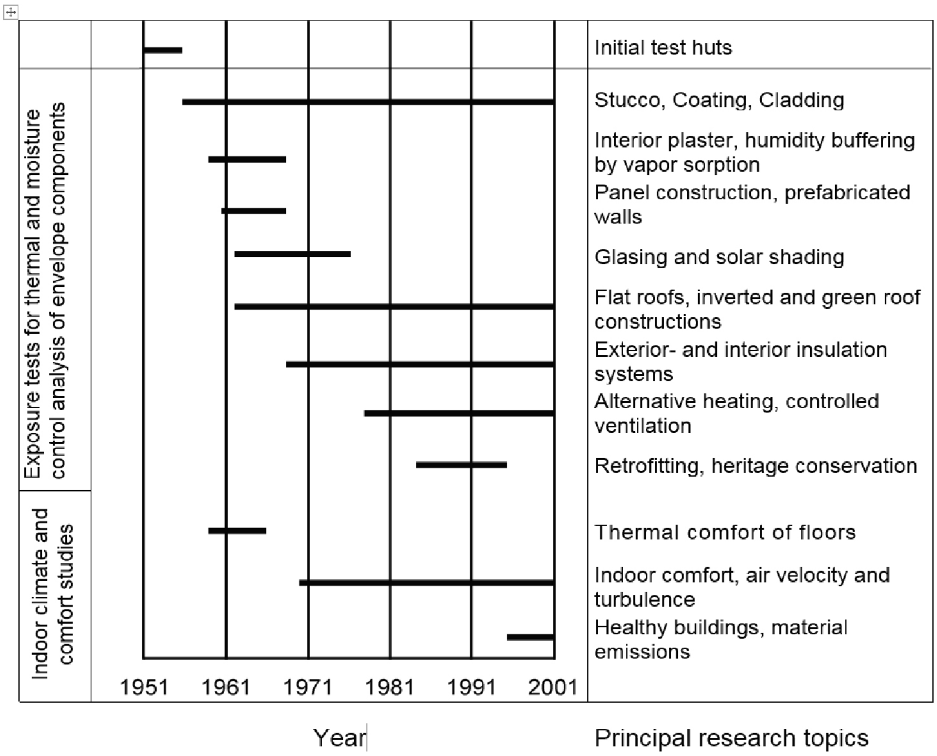

***Figure 3**: Temporal evolution of the principal research topics at the field test site.*

3. EXTERNAL RENDERINGS, COATING, SURFACING

The scientific findings of the field experiments carried out at the test buildings showed, that in all cases the protection against wind driven rain of the traditionally used external rendering was insufficient. Today's self-evident knowledge that the rendering has to match the substrate beneath and that not one single rendering is suitable for various wall materials, did not exist at that time. Water repellant external renderings, assessable by means of the water absorption coefficient and the vapor diffusion resistance, are today standard specification in Germany. Their general solicitation lead to industrially manufactured, application specific, mortar mixtures.

In many variations, the topics "external renderings" and "façade technologies"have been the institute's field of work until today. Just a few key words shall be mentioned to remember what has been the central theme for decades now: synthetic resin render - thermal insulation rendering - salt retaining rendering (so-called renovation rendering) - external wall insulation system (also called ETICS res. EIFS) - ventilated, vented and unvented façade cladding systems.

External wall insulation systems have become increasingly popular in Germany because of their superior performance and excellent durability. However, apart from fire issues there are also hygrothermal challenges that our institute had to deal with in recent years. Examples are surface staining due to microbial growth, rainwater leaks at joints or penetrations (especially around windows), moisture control issues with renewable or nano-porous insulation materials replacing expanded polystyrene or stone wool as well as with the replacement of the external render by ceramic tiles, glass panes or brick veneer.

4. PLASTER, VAPOR ABSORPTION, HUMIDITY BUFFERING

After the first comparative tests had been completed, one topic that was examined at the existing test houses was - besides masonry and rendering - the impact of the plaster or the interior coating on the indoor climate. The course of the internal relative humidity of occupied dwellings is influenced by the vapor absorption and - desorption as well as vapor diffusion properties of the internal surface and home furnishings. The test results showed that vapor absorbing materials dampen the indoor humidity fluctuations by removing water vapor from the indoor air during moisture generation cycles (e.g. as result of cooking, showering, cleaning) and releasing it again when dryer conditions prevail (e.g. when windows are opened). However, it must be noted that the properties of the immediate surface-layer matter most, while the material below, be it concrete, brick or wood is of secondary importance. These findings about the humidity buffering characteristics of interior lining materials discovered in the early 1960’s have been confirmed by later studies. The indoor humidity in rooms equipped with materials of high moisture buffering capacity varies only little during the day and stays therefore mostly within safe and healthy limits (neither too dry nor too humid). This may be beneficial for rooms with changing moisture productions rates or intermittently operating HVAC-systems.

5. STOREY-HIGH WALL PANELS, PRE-CAST CONCRETE WALLS, ETC

In early 1960 it seemed as if laying bricks and rendering of walls would soon be a thing of the past. “Storey-high panel construction” was the slogan of the time, pre-fabricated walls in concrete-sandwich-constructions, made of lightweight concrete or set up as pre-fabricated brick walls, were brought to the market. In order to satisfy the growing demand for usability tests, a hall of 100 m length with removable wall elements was built at the exposed side (west side) of the testing field (Fig. 4). Thus, different wall elements could be installed facing west (main wind-driven rain orientation) and/or east (sheltered side) of this hall. The interior climate was kept constant at 23°C and 50% RH. After the tests on the pre-fabricated walls had been concluded, cavity masonry walls and walls with exterior and interior thermal insulation systems were tested. In the meantime, this test hall has been modernized without changing the principle concept. There is still the possibility to test storey-high wall elements but also smaller wall elements can be installed that may be removed periodically by a forklift for weighing (recording the water content). This test hall has been in continuous use until today, e.g. for all kinds of masonry and wooden wall structures, textile facades, straw bale and other renewable or recycled construction types.

***Figure 4**. Air-condition test hall with removable wall elements from outside and inside.*

6. FLAT ROOFS (INVERTED ROOF, GREEN ROOF)

The flat roof is, to the same extent as the external rendering, typical for field experiments. Already in 1957 three test houses were built in order to examine relevant problems of the time. In one case an unventilated flat roof structure with insulating corkboards of 25 mm thickness was compared to a ventilated structure with 15 mm thick corkboards. It was believed that the additional ventilation gap of the structure would save 10 mm insulation material. Today, we talk of more than 200 mm of roof insulation in Germany, because the roof is the most critical envelope component in term of heat losses or solar heat gains.

***Figure 5**. Green roof with temperature and humidity sensors recording the hygrothermal conditions at various positions.*

In 1977 outdoor tests on inverted roof (protected membrane roof) structures lead to the introduction of an energy malus in order to take into account the temporary rain water penetration of the insulation layer. Furthermore, different roof assemblies, including green roofs (Fig. 5), were subjected to long-term outdoor weathering to assess their thermal performance and service life. In the meantime green (vegetated) roofs have not only become very popular, they are also strongly encouraged by municipalities and sometimes even mandatory. Therefore, field tests and the development of computer models simulating the hygrothermal performance of green roof have intensified in recent years.

The necessity of roof ventilation has also been an issue in many experimental investigations leading to the conclusion that ventilation may work well for poorly insulated structures but may pose increasing problems with highly insulated roofs. Additionally, ventilation gaps may provide easy access to insects and may compromise the roof's thermal performance due to wind-washing and other convective effects. The lack of drying potential of constructions without ventilation was compensated by introducing vapor permeable under-lays, so-called breather membranes on top of the insulation (mainly for sloped roofs) and/or smart vapor retarders at the interior side of the insulation layer that vary theirpermeance with ambient humidity conditions. The latter was an innovation of Fraunhofer IBP. It keeps vapor diffusion into the roof below safe limits in winter and enhances the drying process in summer because its permeance increases by a factor of 10 under typical summer conditions.

7. ALTERNATIVE HEATING METHODS, CONTROLLED VENTILATION, CONVERSION OF ROOF SPACE

The energy crisis of 1973 had a strong impact on research demand. The possibilities for energy saving by adding thermal insulation to the building had been a research topic before, but due to the crises the insulation thickness went up and ventilation heat losses and inefficient heating systems came also into the focus. In order to enable systematic tests of ventilation and heating of dwellings, two similar test buildings (twin houses) with several adjoining rooms (in total about 100 m²) have been erected. They were the "big brothers" of the former smaller test houses (Figure 6). Centralized and de-centralized ventilation systems with and without heat recovery, energy-saving building concepts, conservatories and translucent thermal insulation systems were the topics of investigation at the test houses.

***Figure 6**. Twin test houses, each with four adjoining rooms for systematic testing of dwelling ventilation and alternative heating systems (e.g. heat pumps).*

8. RETROFIT OF EXISTING BUILDINGS AND HERITAGE PRESERVATION

With decreasing activity in the new house-building sector from the early 1970's on, the interest of house owners and the building industry focused on retrofit of old buildings as well as on the preservation of heritage buildings. Especially the preservation and restoration of heritage buildings had long been neglected by building scientist. As a consequence, inappropriate and questionable restoration methods were spreading. Let's just remind of the various methods for "draining" damp masonry, using so-called "dehumidifying tubes" or the different electro-osmotic methods that are still fooling home owners with fake claims today. Here field experiments were able to lead to clarification, even if research results have not convinced all stakeholders concerned. Thanks to subsidies granted by the Federal Ministry of Education and Research, fundamental investigations concerning moisture and salt migration within building materials, natural stone decay and appropriate interior climate control to protect the fabric and the interior furnishings of heritage constructions could be conducted.

Another important research topic concerned the retrofit of buildings whose original appearance must be preserved which means their façades must not be altered. In such cases the application of interior insulations systems is the only possible solution to safe energy and to enhance indoor comfort. However, in cold and moderate climates insulating walls at the interior can be risky because it lowers the average temperature of the structure and may lead to condensation and reduced drying potential. Therefore, extended investigations were carried out at a “Tudor” test house that was erected according to old traditions (Fig. 7). Apart from testing new infill materials such as mortars with polystyrene beadsor different types of insulating clay mixtures, most of the studiesconcentrated on the effect of different interior insulations systems on the moisture behavior of the wooden structure.

***Figure 7**. Half-timbered “Tudor” test house with different infill materials with and without interior insulation. Because of the unavoidable dilatation of joints and the moderate original wall thickness - a result of the framework construction - special problems regarding thermal insulation and driving rain protection can occur.*

9. FINAL OBSERVATION AND PREVIEW

The research tasks carried out reflect the development in the area of heat, air and moisture control in the German building sector after World War II. Almost all new developments were examined at the Fraunhofer Institute for Building Physics outdoor testing site in Holzkirchen.The different points of view that influenced research objectives for almost two generations are remarkable. Whereas immediately after World War II economical use of material was of utmost priority because of lack of building and insulation material, our task today is to save energy and to guarantee comfort in buildings. The research efforts to save energy have been quite successful resulting in net-zero or even plus-energy buildings. While there is still a large building stock with little or no insulation, the energy required for operating modern buildings has become small compared to the amount of energy necessary for construction and material manufacturing. Therefore, the focus of the building sector is slowly shifting towards lightweight structures with less embodied energy preferably made of renewable or recycled materials.

On the other hand, despite great research efforts, progress in reducing moisture damage has been disappointing at least by looking at the staggering amount of money spent on damage repair. There are several reasons for the poor moisture performance of our constructions. Apart from the more efficient construction process that leaves little time for construction moisture to dry before enclosure, our efforts to save energy are also to blame. Insulating buildings and making them airtight results in higher moisture loads and less drying potential for the building envelope. The switch from moisture resilient materials such as concrete and masonry to more sensitive renewable materials won't improve the situation. However, today we possess the technology to design moisture tolerant and durable building components for all climate zones and building operation modes. This includes assemblies composed of renewable materials. The challenge is to disseminate this technology to manufacturers, architects and installers and to convince them that appropriate moisture control measures really work.

By using the immense resources of experience and knowledge gained through experimental research, in combination with modern calculations methods, new possibilities were opened up in the last decades substituting time-consuming and expensive experiments. With the help of numerical simulations of that kind, supported and validated by the existing resources of experimental knowledge, the results of experimental research can be extrapolated and transferred to different boundary conditions, i.e. all sorts of exterior climates and also changing interior conditions.

Today, after 67 years of outdoor testing, the level of awareness concerning the importance of adequate moisture control is finally on the rise. Compared to the initial phase during the times of economic recovery, architects and engineers can rely on design tools and experienced experts helping them to find durable solutions. However, new questions will arise that cannot be answered by laboratory experiments or computer calculations only. This is the reason why field tests will still be necessary in future, especially to assess real innovations or to solve problems caused by climate change or changing occupants' behavior.