Breathing Walls:
A Challenge for New Sustainable Building Techniques in Hungary

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ABSTRACT

In Hungary, and alike in other Middle and East-European countries, the transition from the state-controlled East –European economy to the market economy has had significant consequences in the whole construction sector. This paper addresses the emerging new problem of sustainability with a focus of the possibilities of combining energy efficiency with "breathing qualities" in building envelopes in residential construction in the country.

The performance of the external building envelopes is a critical issue in housing. Applying energy saving measures alone can result in sealed internal environments and too closed buildings. Thus, there is a risk of too little ventilation and natural light, and too much retention of moisture and toxic internal emissions. In many economically developed countries various mechanical ventilation systems are used and provide good solution to the problem. However, as in some countries, like in the UK, Norway or Germany, a new interest has been emerged also for concepts of Building Biology, scientific investigations were started for alternatives, providing more natural than technical solutions. As Building Biology considers buildings as our third skin, these interests lead to the researches of "breathing walls".

As a new interest for energy-efficient, environmental and healthy design emerges also in economically less developed countries, where traditional type of "breathing walls" (e.g. adobe construction) have been widely used and mechanical ventilation is not a common solution in housing, the up-to-date versions of breathing constructions can provide a more affordable and obvious alternative.

***Keywords**: affordable housing; building envelopes; breathing and communication; energy efficiency; health; performance monitoring; vapour.*

Introduction

Traditionally, brick masonry or adobe structures have been applied in residential construction in Hungary, and so in other countries in Middle or Eastern Europe. These traditional forms of construction have been relatively healthy with good breathing qualities, though generally have not had sufficient insulation, hence the energy use has been high. Lately, new demands have emerged in housing such as functional flexibility, rapid and economical construction, convertibility and energy efficiency. As sustainable construction and environmental awareness has also come into prominence, some more up-to date techniques could better serve these new demands. Simultaneously with the developments in energy-efficiency, an achievement to preserve the breathing quality, the heat storage capacity, the good acoustic behavior and the fire safety characteristics of traditional structures would be necessary criteria for a social acceptance of new techniques.

Thus, one can suggest conducting developments in two main technical directions. On one hand, keeping the "breathing quality" will be a challenge when improving the energy efficiency and environment consciousness of the traditional wall structures. This involves not only brick constructions, but also other traditional construction forms using locally available materials like adobe, straw and other wooden base products.

On the other hand, the application of wooden-frame breathing walls with modifications to the local preconditions presumably could provide another good alternative. Though timber-frame constructions have not traditionally been used in Hungary, it has proved itself to be a sound and durable method of construction over many years in other countries. As new demands for superior level of thermal performance, for rapid and flexible construction emerge, timber-frame constructions have good opportunities to come into general use also in the former countries.[1]

The special constructions with the general term of "breathing walls" were developed in the UK and in Norway, from that the basic principles of the behavior of these structures are known. Several best practice examples can be seen in these countries.

In the *Plc for Quality Control and Innovation in Building* a research and development program is to start within this year with an objective of investigating how to adopt this concept and construction on local climatic and cultural condition on one hand, and to convert the concept in the building techniques traditionally used in the Central and East-European region on the other hand. At the same time, one can suggest to use the term "breathing constructions" in a wider sense. This can include not only moisture migration and breathing through the buildings' fabric, but rather a more active connection and "communication" between the building's interior and the external environment. This involves not only physical aspects but also psychical ones, like optimal day-lighting, architectural appearance and the perceived quality of materials and constructions. These factors are all presented on building envelopes. Thus, the focus of the research will be on new "communicative building envelopes", which connect the internal and external environments in a healthier and more natural way. There is an aim to develop prototype constructions addressing different building techniques that can be applied also in affordable housing. Thus, the cost-effectiveness of the total life-cycle of the buildings will be highly considered.

After conducting various tests in laboratories, outdoor test cells and model buildings, there I a long-term aim to build a high-density demonstration housing project for conducting measurements and monitoring the performance of different examined constructions in real urban context. Applying the concept in dense urban context will be another challenge. The term "breathing" is suggested to be widened to the urban level and involve both physical and psychical aspects. This can introduce the notion of the "breathing city".

The concept of breathing walls – state of the art

The increasing use of synthetic materials in construction together with the effort of creating buildings that are more tightly sealed, often for good energy-efficiency reasons, has led to the increasing incidence of too sealed constructions without breathing qualities. The natural storage and transmission processes of heat and solar energy, air, moisture and light have been limited while the emission level of pollutants, harmful radiation and electro-pollution have been increased in buildings. This process increasingly resulted in "sick buildings". Living in a highly sealed construction, polluted by paints, vapours from timber

[1] Though masonry structures still dominate in new constructions in Hungary, more and more local and foreign firms have started to construct timber-frame walls. As no established systems for this construction exist in Hungary, all kinds of systems and new experiments can command interest.

treatments, vinyl and formaldehyde glue has been proved to have a serious effect on the occupants' health.

In many well-developed countries the common solution of this problem lies in air-conditioning or in developing integrated and optimized ventilation design that can reduce indoor air pollution and provide good ventilation rates without significant heat losses. New types of natural ventilation and mechanical ventilation designs with low electricity use and high efficient counter-flow heat recovery function are also spreading. In both cases there is a possibility of applying solar assisted hybrid ventilation units.[2]

In other countries, natural ventilation are more common and in several reasons also preferred to mechanical ones. As the worldwide approach for ecologically sound and healthy constructions has been emerged, employing building envelopes with porous membranes to allow „breathing" through the building fabric has proved to be a new field of interest.

The original concept of breathing walls has considered these aims and was that of internal air flowing out through the walls to reduce the concentration of indoor air pollutants, the level of which has been increased by using more synthetic materials in construction (vapours from timber treatments, paints, vinyl and formaldehyde glues, radon decomposition products, etc.). Theoretically, when dwellings are at positive pressure (generally in winter), this breathing could have been passively induced. However, research and practice showed this approach to be ineffective. Now the simplest concept of a breathing wall refers rather to diffusion of water vapour than air through the fabric. Thus, breathing wall has been defined as a particular timber-frame construction that has higher vapour permeability than conventional designs and hence increased moisture migration from inside to outside of the structure.

Two other related methods for reducing ventilation and building envelope heat losses and achieving high indoor air quality are still under research. The concept of dynamic insulation[3] relates also to air-breathing, while diffusive insulation[4] can be defined as the third type of breathing constructions /Cawthorne 1996/. For demonstrating dynamic insulations there are several built projects by the Gaia Architects in Norway. Breathing walls do not have polyethylene vapour barrier and are constructed of natural materials of carefully selected vapour resistance (controlled and continuous moisture migration). The components are selected so that they are of the correct vapour resistance to allow vapour to diffuse naturally through the structure: "What gets in, gets out" (water vapour can escape more quickly than enter). As a rule of thumb, there will be no predicted risk of interstitial condensation in any timber frame wall where the vapour resistance of layers on the warm side of the insulation is

[2] Several best practices are in EU-Thermie projects in Denmark, like Østerbro, Vesterbro and Farumsødal and EU-Joule, "PV-VENT" projects, Frederiksberg and Skovlunde.

[3] Dynamic insulation ("pore ventilation") involves drawing cold outside air through a porous insulation material within the walls and roof to the inside, powered by slight depressurisation of the internal air through active and passive extraction. The incoming air is warmed by heat trying to escape through the construction. The entire wall is in effect acting as a heat exchanger. In theory, a near-zero U-value is possible, although in practice only 30-40% efficiency has been achieved. Dynamic insulation can act also as a high performance particulate air filter in naturally ventilated buildings, thus providing a viable and attractive alternative to mechanical air conditioning in polluted urban environments (Imbabi, Taylor & Webster 1997) The advantages attributed to dynamic insulation often contradict to each other, thus research should solve yet many questions.

[4] Diffusive insulation is merely a special case of dynamic insulation where the air-flow is zero. Thus, its thermal behaviour is no different from a conventional wall, however it does not contain any vapour barrier. It is claimed that diffusive insulation permits the diffusion of indoor pollutants such as water vapour and volatile organic compounds outwards through the air of the porous insulation material.

at least 5 times greater than the vapour resistance of layers on the cold side of the insulation (BS5250). All timber-frame walls are made to breathe in this way or they do not work (Pitts 1998).

With conventional timber-frame, the more vapour resistant plywood is on the outside and a polyethylene vapour barrier is required on the inside. This minimizes vapour diffusion. By contrast, in the Breathing wall, diffusion is maximized, but in a controlled way to make the structure as free as possible to release of water vapour.

The most frequently used system for breathing wall is a three-component timber frame system. From the inside, this wall consists of Gyproc Duplex plasterboard (with metalized polymer backing), Warmcel cellulose fiber (recycled newsprint treated with borax) insulation between studs and either Bitvent (impregnated softwood) or Panelvent (medium board) as the outside sheathing.[5] Warmcel is generally installed by wet-blowing into the space between the studs. The moisture reacts with the cellulose to glue the insulation into place (100% filling!). The hygroscopic properties of Warmcel enable it to absorb surplus moisture at times of high internal humidity and to release it when conditions allow. Any material can clothe the construction, as long as sufficient ventilation is maintained in the cavity.

Best practice examples of breathing walls can be seen in Swansea or the eco-village in Findhorn, both in the UK. As regards the results, vapour exchange has proved to be effective. Thus, a healthier indoor environment free of excessive moisture and condensation, and a durable structure free of interstitial condensation has been created. Measurements were conducted in Findhorn, which proved that breathing walls had 15% better air tightness and reduced space-heating costs by 24% as compared to conventional timber-frame. Low embodied energy in materials and high recycled content were obvious. Also the ease of construction and disposition was well proved. On the other hand, users' behavior has been proved to be a problem. By frequently opening the windows the intended optimal result could not be achieved.

Currently, higher construction costs and lower running costs can be attributed to breathing walls as compared to conventional timber-frame walls.[6] New research can investigate methods for reducing construction cost as well. Thus, Breathing walls could be appropriate also for new construction of affordable housing and social housing.

The timeliness of the problem

As in many developed West and North-European countries the demand for new housing construction has been reduced (there is no need for more housing units), the main focus of housing provision in these countries has been shifted towards housing refurbishments. However, partly for sustaining economic growth, still there is a continuous and intensive house-building activity throughout Europe.

The competitiveness of new housing construction with refurbishments will increasingly be determined by two major factors. Affordability is one factor and the provision

[5] The Duplex board has a vapour resistance of around 60 MNs/g, the softboard of 0,4 MNs/g and the medium board of 1,5 MNs/g. Thus the vapour resistance ratios are 150:1 and 40:1 respectively (>> 5:1), and the wall breathes freely.

[6] In Findhorn, a wall construction with 150mm thick heat insulation appeared to be optimal ($U=0{,}19 W/m^2K$) with 9% higher construction cost and 50% energy saving during the whole life cycle of the houses.

of a new type of quality is the other one. For selling a new house in the market, its quality should obviously exceed the limits of refurbishments and assure the stability of value of the investment.

A major issue of housing quality is strongly related to building envelopes. On one hand, building envelopes are the most durable building components serving the whole lifetime of the buildings. In addition, envelopes have also proved to be the most problematic ones. Approximately 80% of building failures are related to them. On the other hand, this part of the building has far the greatest influence on indoor air quality and comfort, and also on environmental sustainability, all essential factors in the quality of the urban life. As regards the complexity of the problem, it is time to introduce a more holistic, integrated approach. Aspects such as health, ecology, energy and architecture should be brought together. The suggested widened definition of breathing construction and "communicative building envelopes" is based on this integrated approach.

In Hungary, the new emerging housing programs give another factor of the timeliness of the problem. There is a challenge to make sustainable construction techniques, and so breathing building envelopes affordable in the new housing constructions.

Till now, a major problem of various sustainable building concepts has been their affordability, resulting a narrow application and also the lack of the public's awareness of the importance of related health and environmental issues. In addition, short-term market interest is generally against sustainability. Thus, a real market for sustainable building has not yet been created in Europe. For changing this situation, building cost of sustainable housing should be closely equal to the cost of similar conventional ones (max. 5% more expensive), while the life-cycle cost should be lower (aim: 5% reduction).[7] Prototypes with new materials and technical components can have some additional cost.

Raising the public's awareness of sustainable and healthier life are important goals when developing breathing constructions that can be applied in new large-scale housing programs. It is of utmost importance to make the residents aware of the quality of the house and district they live in. There is a need to create a real market situation for sustainable construction in Europe in the housing context.

The practical installation of this concept can also contribute to several European policies, like optimizing the use of resources, minimizing the production of pollutants and improving the indoor health and comfort of the built environment. Preventing "sick building syndrome" and decreasing risks of health related to the environment (e.g. allergy) is an inherent aim of breathing constructions. The reduction of primary energy consumption in buildings; the reduction in the use of primary raw materials; increasing the level of recycling; and reducing the life cycle cost of the construction process are all related European aims.

Developments

One can suggest to start developments in sustainable and environmentally conscious housing with applying healthier materials. In normal building projects it is nearly impossible to ensure a choice of materials that will not harm the indoor air climate with various emissions. Thus, optimizing ventilation and filtering are strongly related subjects.

[7] For life-cycle cost optimization of building projects several tools can be applied. E.g. the so-called "Optibuild" tool developed by Cenergia Company in Ballerup (Denmark) can be used to show how much one should invest to minimize operation cost in a cost-effective way (total economy optimization).

As beforehand outlined, the outlined developments will aim at improving communication (contact) between inside and outside instead of closing interiors from the outer environment. Different types of constructions will be addressed. On one hand, wood and wooden-like light constructions will be adopted on the basis of „breathing wall" experiences. Various ecological heat insulations can be employed, such as paper granulate cellulose to develop a practice where cold-bridges can be totally avoided and a gap-free construction can be ensured. Other ecological insulations like natural hemp or wool, existing traditionally in the country, can provide further alternatives. In addition to wall structures, a main application area of this kind of construction can be built-in attics of residential buildings also of traditional masonry construction. The possibilities of prefabrication will have a main interest in any cases, as it can improve quality and may obtain the lowest possible building cost.

The other field of developments will address sustainable silicate-base products used in masonry constructions. Research will examine whether the principles of breathing constructions can be converted to these structures. Constructions should have a favorable service life, low embodied energy and high-recycled content. More favorable structural layers of outer walls and roofs and more durable and permeable cladding systems are aimed to be applied and potentially further developed.

Other green building techniques using local or locally available materials that meet the breathing envelope concept will be also considered (like adobe, straw, wood, cellulose and also new ecological products). Possibilities of using self-built and industrialized techniques will be matched.

In summary, the principle of breathing is aimed to widen to several levels. Breathing construction principles should be applied in an integrated approach. Developments will address a range of physical and psychical aspects. As regards physical measures, solar energy, controlled heat and vapour storage and transmission, airflow and filtering, reducing level of indoor pollutants will be addressed. Transmission of useful radiation, light transparency and protection, noise and vibration protection will be also considered. Because of the considerable mass and consequently good heat storage capacity of cellulose, the typical breathing construction has far better chances for a social acceptance also in Hungary than other conventionally insulated timber-frame walls. All other essential requirements should be also met (safety in case of fire, structural stability, etc.) As regards psychical measures, good day-lighting (window/wall ratio, skylights, greenhouses, orientation), the view out from the interior, the protection against the view in and architectural appearance will be addressed.

There is a question of the necessary minimum envelope (energy-efficiency reasons often conflict with good orientation, outlook and day-lighting). This issue is increasingly important in the focused high density housing in urban context, where the surfaces of the envelopes are inherently limited. The optimal ratio and situation of windows should be well determined. Altogether, a change from technical and "conceptual" architecture to a more philanthropic architecture is needed in future housing and cities.

Testing and performance monitoring

Developments will be measured and tested in various ways (ISO and EN standards):

- in laboratory;
- in outdoor test-cells;
- in a full-scale model building;
- in housing estates.

Related aims are:

- to minimize ventilation heat losses by increased air tightness;
- lower fabric heat loss, thus energy saving through the whole life-cycle;
- healthy indoor climate with low pollutant emissions and optimal indoor relative humidity.

Since the transmission and storage processes in buildings change through time and are multidimensional, the researched constructions will be tested in all seasons of the year. An extensive performance monitoring of building elements should be conducted and confronted with control tests of traditional constructions.

Laboratory tests will assess requested performances of materials and components. This will address vapour and heat storage and transmission, air transmission, energy balance and also acoustical behavior. Tests for thermal conductivity of materials; thermal transmittance of components, thermal shock; acoustic dynamic stiffness of materials; sound (air-borne and impact) insulation of building components; moisture permeability and vapour diffusion of building components; air permeability of building components and VOC emissions will be conducted. Fire and load-bearing tests will also be done.

Outdoor test-cells provide a comparison of the thermo-energetic behavior of components and systems under real working conditions. Thus, the energy balance and vapour diffusion of innovative components can be compared with traditional ones.

There is an aim to carry out further tests and complete performance monitoring under real working conditions in experimental buildings. This can involve the effects of construction details, doors, windows and skylights. These measurements can provide an analysis of whole buildings both from the thermo-energetic and the comfort point of view. This includes moisture contents, indoor air quality and pollutant emissions. Analysis of the indoor thermo-hygrometrical and acoustic comfort and that of the thermal bridges or dispersions of the envelope can be conducted. A two-year monitoring period is needed for an extensive evaluation.

There is a long-term aim of monitoring and evaluating the developed breathing envelopes also in new housing estates in real urban context. End-users such as housing providers and occupants should be actively involved. The first phase of monitoring could address the construction process. In the second phase, the operation of the urban housing estate should be monitored in four seasons and focus on energy-balance, indoor air quality and moisture migration. Post-Occupancy Evaluation can examine the users’ behavior and satisfaction. Social, health and psychological aspects are also important to be analyzed. Special tools for life-cycle optimization are available for measuring affordability and life-cycle costs of new ecological constructions. Other tool can assist monitoring energy and environmental impact.

Conclusion

Breathing constructions present good examples for sustainable, healthy, ecological and energy efficient building practice. These constructions are suitable to minimize both toxic impact load on indoor spaces (radon, harmful radiation, VOC, dust, pollutants from outside, noise) and impact load on the environment.

One can suggest widening the common term of breathing constructions and convert their basic principles to various building techniques, climates, cultures and environments. As new demands of energy-efficiency and sustainability emerge in several countries also in Central and Eastern Europe, like in Hungary, breathing constructions on a wider sense can have good chances to be introduced. On one hand, the main principles can be converted also to traditionally used brick or adobe constructions. The main reason of interest can be explained by the challenge of increasing energy-efficiency of these constructions without loosing the good breathing qualities and other advantages traditionally attributed to them. On the other hand, by adopting the already developed timber-frame breathing constructions to local conditions, this can assist the already started, though socially hardly accepted introduction of timber-frame structures in the country. Some advantageous properties of cellulose insulation (e.g. it has a higher weight and better fire safety than glass-wool or rock-wool insulation, which are now in common use in the country) can contribute to the elimination of current aversions to timber-frame constructions.

In case breathing building envelopes are applied in large-scale housing programs in urban context, further essential criteria emerge. Besides sustainability and quality, the demand of affordability (low cost) is a major factor of competitiveness. Moreover, special climatic and cultural conditions (attitudes) can make the application of these techniques even more complicated. The final aim would be to test the researched constructions not only in laboratories, outdoor test cells and experimental buildings, but also in low or medium rise high-density housing estates in real urban context. This would give possibility to test physical issues in a context, where the surface of the envelopes are limited and factors like day-lighting, orientation and architectural appearance should be also strongly considered. After various forms of testing, the final evaluation of the applicable breathing constructions should be done in such a context in the framework of an extensive Post-Occupancy Evaluation study. This can incorporate also occupants' behavior and all kind of environmental, social, psychological and health effects.

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