

## Summary report

14 June 2013



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### Foster suggestions

This research work was fostered by the Research Initiative Zukunft Bau of The Federal Institute for Research on Building, Urban Affairs and Spatial Development

File number:  
SF - 10.08.18.7-09.30/II - F20-09-1-190

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## Background

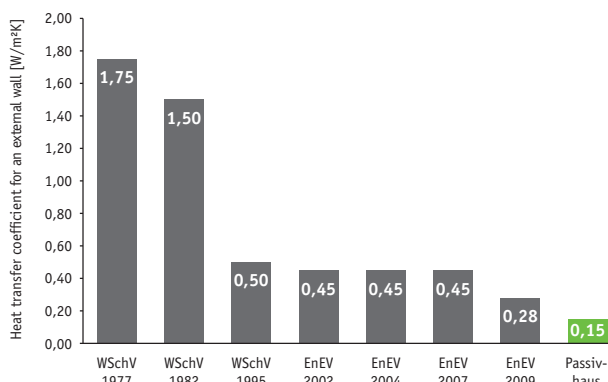
In the next few years, the ecological and energetic requirements for building envelopes will be further tightened. The use of conventional materials would cause wall constructions to become increasingly thicker. To counter this development, new types of construction involving micro- or nano-structural materials facilitate slimmer building elements due to their high-grade properties regarding the reduction of thermal conductivity and the increase of stability, thermal capacity and quality.

The world's increasing demand for energy and the ever-advancing consumption of natural resources are the motivation and motive of this research project. In 2005 for instance, concrete was responsible for 4.2% of the world's carbon dioxide emissions. Thus, concrete is also responsible for the main share of the building industry's CO<sub>2</sub>-emissions. However, in comparison to other materials, concrete proves to have a good life cycle assessment; yet, the problem is the enormous amount of the material being used. In Germany, about 3.6 billion cubic meters of concrete have been used for construction since 1950, most of which is still part of these buildings today [1]. New data bases, such as Ökobau.dat, provide information for an inventory of relevant energy and material inputs and environmental releases and allow for a holistic examination of the ecological impact of buildings, e.g. their global warming potential, demand for primary energy, or recycling potential. These inventories also facilitate a comprehensive examination of the so-called grey (embodied) energy. Compared to the energy demands during a building's

phase of utilization, grey energy is taking up an ever-growing share. However, this grey energy, essential to the life cycle phases of construction, renewal, and demolition, is currently not subject to the analyses required by law. Since the first Ordinance on Thermal Insulation of 1977, the requirements for the energy efficiency of a building have been consistently tightened: the U-value required for an external wall, for example, was reduced to a sixth (Fig. 1). In order to meet the required standards the following is necessary: on the one hand the efficient and renewable production of useful energy, on the other hand the optimization of building envelopes. On April 22 2010, the European Parliament decided on the overall energy efficiency of buildings. As a result, all member states are required to pass national regulations until December 31 2018, according to which all newly constructed public buildings have to meet low-energy standards. After two years, these regulations will apply to all newly constructed buildings in the European Union [2].

## Goals and Potentials of the Research Project

Since March 2010, the research project ‚vaku<sup>tex</sup> - Vakuumgedämmte Fassadenelemente aus Textilbeton‘ (‚vaku<sup>tex</sup> - vacuum-insulated textile concrete facade elements‘) at HTWK Leipzig (Leipzig University of Applied Sciences) has been dedicated to the development of building envelopes made of extremely lightweight and energy-efficient exposed concrete (Fig. 2). The aim was to develop building elements with a minimal thickness that still fulfill all the requirements of a facade regarding its structure, air- and windtightness, thermal insulation, acoustic insulation and fire safety by combining innovative composite materials such as textile-reinforced concrete (Fig. 3), vacuum insulation panels (VIP) (Fig. 4), phase-change materials (PCM) and glass fiber reinforced plastics (GRP). Apart from their resource-saving efficiency these elements show great potentials with respect to floor space savings, cost effectiveness, incidence of daylight, solar heat gains, emission control and the transferability of design possibilities of contemporary concrete architecture (Fig. 5, Fig. 6).



**Fig. 1** Development of the requirements of thermal protection, source: HTWK Leipzig

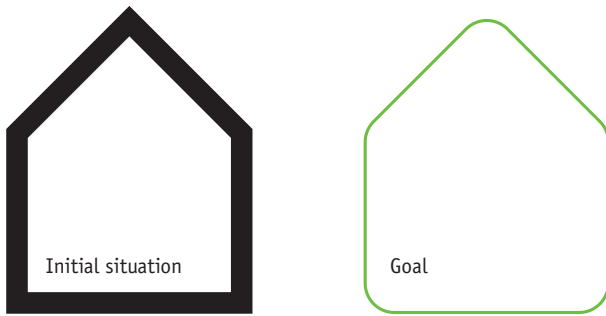


Fig. 2 Goal of vaku<sup>tex</sup>, source: HTWK Leipzig



Fig. 3 Material sample textile reinforced concrete, s.: TU Dresden

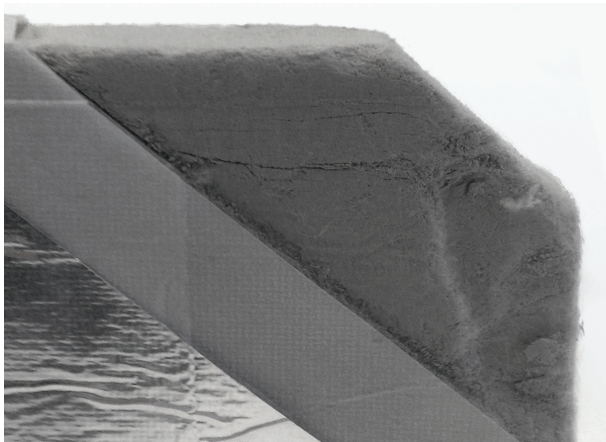


Fig. 4 Vacuum insulation panel (VIP), source: HTWK Leipzig

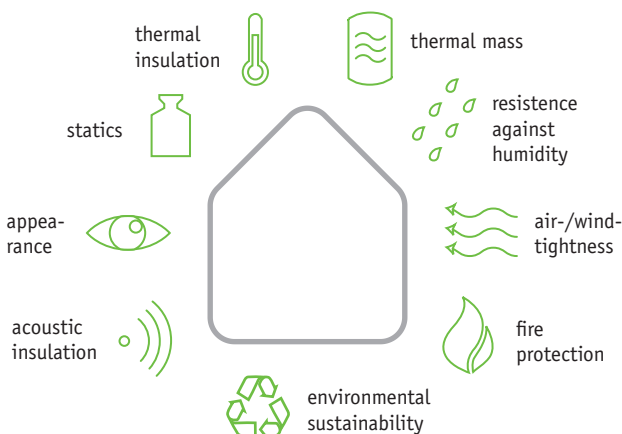


Fig. 5 Requirements for the facade, source: HTWK Leipzig

## Architectural Aspects

Due to the high flexibility of curtain wall systems vaku<sup>tex</sup> was designed to be a curtain wall element instead of a massive and load-bearing building component. Since a curtain wall facade functions independently from the building's primary load-bearing structure, it allows for design freedom regarding the facade and the floor plan of a building. In addition to their thinness, vaku<sup>tex</sup> elements are very light (ca. 100 kg/m<sup>2</sup>) and therefore also allow for a proportionately slender substructure.

Since the outer layers of the facade element are made of concrete, the surfaces can be designed and treated in many ways: by means of acidification, glazing, pigmentation or by using form liners very individual optical and haptic effects can be produced - even pictures are possible (Fig. 7). And yet the concrete remains an 'honest' material. This diversity is attractive to architects, also in combination with other materials.

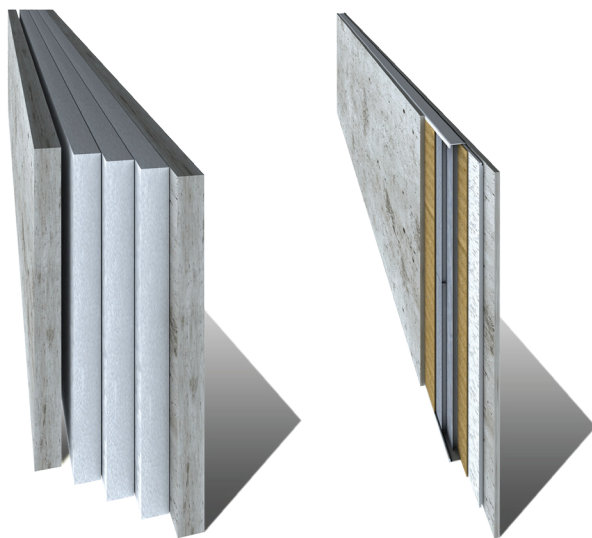
Apart from a common rectangular format, vaku<sup>tex</sup> elements can also have asymmetrical formats and various dimensions that can be combined when assembling the facade, creating architectural suspense (Fig. 8, Fig. 9).

Due to the thinness and lightness of the facade construction the elements are particularly suitable for urban redensification and temporary structures - which are contemporary issues in the architectural discourse.

At the beginning of the vaku<sup>tex</sup> developing process we conducted an empiric analysis of existing building typologies regarding the type of usage, age of the structure and construction. This classification demonstrates the range of common element formats found in the different building types. The interdependencies between use (working, learning, living) and constructional patterns as well as between construction and facade were shown in different categories (Fig. 10). Frequently occurring pattern sizes affected the decision on the dimension of the demonstrating element, which was determined to have a format that is as universal as possible. Consequently, the facade element was designed to be 3.20 m high, according to the height between floors, and 1.50 m wide. Both dimensions can be changed as desired.

## Technical Aspects

After having determined the general specifications and dimensions of the building element to be developed, we worked on constructional solutions. In the first step, a general and broad investigation of facade constructions resulted in a comprehensive collection of different variants and a catalogue encompassing realizable construction details ordered by different categories such as transport fixtures, element fixtures, mounting of the exterior sheet and so on. In the next step, the details were subject to a multi-



State of the art: 44 cm reinforced concrete construction      Goal: 11 cm vaku<sup>tex</sup> facade

**Fig. 6** Comparison of a reinforced concrete facade with a vaku<sup>tex</sup> facade, source: HTWK Leipzig



**Fig. 7** Mock Up, Image: T. Krettek (filmaton.de), s.: HTWK Leipzig

level evaluation concerning relevant criteria such as structure, cost efficiency, dimension tolerances, revision possibility, building physics and architecture related aspects. This practice led to the decision for one detail in each subject area. The work progress was then reevaluated by project partners and experts and their proposals for modification were worked in, which finally led to an optimized construction solution as a result of this process. Parallel to the constructional development of the details and the clarification of technical questions, criteria concerning building physics as well as ecological, economical and aesthetic aspects were continuously taken into consideration. For example, the statics were proven by the BTU Cottbus and the tests evaluating the heat transmission coefficient were conducted in the climatic chamber of the HTWK Leipzig. Furthermore, the facade element underwent evaluations carried out by external testing facilities. At the Leipzig materials research and testing laboratory, orienting fire and acoustic tests were conducted and charted. All test results were summarized and evaluated, which conclusively formed the design of the construction. Eventually the results were compiled on a product specification sheet.

The vaku<sup>tex</sup> facade system as a non-loadbearing curtain wall transfers all loads and impacts directly through the primary structure. This resulted in the development and realization of a facade element with a minimized thickness of only 11 cm (Fig. 11). Through the use of textile reinforced concrete it is possible to achieve material thicknesses of merely 10 - 30 mm, as the textile reinforcement which are composed of alkali-resistant glass or carbon does not corrode. Inevitable cracks are very small and are distributed evenly. For the 30-mm-thick inner sheet and the 15-mm-thick exterior sheet the refined concrete TF 10 by Pagel was used after having carried out multiple test casts.

A frame made of GRP-I profiles served as the connection between the inner and outer sheet of textile reinforced concrete. Moreover, a vertical GRP-I profile stiffens the elements on the inside. The dimensioning of the profiles mainly followed aspects regarding statics and building physics.

For the mounting of the textile reinforced concrete sheets to the GRP profiles, an adhesive was chosen

in consultation with project partners and experts. With the approved and used ‚Tack Panel System‘ by Sika Deutschland GmbH an adhesive bonding in the facade area is possible up to a height of 22 m without any additional mechanical backup (Fig. 12). In



Fig. 8 Facade design proposal, vaku<sup>tex</sup> project, s.: HTWK Leipzig



Fig. 9 Building extension, para<sup>tex</sup> project, source: HTWK Leipzig

Germany for taller buildings there is the provision to integrate brackets in order to prevent the elements from falling off in the event of failing adhesive.

Due to the results of the building physical analysis and ecological evaluations, vacuum insulation panels (VIP) with a thickness of 5,5 cm were chosen as the insulation. These insulation panels are composed of a supporting core made of microporous silicic acid which is evacuated and sealed inside a metalized high-barrier foil. The thermal conductivity is about five times lower than that of mineral wool used in facades. With the use of VIP damages of the foil have to be avoided, as the loss of vacuum would result in an increased thermal conductivity to the triple. For safety reasons, two layers of VIP can be installed so that in the event of a possible failure of a panel the minimum thermal insulation is guaranteed by the second layer. Through 10 cm wide overlaps thermal bridges can be reduced by a third compared to a butt joint between panels. The joint between two facade elements proves to be a thermal weak point because of the limited thermal insulation capacities of the required gaskets (Fig. 13). However, the inner surface temperature is sufficiently high in order to guarantee a damage-free state.

Of great constructional importance in the planning process was to take changes in length and deformations of the facade elements into account. Movements of the facade elements and their fixtures have to be possible in a controlled fashion and in all directions. In order to react to horizontal and vertical measurement tolerances of the skeleton construction work, a three-dimensionally adjustable element fix-

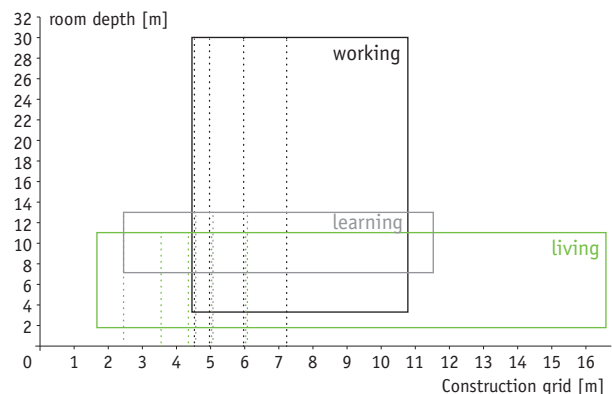


Fig. 10 Connection between grid, room depth and use, source: HTWK Leipzig

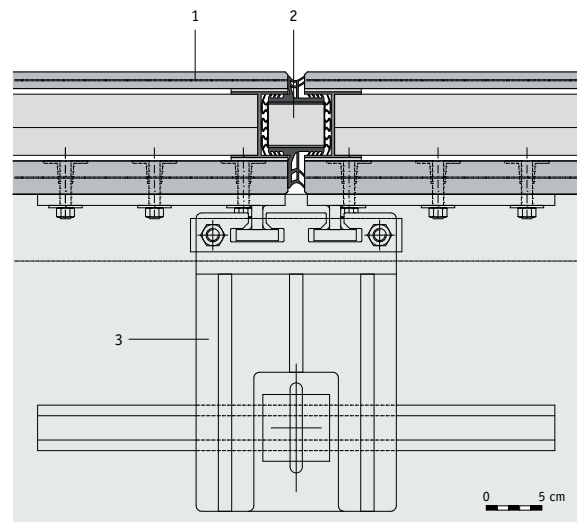
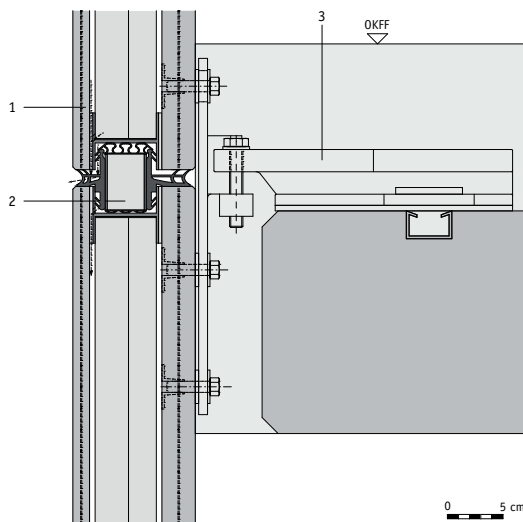


Fig. 11 Axonometric drawing of a facade detail, s.: HTWK Leipzig

ture was chosen and, with the help of the Halfen International GmbH, adapted to the requirements of the vaku<sup>tex</sup>-facade. The joint width between the facade panels was set to be 15 mm in order to res-

pond to the tolerances of the skeleton construction work and fabrication. By including fixed and slide bearings in the suspension system, changes in length in response to temperature and humidity variations are made possible without tension. In order to avoid the leakage of joints due to deflections and changes in length, a gasket system has been developed that helps to react to three-dimensional movements by interconnecting the facade elements. The horizontal joints contain drainage and pressure compensation openings in every field. Despite these openings (< 5 sqcm per facade meter according to DIN EN ISO 6946), the air layer between the textile reinforced concrete sheet on the exterior and the vacuum insulation features the thermotechnical properties of a self-contained air layer.

The facade element underwent fire safety tests at the MFPA Leipzig and was subsequently classified as a A2 building material (non-flammable) (Fig. 14). As a result from an orienting acoustic insulation measurement, a sound-proofing value of  $R_{w,P}$  of 47 dB was determined for the mounted exterior sheets. A second version, where the exterior textile reinforced



**1: Composition from the outside to the inside:**

- 1.5 cm textile reinforced concrete panel
- 0.5 cm corrugated plastic sheet
- 3.0 cm vacuum insulation panel
- 2.5 cm vacuum insulation panel
- 0.5 cm corrugated plastic sheet
- 3.0 cm textile reinforced concrete sheet
- Total: 11.0 cm

**2: Joint Sealing**

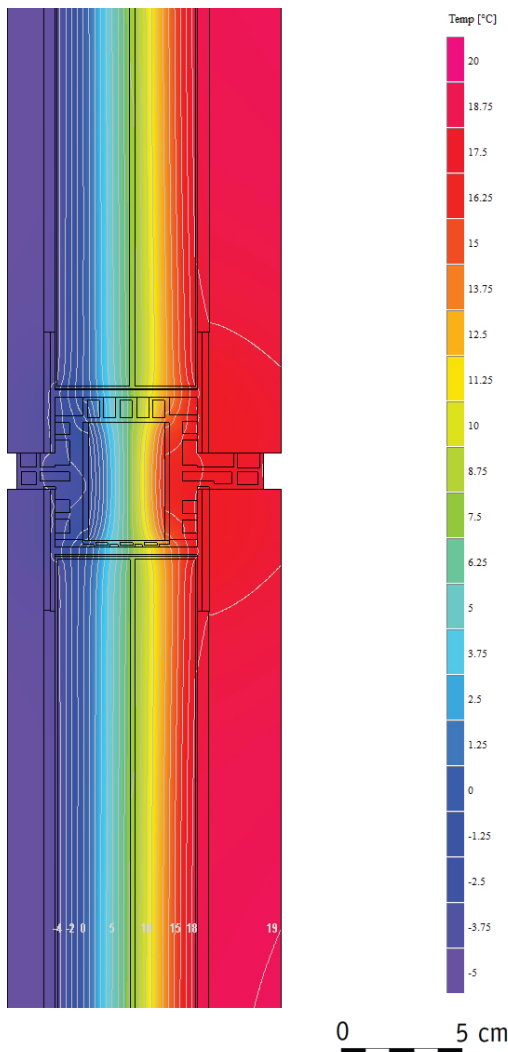
- cm EPDM-rubber profile
- 0,2 cm glass-fibre reinforced plastic (GRP)
- 3,2 cm vacuum insulation panel
- 0,2 cm glass-fibre reinforced plastic (GRP)
- cm EPDM-rubber profile

**3: Floor Slab Construction**

- 15,0 cm technical equipment / impact sound insulation / floating screed / floor cover
- three-dimensionally adjustable facade mounting bracket
- 20,0 cm concrete ceiling

Fig. 12 Horizontal and vertical sectional details, source: HTWK Leipzig

concrete sheet was attached to the element with agraffes, achieved a  $R_{w,P}$  of 56 dB. Thus, the elements even comply with sound-proofing requirements for areas with high noise levels on the exterior. Because the elements are entirely produced in a factory, high build quality can be guaranteed and the elements can be delivered and installed right on time, which ensures an optimized construction sequence and a short construction period (Fig. 15). Due to their light weight the elements facilitate transport and assembly. On the construction site the entire facade can be mounted without scaffolding. With the help of existing tower cranes or a mobile crane the elements are lifted up to the skeleton construction work where they are mounted and suspended. This is followed by three-dimensional adjustments with the help of adjusting screws.



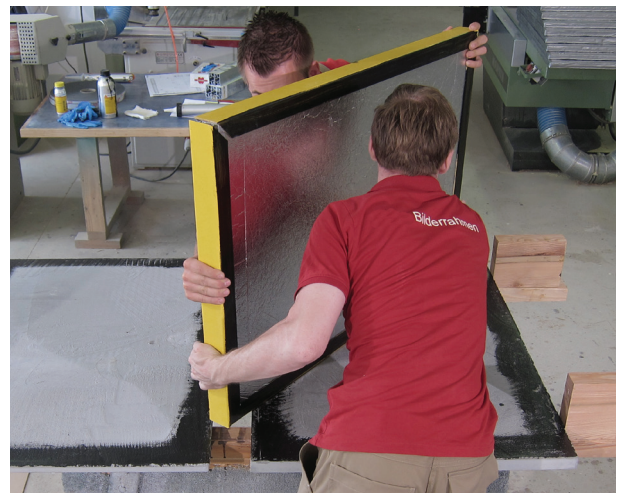
**Fig. 13** Thermal simulation of the element joint, source: HTWK Leipzig

## Ecological Aspects

The Life Cycle Assessment (LCA) examines the entire life cycle of a building product, so to speak «from the cradle to the grave». Every process of a life cycle is included in this assessment - that is the production of raw materials, processing the materials, fabrication of the product, transport, assembly, use, maintenance, demolition and recycling. Furthermore, data concerning the consumption of resources, all environmental impacts in the air, water and soil as well as the use of land is gathered and rated. Life Cycle Assessments enable planners and users to consider environmental aspects in the decision-making for or against a building product [3], [4]. The basis of calculation is, according to the German guideline for sustainable building (Leitfaden Nachhaltiges



**Fig. 14** Fire test, source: HTWK Leipzig



**Fig. 15** Prefabrication in the workshop, source: HTWK Leipzig

Bauen), a 50-year life cycle [5]. Regardless whether a construction actually still has many years to live it has to be disposed mathematically (by depositing, burning or recycling).

The vaku<sup>tex</sup> facade was compared to different facade types according to ecological criteria (Fig. 16, Fig. 17). This assessment is based on one sqm facade area with the heat transfer coefficient of 0,15 W/m<sup>2</sup>K (Passive House standard). The ecological potential of the vaku<sup>tex</sup> material combination lies within the reduction of the building element's weight to a fifth compared to a thermotechnically equal reinforced concrete construction. Furthermore, compared to a reinforced concrete construction, the soil sealing can be reduced up to 15%, depending on the building geometry. The greenhouse gas emissions of vaku<sup>tex</sup> are reduced to a quarter. The primary energy required for the production, maintenance and disposal of the vaku<sup>tex</sup> elements is only 40 % versus reinforced concrete elements. The savings are mainly achieved by a reduced exhaustion of natural resources as well as recyclable building materials.

The realized demonstrating element attains a heat transfer coefficient (U-value) of 0,15 W/m<sup>2</sup>K, which meets the Passive House standard. Through the use of anorganic materials the product is not competing against agriculture and forestry, which is the case with renewable resources.

However, critical is the relatively short life span of the vacuum insulation panels that are currently specified with 30 years [5]. In the future, vaku<sup>tex</sup> facades can contribute to the execution of ecopolitical

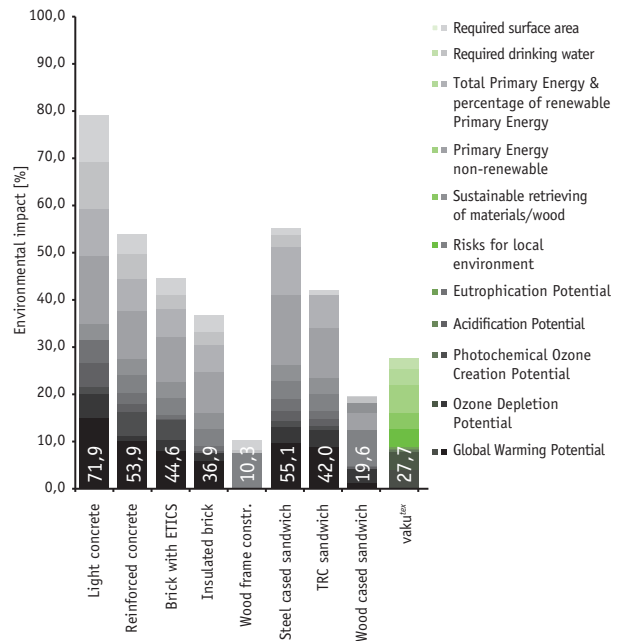


Fig. 17 Environmental impact of different facade types (calculated with a relative evaluation method based on the rating system for sustainable building), source: HTWK Leipzig

goals such as the increase of energy and resource productivity, because they are extremely resource- and energy-efficient.

### Economic Aspects

The assessment of the economic efficiency of the vaku<sup>tex</sup> facade was conducted with the help of the investment calculation. It serves to obtain a rational evaluation of an investment and to quantify its financial consequences. For potential investors,

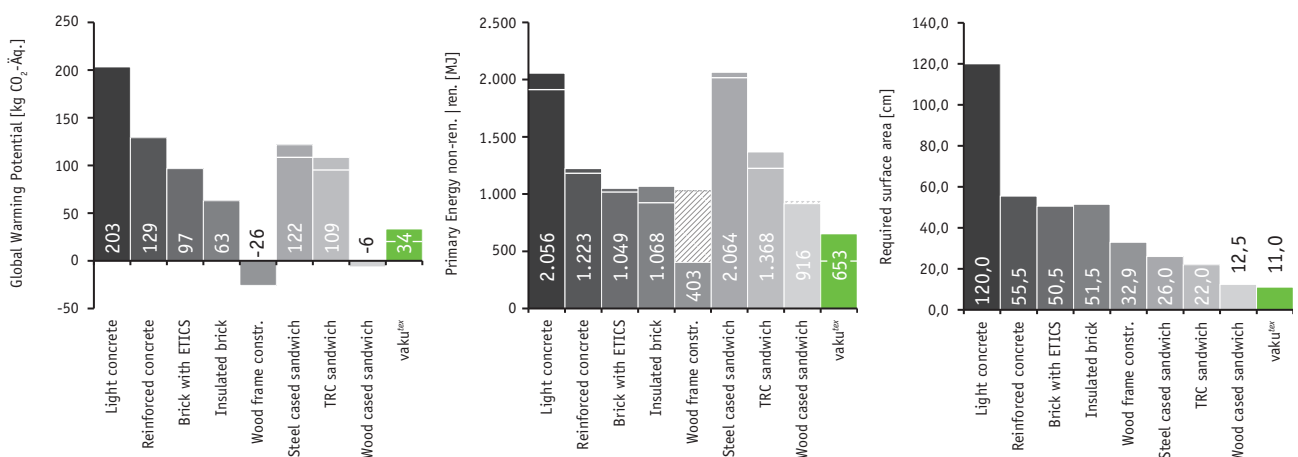


Fig. 16 Quantitative comparison of different facade types according to aspects of the LCA (course of 50 years), source: HTWK Leipzig



the economic efficiency of the vaku<sup>tex</sup> facade should be formulated with the gain of floor space. In order to achieve the energy standard of a Passive House a diverse range of test buildings were subject to two cases: in one case a reinforced concrete sandwich element with a thickness of 44 cm was estimated as the building envelope, in the other case the vaku<sup>tex</sup> technology with a thickness of 11 cm. With a vaku<sup>tex</sup> facade, the net floor area can be increased by marketable 15 %, depending on the building geometry. This gain of floor area was compared to the additional costs for the vaku<sup>tex</sup> facade and the data were fed into a dynamic investment assessment. For this, three representative cities were chosen (Munich, Frankfurt/Main and Leipzig), whose average rental fee for office spaces was discounted over a period of 20 years. All payments were cumulated and compared with the higher initial investment of vaku<sup>tex</sup>. For properties with rents above 9 €/m<sup>2</sup>, the vaku<sup>tex</sup> facade gains an advantage over the object of comparison no later than after 18 years. In Frankfurt/Main with rents from 33,60 €/m<sup>2</sup> for office spaces, the payback period is below five years, although the initial investment for the facade element of ca. 500 €/m<sup>2</sup> is 40 % higher. Thus, from an economic point of view, the deployment is mainly reasonable in upscale inner city locations.

## Conclusion

The result of the two-year research project is a demonstrating vaku<sup>tex</sup> element with the dimensions 1,50 m x 3,20 m as a non-loadbearing curtain wall facade. With a total thickness of 11 cm all static, constructional and building physical requirements can be met. The element can be designed in many different colours and structures and possible panel dimensions range from small to large formats. It is durable, low-maintenance and equally high-quality. The light appearance through the thin walls increases the quality of inhabitation of the spaces, accompanied by higher daylight and solar energy gains (Fig. 18). Using vaku<sup>tex</sup> facade elements can generate more usable floor space from the same gross floor area, which especially adds economic value to buildings in upscale inner city locations. Moreover, the

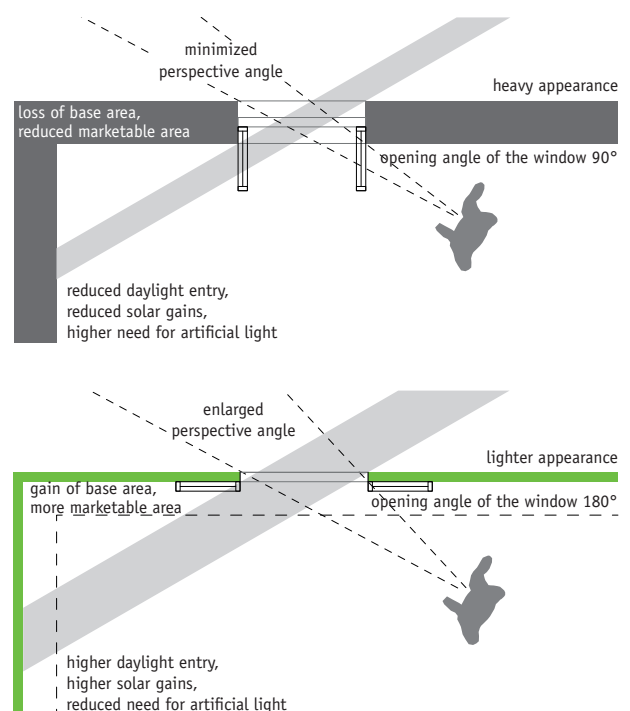
developed vacuum-insulated textile concrete facade elements make a considerable ecological contribution to sustainable concrete architecture.

There remain development needs with regard to the thermal optimization of the joints between the elements, the improvement of the life cycle assessment and the durability of high performance insulation materials such as vacuum insulation panels.

For a conversion of the research results into the practical use, the technology, which is so far worked out generally, has to be adapted to company-specific needs first. The stream-lining of the production process and the expansion of the field of application to existing building structures would subsequently open up further economic and ecological potentials.

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**Fig. 18** Comparative floor plan illustration of the potentials, source: HTWK Leipzig