Possibilities of serviceability design during the development of new constructions

New ways for the approval of building products

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1 Abstract and Purpose

Within the development of a new heat-insulation systems, new procedures of the determination of the serviceability under realistic, building-practical conditions were used. Supplemented through standardised laboratory-examinations of components and numerical simulations of the system, the effects of a regionally different, European climate on a whole building and its components were tested and assessed in a full-scale practice-tests. In order to determine the serviceability, an examination-program was worked out by the BBS INSTITUTE. This program was conducted in the climate - and wind tunnel „Jules Verne “of the „Centre Scientifique et Technique you Bâtiment (CSTB) “in Nantes-France. The aim of such an examination was to get a better understanding of the physical influences of wind and other climatic influences like rain, snow and temperature on whole buildings, their components and the structure and to guarantee the quality of a product without a test of several years in the practice.

2 Preface

Leading businesses are characterised amongst others by connecting commitment, capability and innovations and consolidate their market-positions through strategic alignments of their product portfolio. On this, the economic aspects of new building materials and systems must be analysed very precisely beside the requirements of the market. At such developments of building materials, 2 possibilities are available to the businesses in principle:

- The development of " Me-too " products,
- The development of new products and/or combination of singular products to adjusted systems.

While the first possibility in principle aims on developing directly comparable products, which, caused by their high profile, limit innovations on the optimisation of the manufacture with low modifications of the product-capability, basic considerations for use, production and assembly become necessary at the new building products development. Such a development stretches over several years and demands as result a serviceable product, that corresponds to the bases of the acknowledged rules of the technology.

The legal concept of the “(generally) acknowledged rules of the technology” means the written and unwritten rules of technology, founded on realisations and experiences, that are known in affiliated circles of experts and their compliance must be attended. These rules are acknowledged to be right and are founded on scientific bases which have proven itself in practice. This is demanding the serviceability of products and systems, that satisfy effectively, efficiently their assured qualities and suffices appropriately the requests put at them in the corresponding use (according to DIN 55350-11, 1995-08, No. 4).

How can the suitability of new building products and systems be proven?

The suitability of new building products and systems is regulated by the national and international approval offices for building products in Germany in accordance with the guideline for building products (BPR).

According to the guideline, building products can be put in circulation only if they are usable, i.e. showing such characteristics, that the building, in which they should be installed, with proper planning and construction can fulfil the essential demands, if and as such is nationally intended. To concretise the legal demands, the guideline for building products refers to "technical specifications", i.e. to harmonised European standards (EN) and to European Technical Approvals (ETA).

In Germany, the country building codes stipulate this suitability for procedures and products, that may be put in circulation and can be traded according to rules of the member states of the EC - including German rules - and the contract-states of the agreement over the European economic area to the transposition of guidelines of the EC and that carry the CE-labelling.

The German Institute for Building Technology (Deutsches Institut für Bautechnik – DIBt) has the task to list the technical rules for building products and constructions in the construction standard catalogue À and B as well as catalogue C. Basically, building products for which there are technical rules (regulated building products) are distinguished of those where there are no rules (non-regulated building products).

General approvals by the building authorities are demanded for such building products and constructions in the scope of the country building code, for which there are no generally acknowledged rules of technology or no national or international standards or which varies essentially of those. Within the scope of the approval, the "essential requests" on the products and procedures are to be proven by means of internationally fixed test procedures. These laboratory examinations or numerical computer simulations include the aspects

- Mechanical solidity and stability
- Fire protection
- Sound-insulation
- Heat-insulation
- Environmental protection and energy-saving
- Hygiene and health
- Security of utilisation.

The examinations for the security of utilisation, especially under consideration of the serviceability and permanence under realistic constructive conditions, could not be led sufficiently to this day, because regional influences of the climate like temperature, relative humidity, driving-rain, snow, wind and radiation could not be taken into account extensively under non-stationary conditions.

The determination of the serviceability is necessary especially for the long-term approval of such new building products or systems. Influences during the utilisation can be conducted just by means of numerical simulation-procedures or full-scale practical tests in special climate chambers.

In the framework of a development of a new insulation system, the proof of the regulation of the serviceability under realistic constructive conditions was led through the BBS INSTITUTE on behalf of the company URSA International by means of new procedures. Supplemented by standardised laboratory-examinations at discrete components and numerical computer simulations at the entire system, the regional influences as well as the effects of the different climates in Europe on a whole building and its components were checked and assessed in the context of a full-scale “on-road”-test. These results were incorporated as well in the project-development as in the approval at the DIBt.

3 Determination of the Serviceability of New Components and Systems Under Realistic Conditions

For the determination of the serviceability of new components and systems under realistic conditions, a program for a test house was worked out by the BBS INSTITUTE. The program was conducted in the climate - and wind tunnel „Jules Verne “of the department „Aerodynamique et Environnement Climatique (AEC) “of the „Centre Scientifique et Technique you Bâtiment (CSTB) “in Nantes-France. The aim of such a laboratory is to get a better understanding of the physical influences of wind and other climatic influences on whole buildings and structures, but also on miscellaneous large-size industry-products and motor vehicles.

Picture 1: Test house in the wind tunnel

The wind tunnel is divided in two separate test-ovals, which can be driven independently of each other. There is the possibility to combine and to regulate several climate parameters like wind, rain, snow, temperature, radiation as demanded. Thus, climate demands can be enforced on a building under very realistic conditions. The significance of the tests is accordingly high.

In the larger, outer wind tunnel, regional and temporal alterable wind incidences up to 100 km/h can be constituted in the area 5 (see illustration 1). The highest wind speeds up to 280 km/h are reached in the area 1.

In the inner wind tunnel, the temperatures can be regulated in a range of –25°C to 50°C and air humidity from 30%RH to 100%RH. The maximum air-speed can be regulated in the area 13 from 90 km/h to 140 km/h. Rain-events up to a precipitation of 250 mm/h and if required even sandstorms can be generated. Additionally, it is possible to generate a blizzard with snow-cannons in the climate-tunnel. The snowfall amounts up to 150mm snow/h.

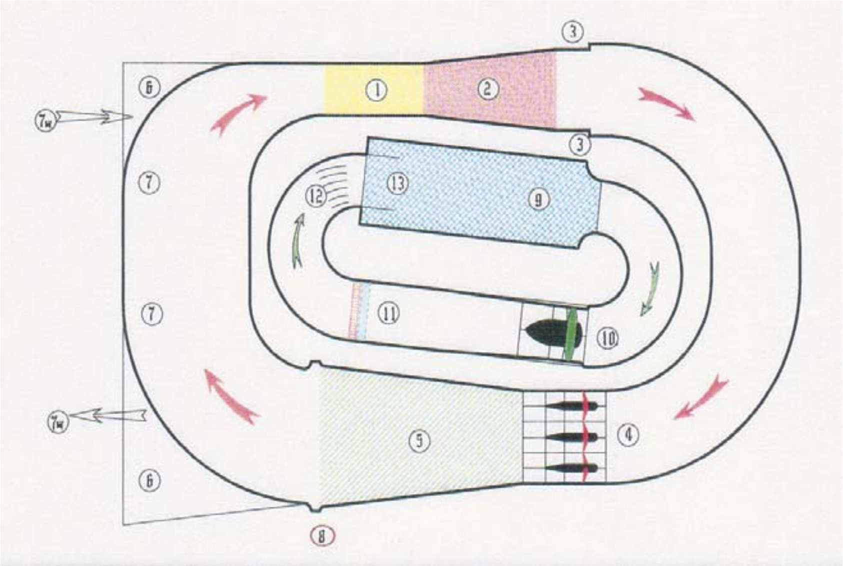


Illustration 1: Wind tunnel „Jules Verne“ at the CSTB in Nantes

1.	High-speed-section	30 m² test section; wind speed = 78m/s
2.	Distribution sector	50 m² test section
3.	Air intake	Temperature regulation
4.	Ventilators	
5.	Examinations of environmental parameters	134 m² test section
8.	Control of the atmosphere-pressure	
9.	Test-chamber; climatetunnel	length: 25 m; height:7 m; test section 30 m² emulation of natural air-current, fog and frost; snow (up to 15cm/h); blizzard; solar radiation wind speed up to 35m/s temperature-range -25°C to 50°C humidity 30% to 100%RH Radiation intensity up to 1100W/m²
10.	Ventilator	
11.	Heat and cold registers	
12.	Deflectors	
13.	Nozzle	Adjustable test section 18 to 30 m² Wind speed < 40 m/s

4 The Test House and Roof System

The test-house had to be adapted on the proportions of the wind tunnel of the CSTB only negligibly in order to be able to enforce the tests in the wind tunnel. The test-house consists of a metal framework, on which the corresponding modules can be put as and when required. A variation of the angle of the roofslope is arbitrarily possible. A roofslope of 45° was chosen for the tests described below. The main attention of this examination was on the roof elements and the underlying attic storey. In order to get a significant thermography during the winter-test, it was necessary to insulate the floor and the gable walls and to connect the prefabricated parts in an airtight way. The interior was heated on usual inside temperatures of approximately 20 °C.

An extensive measuring technique for recording of air-temperatures, air humidity, surface temperatures as well as material temperatures and humidity was installed and the data logged during the tests.

5 The Test Program

The test program for the serviceability of the roof-elements is divided into 6 sections:

1. Rain-test
2. Summer-test
3. Winter-test
4. Flue snow
5. Wind-test with rooftiles
6. Wind-test without rooftiles

A test-schedule, generating in each case the most unfavourable test-conditions in the climate-chamber, was arranged in order to detect the interactions of the climate on the test-house. The sequences of the individual examinations were coordinated in a way that also other effects like reversed diffusion could be investigated. The rain-test e.g. was conducted before the summer-test and the roof-tiles were assembled after the summer-test. Moreover, the roof-elements were exposed to an extreme magnitude by testing the roof with maximum wind load without extra load from a hard roofing .

Table 1 : Test Program

	test 1	test 2	test 3	test 4	test 5	test 6
	Rain	Summer	Winter	Snow	Wind	Wind
Temperature [°C]	25	30	-10	-10	23	23
Wind velocity [m/s]	12	3	3	12	5 – 35	5 – 50
Rainfall [mm]	60					
Snowfall [g/m³]				2		
Radiation intensity [W/m²]		1000				
Orientation [°]	0	90	90	0	30	30
Length of test [h]	60	150	3	1	30	30

5.1 Rain-test

The rain-test was conducted in the area 9 „thermal unit “ (see illustration 1) in the inner tunnel. Here, the rain-security of the roof-system should be checked without roof covering in accordance with a load under construction. The rain was applied to the eaves of the test-house. A rain-intensity of 60 mm/h was regulated by means of water-pressure in the inlet-tubes and in dependence on the wind speed of 12 m/s. The rain-strength corresponds to a rain yield factor of 167 l/s*ha. The value is equivalent to the 3-fold rain-quantity, that was measured in the summer 2002 during the century-flood in Dresden.

The test-duration amounted to 1 h. During the entire test, the temperature was kept on a constant level of 25°C in the climate-tunnel.

Picture 2: Test house during rain-test

At the end of the test, no leakages could be determined after examination in the sub-cover as well as on the interior surface of the roof-elements. Increased humidity in the timber plates below the underlay and the roof view from below were not determined after the (short) test-duration.

5.2 Summer-test

Within the scope of this test, the reversed diffusion should be tested. Reversed diffusion is caused by the moisture on the underlay and the temperature increase on the surface of the prefabricated parts. It is directed into the cross-section of the component. The effects of an increased irradiation on the roof-system should be checked in addition. The permanence against UV radiation was not object of the examination. The examination of the permanence against UV radiation can be conducted in permanence-tests according to DIN EN 1297.
The test house was arranged at 90° for this test on the irradiation area below the radiators with a maximum performance of 1200 WS in order to make an irradiation through the lateral positioned radiators possible. The temperature in the climate-tunnel was increased from 25°C to 30°C. The wind speed was turned down on 3 m/s. The test duration amounted altogether to 150 min including 90 min warming-up phase and 60 min test phase under constant conditions. The intensity of radiation measured on the test surface is shown in table 2.

Table 2 Radiation measurements on the roof during summer-test

Measuring point	Eave	Middle	Ridge	Ridge	Middle	Eave
Height [m]	1,5	2,2	2,8	2,8	2,2	1,5
Radiation [W/m²]	625	930	1100	1050	1100	625

Picture 3: Test house during summer-test

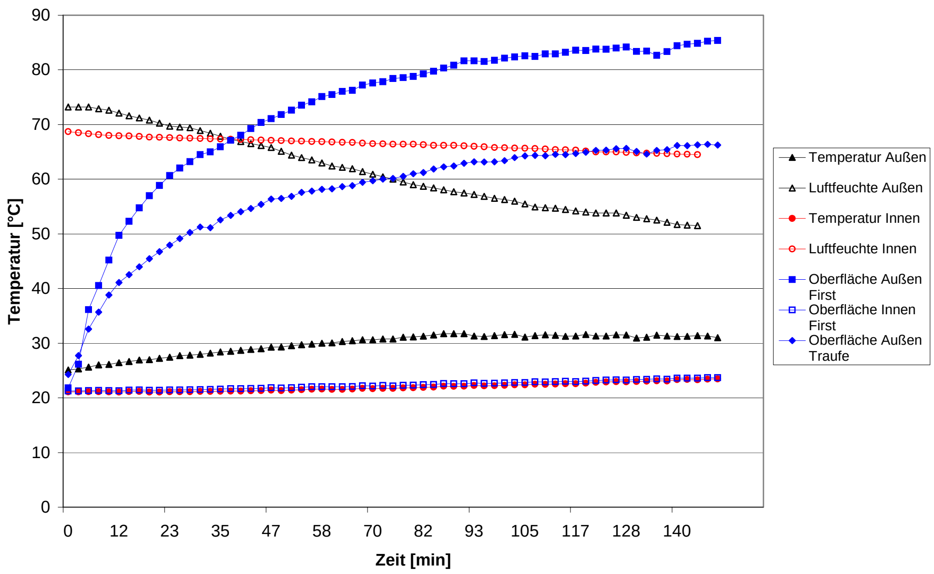


Chart 1: Temperatures and air humidity in the wind tunnel and in the test house

The development of temperature of the indoor and outside air, as well as at the surface were recorded during the test. The surface temperatures close to the ridge exceeded 80°C because of the higher closeness to the headlights. Nearby the eaves, the temperatures were with 65°C clearly lower. During the test, the surface temperature on the roof and the temperature of the inside air increased with delay. Caused by the warming of the wind tunnel, the high outside humidity, resulting from the rain-test, decreased. In the interior, the relative humidity of the air declines in correlation to the increase of the indoor air temperature. The low fluctuations of the temperatures of the climate tunnel are to be attributed to the inertia of the heat register.

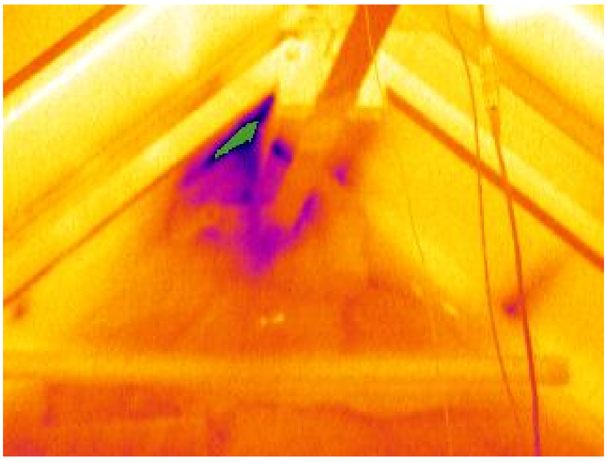
5.3 Winter-Test

The extreme cooling down to a winter climate after the summer-test should show effects of alternating freeze-dew-strain of the roof-system. On this occasion, especially thermal longitudinal-alterations of the system should be observed.

Within the test, the temperature was reduced to –10°C, the wind speed was minimised (3 m/s) and the temperature in the attic storey was kept constant on 20°C.

The effects of a cold climate on the interior of the building were analysed on the basis of heat bridges . At this, a negative pressure was applied to the attic and the, indeed only negligibly existing, imperfections were recorded with the aid of a thermography camera (see picture 4). The thermography camera (THERMA CAM TH Reporter 2000) was mounted in an opening in the gable wall.

Examinations of the building’s tightness were conducted via the Blower-door method. Outside air was blown in the overpressure procedure together with smoke into the attic in order to determine the leakages. This test was conducted without rooftiles in order to get a better visual examination.



Picture 4: Thermography of the roof and gable-top, seen from inside the attic

Picture 5: Interior view of the roof according to the thermography picture

During the examination by means of thermography and Blower-door method, leakages were detected on a gable wall of the test house (pictures 4, 5). It could be determined, that they did not result neither from leakiness of the elements nor from the element joints of the insulation system, but from mistakes at connecting the roof elements to the gable wall. These imperfections were sealed during the attempt. The prefabricated parts as well as the element joints showed no effects of heat bridges or leakiness.

5.4 Flue Snow

A crucial statement over the serviceability of roofs yields the performance of the construction against the penetration of very fine-grained flue snow under the hard roofing, beneath the underlay and into the system.

The roof covered with bricks was turned with the eaves into the wind-direction. The snow was generated by means of a snow cannon. The wind speed was increased on 12m/s and the air-temperature kept constant with –10°C.

Picture 6: Wind tunnel during the snow-test

After the test-duration of 1 h and an average snow-quantity of about 2 g/m³ (in the revolved air), distinct snowdrifts have been formed in the test-chamber and on the roof. In the area of the eaves on both sides of the roof, a considerable quantity of snow had penetrated between tiles and underlay. A penetration of snow beneath the underlay or even into the attic could not be determined.

Picture 7: Test house after snow-test

5.5 Wind-Test

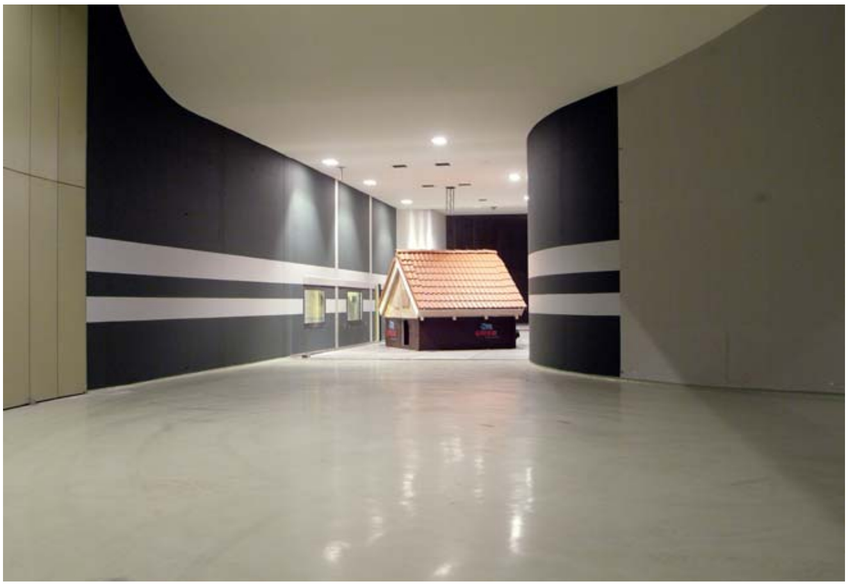
One of the decisive requirements on the serviceability of roof systems is the resistance against wind pressure and wind suction. Only via the functional maintenance of the roof, a protection of the building is possible. For this reason, two wind-tests were conducted one after the other in the high-speed area 1 of the outer wind tunnel (see illustration 1). The roof was arranged in an angle of 30° to the wind direction (most unfavourable position).

5.5.1 ... with rooftiles

The test was carried out at wind speeds up to 126 km/h according to wind force 12 on the Beaufort scale, without additional safeguarding of the rooftiles using clamps. The wind speed was increased slowly in steps of 5m/s up to 35m/s. The roof-system showed no damages at the construction as well as at the elements and their connections.

5.5.2 ... without rooftiles

The second test, as worst case without loads of the roofing, was a measure for the functional maintenance of the roof at maximum wind speed up to 180 km/h, according to wind force > 12, which means strong hurricane. The wind speed was increased in steps of 5m/s until on 50 m/s. At maximum wind speed and without recognisable damages, this test was aborted.



Picture 8: Wind tunnel with test house in the high-speed area

The wind-tests give good indications for performance of the roof in a storm. Although natural storm events can occure with additional different climatic and natural conditions and high wind speeds appear particularly in gusts of wind, the tests conducted in the wind tunnel can nevertheless guarantee a maximum serviceability.

6 Results

At finishing analysis and complete dismantling of the roof system after the conducted tests 1-6, no damages or impairments of the functional maintenance of the roof system appeared from the strains of the different, extreme tests.

It is known that „small-tests“, which usually are conducted under development of a product, can only examine singular aspects. On this occasion, it is not possible to re-create the performance of entire buildings or components in a realistic way by means of standardised laboratory-tests. By means of full-scale tests, as represented here, in particular questions concerning the serviceability of buildings and of components can be answered under extreme utilisation conditions. This ensures suitability of systems to the consumer, whose confirmation within the scope of the acknowledged rules of the technology can be proven - if at all - as recently as after years.

7 To the persons

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1984 to 1989 scientific co-worker at the institute for Structural Design and Timber Construction, Prof. Horst Schulze, TU Braunschweig. Since 1990 independent function in the BBS INGENIEURBÜRO/BBS INSTITUTE. Since Sept. 2000 professorships for Structural Design and Building Physics at the College for Applied Science and Art - Hildesheim. Since 2001 chairpersons of the registered association Scientific Engineering Consortium for Conservation of Constructions and Monuments e.V. in Europe.

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