SANDWICH PANELS WITH FOAMED POLYURETHANE INSULATION

by

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Abstract

A large number of long-term tests (most tests over 7 years) on sandwich panels comprising thermal insulation of foamed polyurethane of 30-40 kg/m^3 density and different thicknesses, and different facing layers such as glass fibre reinforced polyester, plasterboard, chipboard, wood fibre board, asfaboard, plywood and steel sheeting demonstrate that the very good thermal insulation properties of foamed polyurethane, apparent thermal conductivity λ = 0.017 - 0.024 $W/m^{o}C$ (0.12 - 0.17 $BTU \cdot in/h\ ft^{2\,o}F$) in the different tests, are not changed over a period of time. Test loading of wall and floor panels has shown that these panels can easily be constructed in such a way as to satisfy code requirements relating to loadbearing capacity and limitation of deformations, for instance in single-family houses. Fire tests show that the inside facing layer is critical with regard to the fire resistance of the construction. A wall panel comprising a loadbearing timber frame, 110 mm thermal insulation of foamed polyurethane and an inside facing layer of 15 mm glass fibre reinforced plasterboard resisted a standard fire in conformity with ISO 834 for 35 minutes without failure in the wall subjected to a compressive force. There was no rise in temperature at all on the side remote from the fire. Evolution of smoke was of limited extent.

Introduction

One of the fields of research at the Division of Building Technology, Chalmers University of Technology, is study of foamed polyurethane as thermal insulation in sandwich panels for different purposes, such as floors, walls and roofs in single-family houses, infill panels in multistorey buildings, walls and roofs for industrial and large-span buildings, cold storage premises, etc. The study has been concerned with panels made only of plastics, consisting of facing sheets of glass-fibre reinforced polyester glued to sheets of foamed polyurethane (1, 2, 3), and also, more recently, mainly with sandwich panels comprising a loadbearing timber frame and polyurethane foamed in situ between inner and outer facing sheets of different materials such as plasterboard, wood chipboard, wood fibre board, asfaboard, plywood and steel sheeting (4, 5, 6, 7, 8).

To a large extent, the work has been financed by the National Swedish Council for Building Research, and carried out in close collaboration with the building plastics industry which is very interested in developing polyurethane foam as thermal insulation material in sandwich panels. By virtue of the expansion process, polyurethane foam is particularly well suited for the production of this type of building element. According to another production process, it can

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also be placed, in the form of sheets, between facing sheets of the desired material and glued to these. The properties of the glue film are of decisive importance for the strength. The performance of the panel with regard to flexural stiffness, loadbearing capacity and thermal insulation is dependent on the method of manufacture. Owing to the high thermal insulation capacity of foamed polyurethane, the U-value of this type of wall is very favourable, which contributes to improved energy management.

The Thermal Conductivity λ of Foamed Polyurethane as Determined in Sandwich Panels in Long-Term (7 year) Tests

In an investigation (3) which went on for several years, a study was made to see whether the thermal conductivity of foamed polyurethane changes in time when it is placed in the form of sheets between facing sheets which, in the test, consisted of sheets of glass fibre reinforced polyester. As long as a sheet of foamed polyurethane is freely exposed to air, there is diffusion of air into the sheet and a diffusion of the included gas trichlorofluoromethane ($CFCl_3$) out of the sheet. It is estimated that diffusion of air into the foamed polyurethane proceeds about 10 times as fast as diffusion of $CFCl_3$. This means that the thermal conductivity of foamed polyurethane gradually increases if the surfaces of the sheets are not provided with facing sheets (1, 3, 9, 10, 11, 12, 13,).

In the investigation (3), a study was made of test sheets of 40, 60 and 80 mm thickness made of material with a density of 29 kg/m^3 (1,8 lb/ft^3), there being 4 samples of each type (4 types) and thickness, i.e. a total of 48 test sheets of the dimensions 450x450 mm. Of the sheets, 12 were not covered while the remaining 36 had facing sheets of 3 mm glass fibre reinforced polyester all over. Of these latter, some had aluminium foil glued onto one side or both sides in contact with the polyurethane. The thermal conductivity was determined in a Lang apparatus calibrated to sheets of reference from the National Swedish Institute for Testing and Metrology, there being 2 determinations on each sheet at 4 different times, i.e. a total of about 400 determinations.

Eight test sheets of the dimensions 1190x1190 mm, two without facing sheets and six with facing sheets of 3 mm glass fibre reinforced polyester all over, were also tested in the "wind apparatus" of the Department. In this apparatus, the sheets are tested in the horizontal position according to the Lang principle. It owes its name to the fact that it has been used for determination of the thermal conductivity of different materials under the influence of air flows of different velocities. In these tests, however, the fan was not used. The density of foamed polyurethane in these sheets was higher than in the previous ones, viz. 37 kg/m^3 (2,3 lb/ft^3). Tests on these were carried out only on the first three occasions. A total of about 50 determinations were made using these sheets.

The first measurement was made in the spring of 1970, about 2 months after fabrication of the test sheets, the second one six months later, and the third one 20 months after the first measurement. The fourth measurement was finally made in 1977, i.e. 7 years after the first measurement. Details of the different panel types studied are given below.

The Investigated Panel Types

Test sheets 450x450 mm, Type A, were tested in the Lang apparatus, three thicknesses of 40, 60 and 80 mm, 4 No of each type and thickness. Test sheets 1190x1190 mm, Type B, were tested in the wind apparatus, thickness 80 mm, 2 No of each type.

Designation:

A1, B1	Foamed polyurethane without facing
A2c, B2a	Glass fibre reinforced polyester all over, with aluminium foil adjacent to the foamed polyurethane
A2d, B2b	Glass fibre reinforced polyester all over, aluminium foil on one side and the four edges

A2e, B2c   Glass fibre reinforced polyester all over

The test results are set out in FIG. 1 and 2. In the tests on sheets without a facing layer, see FIG. 1, there was a gradual increase in time in the thermal conductivity of the foamed polyurethane. This increase was about 9% after 6 months, about 16% after 20 months, and about 25% after 7 years, for all the sheet thicknesses tested.

By way of explanation of the lack of agreement between tests and theoretical calculations, as seen in FIG. 1, it may be stated that the age of the foamed polyurethane at the beginning of the tests could not be determined. The calculation according to Norton (11) refers to foamed polyurethane of density 35 kg/m^3 (2,2 lb/ft^3), while the density of the sheets tested was 29 kg/m^3 (1,8 lb/ft^3). The density of the sheets tested in the wind apparatus is an exception; this was 37 kg/m^3 (2,3 lb/ft^3). In the case of these sheets, there was better agreement with theoretical calculations.

As a rule, foamed polyurethane is not made with a density below about 30 kg/m^3 (1,9 lb/ft^3). If the density is less, the cell walls are mechanically week and there is no improvement in thermal conductivity, rather the contrary; this is also suggested by the tests which have been carried out.

On the other hand, no rise in thermal conductivity could be found in time in the case of sheets with a facing sheet of glass fibre reinforced polyester, or in constructions with glass fibre reinforced polyester as a covering layer and with aluminium foil nearest the foamed polyurethane, see FIG. 2.

Thermal Insulation Properties of Sandwich Panels with Thermal Insulation of Polyurethane Foamed in Situ

It was suggested in the course of later discussions that it would be desirable to carry out further studies of the heat and moisture engineering properties of foamed polyurethane, and it was decided to perform full-scale tests on wall panels of the sandwich type consisting of a loadbearing timber frame and different facing sheets, adapted for testing in the Fiskebäck field station of Chalmers University of Technology. This is equipped with a complete set of measuring apparatus for the study of the behaviour of wall panels in a west coast climate by means of flow, temperature and moisture measurements, while at the same time the climate indoors and outdoors is recorded on punched tape. Measurement of driving rain and measurement of insolation intensity with a solarimeter are also carried out.

The field station is constructed in such a way that wall sections measuring 1.20x2.50 m can be interchanged. The panels, see FIG. 3 and 4, are attached at the top and bottom. A total of 8 panels of different construction and with 8 cm PUR insulation, Bonofoam 1107, density 41 kg/m^3 (2,6 lb/ft^3), were made. The inner and outer facing layers and types of facade cladding for the different test panels are set out in TABLE 1. In the case of test panel No 3, the internal facing sheet consisted of plasterboard lined with plastics foil, i.e. the test panel was fitted with a vapour barrier. The other test panels were made without a vapour barrier. The panels were provided with a sheet of plasterboard or wood chipboard on the inside. The outer facing sheet consisted of plasterboard, asfaboard, semi-hard wood fibre board or wood chipboard for outdoor use, with a facade cladding of aluminium sheeting. In the case of some panels, the polyurethane was foamed in situ directly onto the facade cladding of plastics coated steel sheeting or plywood treated with a preservative.

At the Fiskebäck field station, all panels were tested continually over a period of one year with regard to determination of the U-value (measurements of flow and temperature), moisture movements (moisture tests comprising weighing before and after drying), and also determination of mechanical movements in the panels for an assessment of their dimensional stability (6). Laboratory tests were carried out at the same time for determination of the thermal conductivity and the vapour permeability of the foamed polyurethane, the properties of the facing sheets, etc. At present, the test panels have been in position for more than 2 years. After 2 years, renewed determinations of the thermal conductivity and moisture ratios were made for all panels.

The results of the investigation were that the thermal resistance of all panels was around 4 $m^2 {}^oC/W$ (22,6 h $ft^2 {}^oF/BTU$), there being some scatter depending mainly on the resistance of the facing layer. Over the test period, which included the time up to 336 days after manufacture, no obvious changes occurred in the thermal properties of the panels. Converted to thermal conductivity, the results corresponded to a value of λ of between 0.019 and 0.021 W/m^oC (0,132 and 0,146 BTU·in/h $ft^2 {}^oF$). The thermal transmittance or U-value was calculated, on average, as about 0.24 $W/m^2 {}^oC$ (0,042 BTU/h $ft^2 {}^oF$), the surface resistance $m_i + m_u$ = 0.25 $m^2 {}^oC/W$ (1,41 h $ft^2 {}^oF/BTU$) according to Swedish Building Regulations SBN 75 being included in the calculation. The value obtained must be compared with the maximum permissible values according to SBN 75, 0,25 $W/m^2 {}^oC$ and 0.30 $W/m^2 {}^oC$ (0,043 and 0,053 BTU/h $ft^2 {}^oF$) respectively for different zones. Nor was there any change in thermal insulation capacity when renewed measurements were made after 2 years.

During the field tests, the necessity for a vapour barrier in this type of panel was also investigated. The investigation was performed by determining the moisture distribution in the panel. The moisture ratios found were very small, a maximum of 0.15% by volume, the same order as measured in panels stored in normal room climate. No difference could be found between panels with and without a plastics foil. The field tests were carried out under special conditions without any appreciable supply of moisture from the inside. The tests are being supplemented at present by laboratory tests under variable climatic conditions.

The Test Building of the HSB at Landsbro. Heat Engineering Investigation of Sandwich Panels Insulated with Foamed Polyurethane

In the course of discussions which preceded the fullscale tests described above, it was considered that evaluation of thermal economy and determination of the U-values and moisture contents in external wall panels in the test building of the HSB at Landsbro would be advantageous. The test building which was constructed in 1965 is a detached house of 121 m^2 area with a loadbearing system of steel columns and steel girders. The walls consist of sandwich panels comprising 9 mm semi-hard wood fibre board and 50 mm foamed polyurethane expanded in situ, of density 37 kg/m^3 (2,3 lb/ft^3), see FIG. 5. The facade cladding is aluminium sheeting. The components of the panels are held together by adhesive, and the joints between panels are also glued. The floors are insulated with mineral wool in the conventional manner. The heating system consists of a thermostatically controlled oil-fired boiler.

The measurements, which were made over the period 9/11 - 30/11 1976, comprised determination of the U-value by means of temperature and flow measurements, measurement of the total energy demand and determination of unintentional ventilation (5). At the same time, tests for determination of the U-value were made in the guarded hot box apparatus in the laboratory at Chalmers University of Technology on some sandwich panels left over from the construction period. The construction of the sandwich panels can be seen in FIG. 5 which shows a section through the panel wall tested in the laboratory (4).

The measurements at Landsbro gave, excluding the influence of joints, a thermal transmittance U = 0.38 $W/m^2 {}^oC$ (0,067 BTU/h $ft^2 {}^oF$). The corresponding thermal conductivity for foamed polyurethene was found to be 0.023 W/m^oC (0,160 BTU·in/h $ft^2 {}^oF$). In laboratory tests, the values obtained, including joints, were U = 0.46 $W/m^2 {}^oC$ (0,081 BTU/h $ft^2 {}^oF$) and the corresponding thermal conductivity λ=0.024 W/m^oC (0,167 BTU·in/h $ft^2 {}^oF$). The investigation shows that the foamed polyurethane even after about 10 years, still has very low thermal conductivity. It is not known how large the value was initially, as no measurements were made at the time of construction. In view of its small thickness, 7 cm, the U-value of the wall must be regarded as very favourable. Calculation of the energy balance for the whole building showed that, in spite of the wall thickness of only 7 cm and an abnormally large window area, the test building has the same energy consumption as a normal building, about 25,000 kWh/year.

Development Trends and Further Research into the Thermal Insulation Properties of Foamed Polyurethane

Over the past few years, there has been a tendency to construct an increasing number of single-family houses with walls, floors and roofs of sandwich panels containing foamed polyurethane thermal insulation. The construction of such a wall panel is shown in FIG. 6. In conjunction with this development, different types of further tests were carried out on wall, floor and roof panels at the Division of Building Technology, Chalmers University of Technology. During determinations of the U-value in the guarded hot box apparatus for a sandwich panel as in FIG. 6, comprising 110 mm thermal insulation of foamed polyurethane, the value $U = 0.20$ $W/m^2 {}^oC$ (0,035 $BTU/h\ ft^2 {}^oF$) was obtained inclusive of the thermal bridge effects due to the masonite studs. The corresponding thermal conductivity of the foamed polyurethane in the panel, of density 45 kg/m^3, was found to be $\lambda = 0.020 - 0.021$ W/m^oC (0,139-0,146 $BTU \cdot in/h\ ft^2 {}^oF$) in different tests.

The Loadbearing Capacity of Wall, Roof and Floor Units

Since the sandwich panels in question also have an important loadbearing function, the problem of studying their strength and deformation properties has also been considered. The wall panel according to FIG. 6 was subjected to a central load and also to a combination of central load and lateral loading, which permitted study of the effect due to wind load. The ultimate load for a whole panel is about 200 kN on short-term loading (7). This is about 10 times as large as the working load in a normal single or one-and-a-half storey house. Investigations concerning the study of the loadbearing capacity of floor and roof panels subjected to stresses due to pure bending are in progress.

Fire Tests

In connection with discussions concerning development of sandwich panels with foamed polyurethane thermal insulation, the issue of the fire resistance of the construction has assumed great importance. The reason for this is that the panels contain a considerable quantity of plastics which is both combustible and develops smoke when burning. At present, no special requirements are stipulated in Swedish regulations concerning the fire resistance of enclosing surfaces, for instance in single-family houses. According to requirements for single-family houses in Fire Category B30, which are at present being drawn up, the structural element in question shall resist the effect of a fire for 30 minutes and shall retain its loadbearing capacity during the subsequent cooling-down period. In order that these requirements may be satisfied, fire tests have been carried out on 1 floor unit and 2 wall units of gradually modified construction (8).

The floor unit, shown in FIG. 7, had a span of 4.5 m and was subjected to two line loads in the quarter points of the construction, corresponding to a total load of 150 kg/m^2. The thermal insulation of foamed polyurethane, of density 36 kg/m^3 (2,3 lb/ft^3), had a thickness of 150 mm. The loadbearing elements consisted of masonite beams, with flanges of ordinary timber 45x45 mm, and a web of 8 mm hard wood fibre board (masonite), see FIG. 7. The top face of the floor unit consisted of 22 mm chipboard, and its bottom face of 9 mm plasterboard of standard type. The floor was exposed on its underside to standard fire in accordance with ISO 834. After 10 minutes violent fire broke out in the foamed plastics insulation, and after 11 minutes the sheets of plasterboard had fallen down. After 20 minutes 10 seconds, the floor failed and fell down into the furnace.

The wall construction subjected to fire test, No 1, is illustrated in FIG. 8. The wall consisted of 3 units, each of 1.20 m width and 2.50 m height. The load applied at the top was 16.4 kN/m. The thermal insulation of foamed polyurethane, of density 40 kg/m^3 (2,5 lb/ft^3), was 110 mm thick. The loadbearing masonite studs had flanges of ordinary timber 45x35 mm and webs of 6 mm masonite. The inside face of the wall consisted of glass fibre reinforced plasterboard 13 mm thick. In the sheet used in this case, the reinforcement was made up of about 5% very thin short glass fibres which were mixed into the plaster mass during manufacture. The wall units were joined by single-component jointing compound of polyurethane, and on the side exposed to fire the joints between the sheets of plasterboard were treated with sand filler. The wall was exposed to standard fire in accordance with ISO 834.

In contrast to previous tests, the inside face of the wall was given a more fire resistant cladding of 13 mm glass fibre reinforced plasterboard, instead of the 9 mm plasterboard in the standard version. There was a corresponding improvement in the results in relation to the test on the floor construction. After about 4 minutes, a crack pattern began to appear on the sheets of plasterboard. After 18 minutes 20 seconds, small pieces of the cracked sheets of plasterboard began to fall down, and the insulation caught fire. After 27 minutes the wall deflected 15 cm. After 27 minutes 15 seconds the wall collapsed under load. The construction had lost its loadbearing capacity due to penetration of fire through the masonite webs of the studs. Wall construction No 1 thus did not fully satisfy the requirements applicable to Fire Category B30.

In the third fire test on wall construction No 2, see FIG. 8, certain modifications were made to the construction. The inside facing of 13 mm glass fibre reinforced plasterboard was replaced by one 15 mm thick. The thickness of the masonite webs in the studs was increased from 6 to 8 mm. The studs were given two coats of fire resistant paint. In orther respects, the construction was identical to wall No 1.

As in the previous tests, the fire resistance of the construction was determined in accordance with the method specified in ISO 834. The results show that the modified wall construction satisfied the requirements applicable to Fire Category B30 as a loadbearing structural element and partition. After 35 minutes when the test was discontinued, the wall had retained its loadbearing capacity, and the temperature on the side remote from the fire had not risen at all. Compared with the two previous tests, evolution of smoke in this test was also considerably less extensive.

To sum up, it is evident that the fire resistance of the inner facing layer was critical with regard to the fire resistance of the entire construction. Decomposition of the foamed polyurethane occurs more slowly while the supply of air is restricted (as long as the facing layer is intact), and evolution of smoke is considerably less extensive. It is considered that the greater thickness of the masonite webs in the studs contributes to the stability of the wall during a fire. Treatment of the masonite studs with a fire resistant paint was a measure which was found to be superfluous.

Conclusions

The following conclusions can be drawn from the results of these investigations:

1. In tests on sheets of foamed polyurethane without a facing layer, there was a gradual rise in time in the thermal conductivity of the foamed polyurethane (3). In longterm tests, the increase in the value of λ was about 9% after 6 months, about 16% after 20 months, and about 25% after 7 years for the tested sheet thicknesses of 40 mm, 60 mm and 80 mm, see FIG. 1. In different tests, the original value of the apparent thermal conductivity λ varied between 0.017 and 0.024 W/m^{2} ^{o}C (0,12 and 0,17 BTU·in/h ft^{2} ^{o}F).

2. In tests on sheets with a facing layer of 3 mm glass fibre reinforced polyester all over, or in a construction with glass fibre reinforced polyester as facing layer all over and aluminium foil adjacent to the foamed polyurethane, no increase in time could be found in the value of λ in longterm tests (7 years) (3). The sheets retained their good thermal insulation property, see FIG. 2. The value of the thermal conductivity varied between 0.017 and 0.024 W/m^{o}C (0,12 and 0,17 BTU·in/h ft^{2} ^{o}F) in different tests.

3. In full-scale tests, which have now been going on for 3 years, on wall panels of the sandwich type consisting of a loadbearing timber frame, 80 mm thick thermal insulation of foamed polyurethane, and different facing sheets such as plasterboard, chipboard, etc, see FIG. 3 and 4 and TABLE 1, adapted for testing in the Fiskebäck field station of Chalmers University of Technology,

determinations have been made of the U-value of the test walls and the moisture movement in these (by means of moisture tests comprising weighing before and after drying). The results of the tests are that the test walls retained their good thermal insulation properties, and that the value λ for the polyurethane of 41 kg/m^3 (2,6 lb/ft^3) density, as given by different tests, was between 0.019 and 0.021 W/m^oC (0,132 and 0,146 $BTU \cdot in/h\ ft^{2\,o}F$) during the test period (6).

4. In the tests as in 3), the measured moisture ratios were very small, a maximum of 0.15% by volume, the same magnitude as measured in units stored in a normal room climate. No difference could be found between units with and without a vapour barrier. These tests are at present being supplemented by laboratory tests under variable climatic conditions.

5. In a test house built in 1965, the walls consisted of sandwich panels comprising 9 mm sheets of semi-hard wood fibre board with 50 mm polyurethane of 37 kg/m^3 (2,3 lb/ft^3) density foamed between them in situ. See FIG. 5. When measurements were made in the test house 11 years later, the thermal transmittance was found to be U = 0.38 $W/m^{2\,o}C$ (0,067 $BTU/h\ ft^{2\,o}F$) and the corresponding thermal conductivity of the foamed polyurethane was λ = 0.023 W/m^oC (0,160 $BTU \cdot in/h\ ft^{2\,o}F$) (4, 5). It is not known what the U-value was originally, as no measurements were made when the house was built. In view of the small wall thickness of 7 cm, the measured U-value of the wall must be regarded as very favourable.

6. In fire tests performed on 1 floor unit and 2 wall units, it was found that the fire resistance of the inside facing layer is critical with regard to the fire resistance of the entire construction. Satisfactory results were obtained when a facing layer of 15 mm glass fibre reinforced plasterboard was used. The results of tests on a modified wall construction comprising such a facing layer mean that the wall in question satisfies the new requirements applicable to Fire Category B30 as a loadbearing structural element and partition (8).

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TABLE 1. Details of the Test Panels. See also FIG. 4.

TEST PANEL NO	FACING LAYER INSIDE (1)	OUTSIDE (2)	FACADE CLADDING (3)
1	13 mm plasterboard 1)	9 mm Masonite 4)	Type A, profiled aluminium sheeting, Gränges VAP 25 with brown PVF_2 lacquer, on 25x50 mm battens at 600 mm centres
2	13mm plasterboard 1)	13 mm Asfaboard 5)	"
3	13 mm plasterboard 2) (plastics foil coating)	9 mm plasterboard 6)	"
4	12 mm chipboard 3)	12 mm chipboard 7)	"
5	13 mm plasterboard 1)	12 mm plywood 8)	Type B, polyurethane foamed in situ
6	12 mm chipboard 3)	12 mm plywood 8)	Type B, against plywood
7	13 mm plasterboard 1)	0.7 mm smooth steel sheeting 9)	Type B, polyurethane foamed in situ against steel sheeting
8	12 mm chipboard 3)	0.7 mm smooth steel sheeting 9)	"

1) Gyproc normal GN

2) Gyproc normal GND

3) Climatic Class 3, indoor use

4) Semi-hard wood fibre board

5) Asphalt impregnated porous wood fibre board

6) Gyproc normal GNU, outdoor use

7) Climatic Class 2, outdoor use

8) Climatic Class 3, coated with Exponyl PL 50 wood glaze, 1 coat brown, 1 coat colourless

9) Coated with brown silicone polyester 234/protective lacquer 012

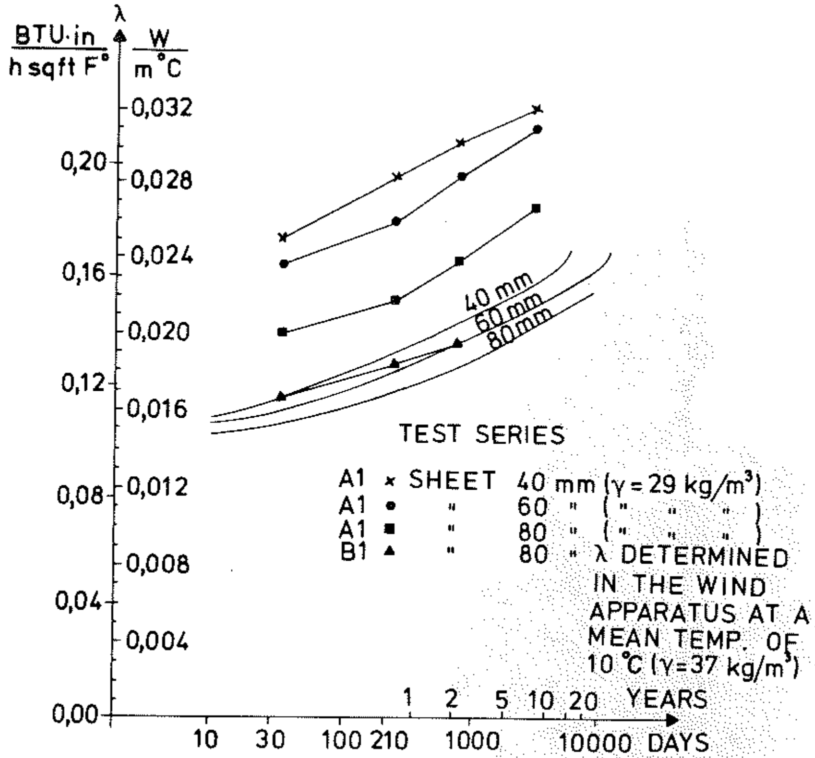

FIG. 1. Variation of apparent thermal conductivity in time in sheets of foamed polyurethane (20°C) of 29 and 37 kg/m³ (1,8 and 2,3 lb/ft³) density, of different thicknesses, according to theoretical calculations (NORTON) for λ = 35 kg/m³ (2,2 lb/ft³) and according to our own tests. The sheets were freely exposed on both sides.

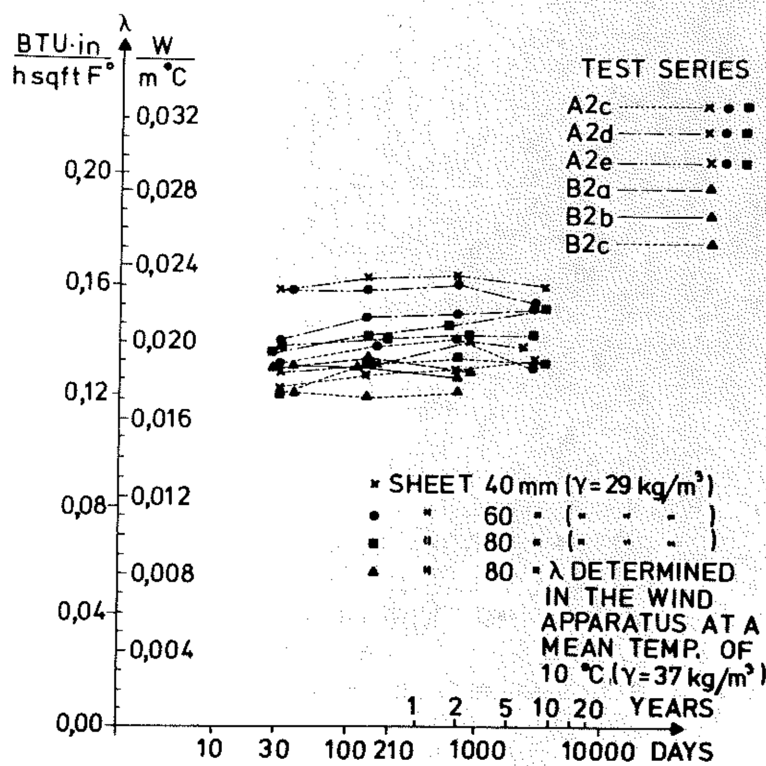

FIG. 2. Variation of apparent thermal conductivity in time in sheets of foamed polyurethane (20°C) of 29 and 37 kg/m³ (1,8 and 2,3 lb/ft³) density, of different thicknesses. Sheets with or without aluminium foil lining next to the polyurethane, and faced in all cases with glass fibre reinforced polyester all over.

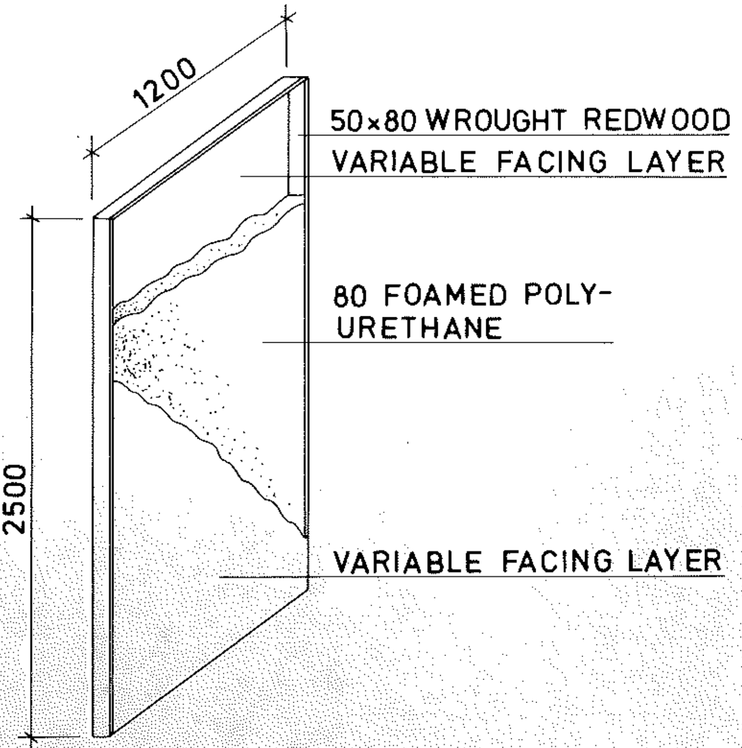

FIG. 3. Detail of sandwich panel with thermal insulation of foamed polyurethane, tested at the Fiskebäck field station of Chalmers University of Technology for determination of U-values and moisture contents. Dimensions in mm.

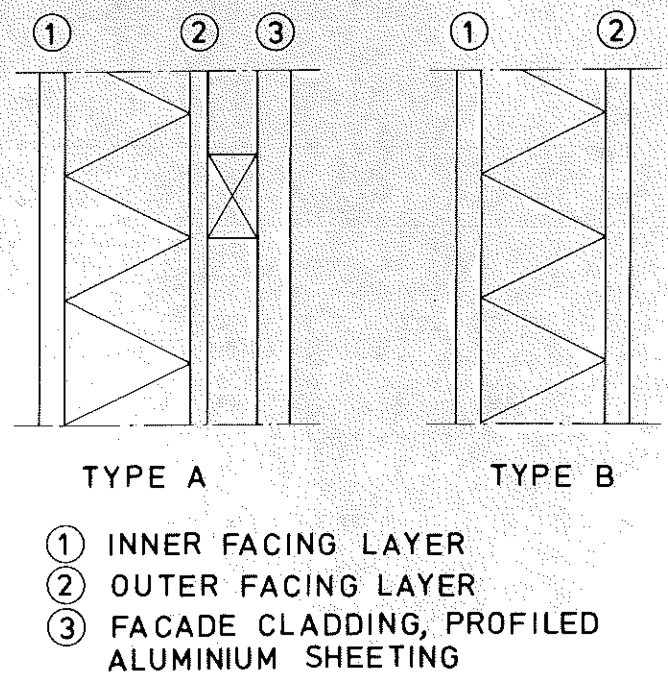

FIG. 4. Sketch showing general arrangement with inner (1) and outer (2) facing layer and facade cladding of profiled aluminium sheeting (3), TYPE A, and outer facing layer (2) of preservative-treated plywood or smooth steel sheeting with in-situ foamed polyurethane, TYPE B. See also TABLE 1 which gives details of panel types tested at the Fiskebäck field station of Chalmers University of Technology for determination of U-values and moisture contents. Thermal insulation of 80 mm Bonofoam 1107, density 41 kg/m^3.

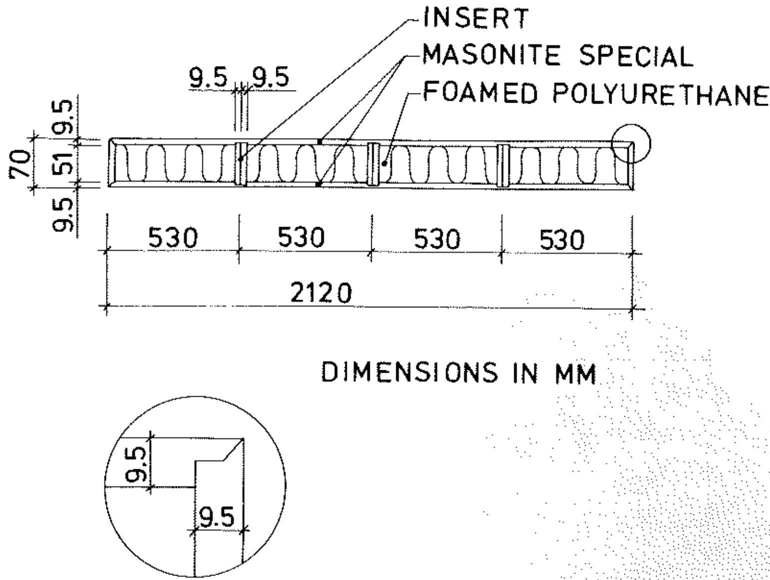

FIG. 5. Section through panel wall made up of sandwich panels left over from the construction in 1965 of the HSB test building at Landsbro, for testing in the laboratory 11 years later for determination of the U-value in the Guarded Hot Box. Dimensions in mm.

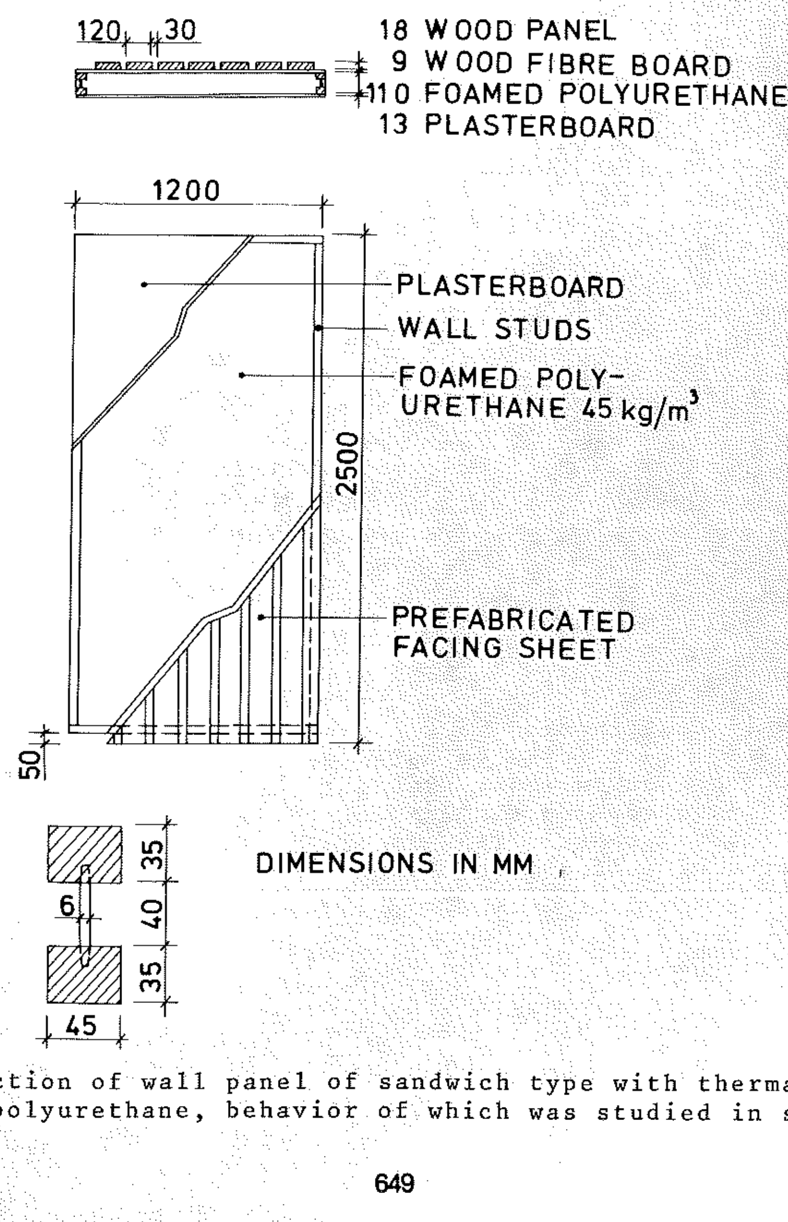

FIG. 6. Construction of wall panel of sandwich type with thermal insulation of foamed polyurethane, behavior of which was studied in strength and fire tests.

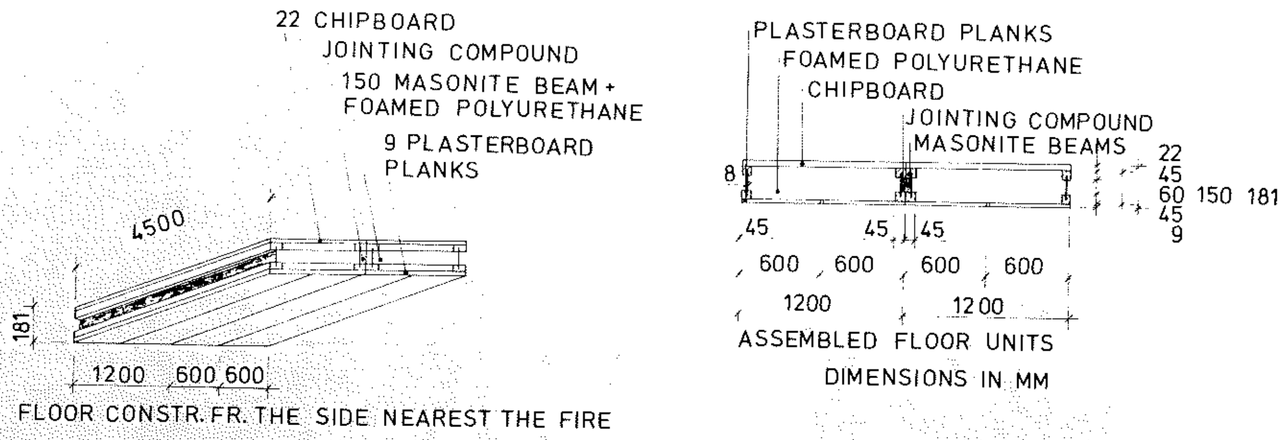

FIG. 7. Floor construction subjected to fire test.

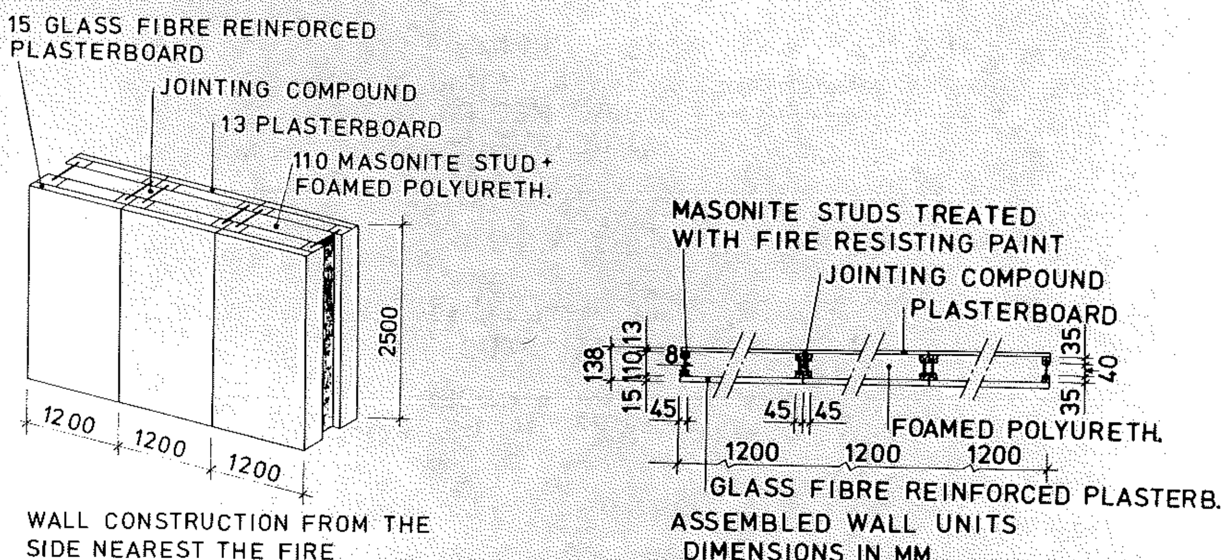

FIG. 8. Modified wall construction No 2 subjected to fire test. This wall resisted the fire test for 35 minutes without failure. Wall No 1 subjected to fire test had an inner facing layer of 13 mm glass fibre reinforced plasterboard, and the webs of the masonite studs were 6 mm thick and had not been treated with fire resisting paint. Wall No 1 failed after 27 minutes in the fire test.