Impact of solar radiation on the temperature of thermal insulation materials in roof applications

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EXECUTIVE SUMMARY

The effectiveness of thermal insulation materials in roof applications is affected by the thermal impact of solar radiation. This is particularly true for flat roofs where the insulation material is applied directly under a water-proof membrane.

The two most important aspects of this application are:

- The high temperature levels due to solar radiation;
- The significant temperature variations during the different periods of the day and of the year.

This research study examined the temperature spread inside a water proof kit and in particular the maximum temperatures that can be reached in the insulation layer.

The research study consisted of two phases:

- Modelling: Using a calculation model, the temperature gradient was calculated for all the different layers of a typical water-proof kit configuration simulating the possible variation of several climatic parameters.
- Practical validation: the real conditions on two different roofs were measured to proof the validity of the model.

The project results showed that the insulation layer in contact with the external water-proof membrane of flat roofs can reach temperature peaks of more than 70 °C during the period of highest solar radiation. In the hot Mediterranean climate of southern Europe, temperatures can reach 80 °C. The maximum temperatures on curved roofs in more moderate climate zones can reach 67 °C. The project showed daily temperature variations of close to 40 °K inside the insulation material and about 50 °K on the surface.

These temperature peaks exceed the maximum functional temperatures of several insulation materials. With a view to guaranteeing the quality and durability of roof kits, specifiers and architects should be aware of how high temperature levels reached in zones of intensive solar radiation affect the dimensional stability of insulation material.

PHASE 1: THEORETICAL ANALYSIS

The analysis used the calculation model HEAT 2. This modelling software has been developed by Lund University (Gothenburg Group for Computational Building Physics in partnership with the Department of Building Physics) and by the Building Technology Group of the MIT (USA).

The calculation method allows the modelling of composite structures of different materials (in this case the water-proof kit) and the simulation of the heat exchange in order to determine the exact temperature in each of these layers.

Once the model created and the data relating to the materials of the water-proof kit defined (e.g. thickness of the insulation layer, thermal conductivity, density and specific heat of the membranes…), the specific climatic conditions (intensity of sun radiation, air temperature, humidity…) are introduced. The model then provides a detailed description of the temperature gradient in each single layer.

The model takes account of radiant and convective heat exchange towards both the outside and the inside of the roof kit. These two aspects could be the cause of a significant variability between real and calculated data.

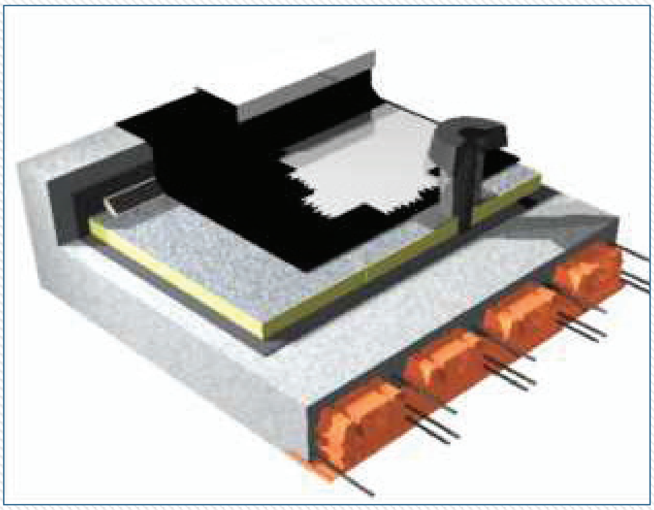
The simulation analysed the climatic conditions of different European regions taking into account the peak of July which represents the period with the highest sun radiation.

Literature sources provided the average data for Trapani (I - 38° 01'), Rome (I - 41° 53'), Venice (I - 45° 26'N) and London (UK - 52°N).

It was also possible to identify the exact statistics of July 2003 for Venice and July 1984 for Zurich (CH - 47° 48' N).

The thermal flow analysis took into account a time frame of seven days in order to evaluate the progressive heating of the roof. In the modelling, different insulation materials have been evaluated. It was established that, for the same transmittance value (different thicknesses) the differences in terms of temperature levels were insignificant.

The modelling analyses different roofing types. The most critical, in terms of temperature levels obtained, has been the flat roof with an external bituminous water-proof membrane.



The analysis has been carried out considering the stratigraphy in **Table 1**.

PHASE 1: MAIN FINDINGS

The flat roof with external waterproof membrane is subject to significant heating up and the insulation layer in contact with the upper membrane can reach temperatures above 70 °C even in climate zones with moderate sun radiation.

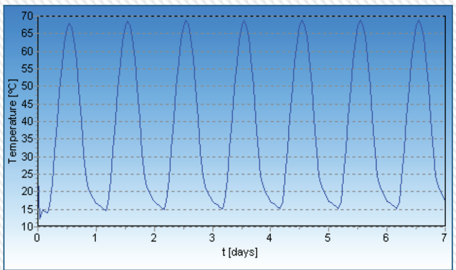
The external layer (water-proof membrane) has a relatively small mass and thickness but possesses a relatively high absorption coefficient (a = 0.95). This fact can determine the heating up of the insulation

Stratigraphy	Description	Thickness [m]	Density [kg/m³]	Thermal conductivity λ [W/(m K)]	Specific Heat [kJ/(kg K)]
Base support	Pre-stressed reinforced concrete slabs	0.25	1800	0.90	0.90
Primer	Bituminous emulsion	0.001	600	0.17	1.80
Vapour barrier	Bituminous membrane reinforced with aluminium foil	0.003	1300	0.26	0.88
Layer of melted oxidise bitumen (1.5 kg/m²), cold melt, PUR one component foam (30 g/m²)		0.004	1300	0.26	0.88
Thermal insulation	PUR/PIR board (facing: glass fibre)	0.060	35	0.03	1.40
Bituminous membrane	Bituminous membrane reinforced with polyester fibre	0.004	1125	0.17	1.47
Bituminous membrane finished with slate chips	Bituminous membrane finished with slate chips reinforced with polyester fibre	0.004	1000	0.15	1.20

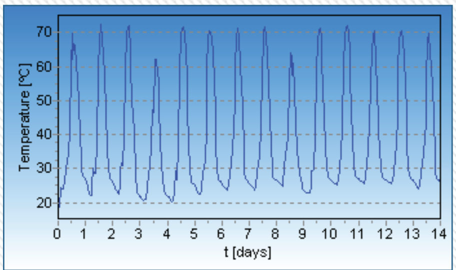
Table 1

layer close to temperatures of 90 °C in "very hot" climate zones" (Trapani).

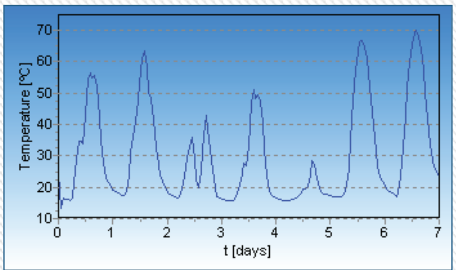
The data obtained from the mathematical model for the temperatures inside the insulation layer (about 3 mm from the top of the insulation board) are shown in the following graphs:



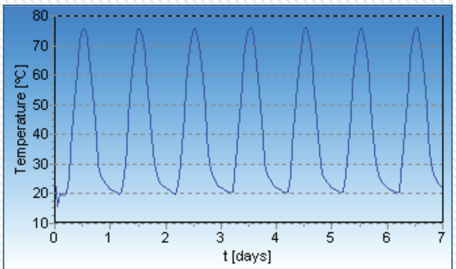
London: average climate data



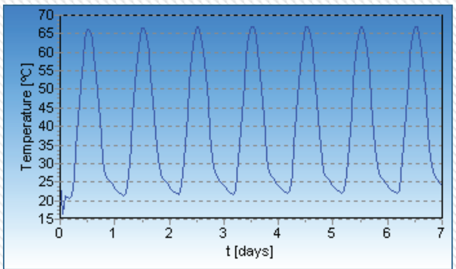
Venice: Real climate data (July 2003)



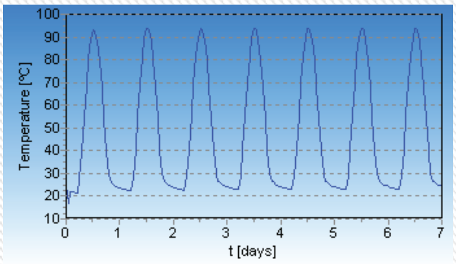
Zurich: Real climate data (July 1984)



Rome: average climate data



Venice: average climate data



Trapani: average climate data

The calculated temperatures, in particular for the hotter climate zones and during the day period of maximum solar radiation, are very often above the highest functional temperatures of a number of insulation materials and, as a consequence, represent a risk factor for the integrity and the dimensional stability of the whole waterproof kit.

PHASE 2: PRACTICAL VALIDATION OF THE MODEL

Following the simulation process of HEAT 2, the research project proceeded with the practical validation of the model including verification of the following aspects:

- Impact of the specific conditions affecting the environment of every location (roof ventilation, shadowing factors);
- Impact of the parameters assumed for the calculation (absorption coefficient, emission coefficient…) in real end-use conditions.

LOCATION AND TOOLS USED FOR THE EXPERIMENTAL PHASE

The experimental measurements have been carried out on an office building located in the Industrial Area of Padua (45° 19’).

Two different roof configurations were monitored:

- Flat roof (1): water-proof kit with an external bituminous membrane (very similar to that analysed for the modelling);
- Curved roof (2): curved sandwich panel (external surface: aluminium metal sheet, thickness 7/10 mm, painted red colour – insulation layer: polyurethane foam thickness 40 mm – internal surface: galvanized metal sheet corrugated, thickness 4/10 mm).

MEASUREMENT TOOLS

Nine thermocouples were installed (4 on the flat roof and 5 on the curved) in order to measure the temperature on the upper surface as well as on the internal layer (insulation material). Temperatures were registered continuously and collected by a multichannel data logger directly connected with the thermocouples. In parallel, a weather station was set up in the immediate vicinity to the thermocouples in order to register solar radiation, air temperature and humidity and wind speed and direction. All data coming from the meteorological station were also collected continuously.

SURVEY PERIOD

Measurements have been registered during several months in 2005 and the whole of 2006.

COLLECTED DATA

The following graphs and tables show the average data registered by the thermocouples during the month of July 2006. They also show the data relating to 21st of July in order to put emphasise the maximum temperature registered.

LEGEND:

Flat roof:

- Thermocouple 1: surface temperature (right side)
- Thermocouple 2: internal temperature of insulating layer (right side, 3 cm deep)
- Thermocouple 3: surface temperature (left side)
- Thermocouple 4: internal temperature of insulating layer (left side, 3 cm deep)

Curved roof:

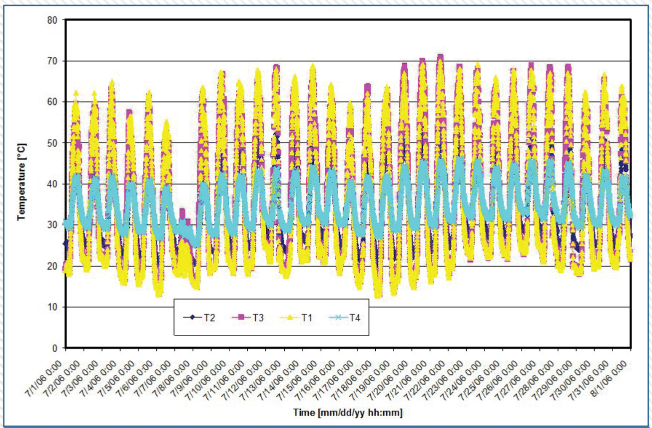
- T5: surface temperature (low)
- T6: internal temperature of insulating layer 3 cm deep (low)
- T7: internal temperature of insulating layer 3 cm deep (top)
- T8: surface temperature (top of the roof)
- T9: internal temperature of insulating layer 3 cm deep (low, east side)

	Thermocouple			
July 2006	3	1	2	4
Max	70.87	69.91	54.27	46.31
Min	12.86	12.64	20.07	24.88
Average	35.54	35.49	34.23	34.87
Δ	58.01	57.27	34.20	21.43

Table 2: Flat roof

	Thermocouple			
July, 21 2006	3	1	2	4
Max	70.87	69.91	54.27	45.78
Min	16.41	16.24	23.27	23.25
Average	54.46	53.67	30.91	16.41
Δ	39.17	38.74	36.92	36.76

Table 3: Flat roof on the 21st of July



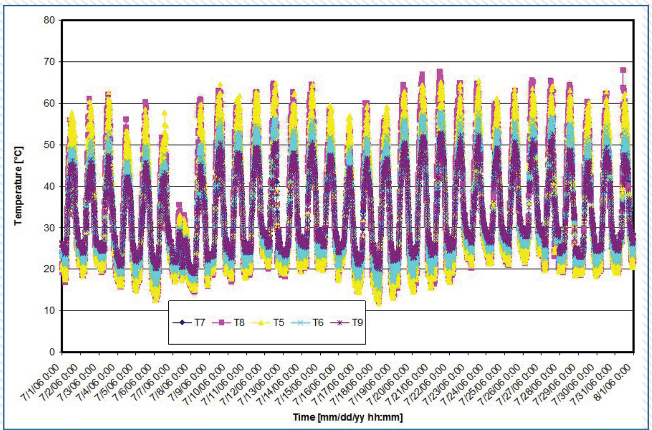
Graph 1: Flat roof

July 2006	TC 8	TC 5	TC 6	TC 7	TC 9
Max	67.93	65.53	57.82	55.55	52.90
Min	12.09	11.92	15.29	17.64	18.91
Average	33.58	33.94	33.16	33.21	33.22
Δ	55.84	53.61	42.54	37.90	33.99

Table 4: Curved coof

July, 21 2006	TC 8	TC 5	TC 6	TC 7	TC 9
Max	67.93	65.53	57.82	55.55	52.90
Min	12.09	11.92	15.29	17.64	18.91
Average	33.58	33.94	33.16	33.21	33.22
Δ	55.84	53.61	42.54	37.90	33.99

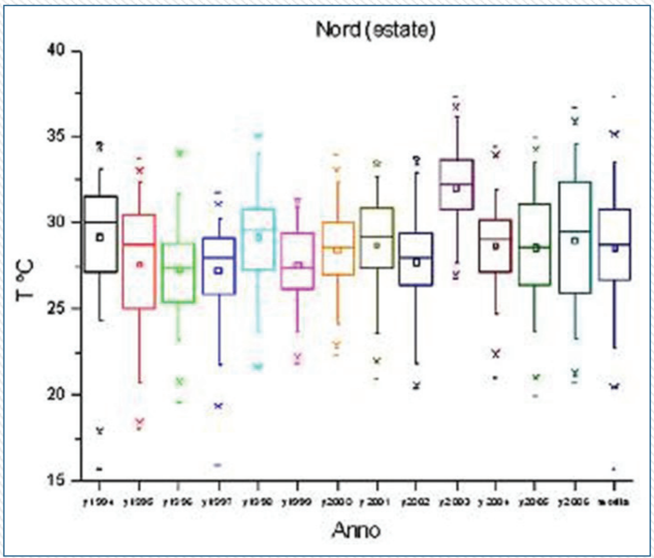
Table 5: Curved roof on the 21st of July



Graph 2: Curved roof

ANALYSIS OF THE DATA

- The summer of 2006 was characterised by a relatively high variability in weather conditions. Heat waves were shorter than in the summer 2003, even if the maximum value was close to the typical average (see below comparison of the maximum summer temperatures in Venice, 45°26’).



- The data show strong temperature variations not only during the summer months but all through the measurement period: inside the insulation material, a range of temperatures close to 40 °K was measured whereas 50 °K were registered on the surface.

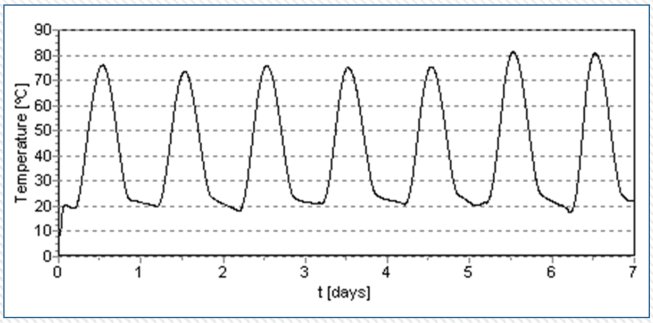
- Flat roofs reached a maximum temperature of 70 °C remaining unchanged for a period of 3 hours.

- Curved roofs (were the inclination of the sun radiation is different) reached a maximum temperature of 67 °C remaining unchanged for a period of 3 hours.

COMPARISON OF THE END-USE DATA WITH THE MODELLING METHOD

The comparison of the data detected on the two different roof configurations and those calculated in the model simulation HEAT 2 showed a high degree of correspondence. This was mainly due to the fine-tuning of the adsorption and emission data of the two roof surfaces.

Using the data obtained indirectly from the study, the modelling for the city of Trapani was repeated as shown in the following graphic.



Maximum values according to this modelling are about 8-10 °C lower than in the simulation obtained with the previous absorption and emission coefficients. Nevertheless, the analysis of surface temperatures for the roof leads to the conclusion that temperatures of about 80 °C over a limited time span.

CONCLUSIONS

The study identified several critical aspects that should be taken into account by designers when choosing the insulation material for roofing applications:

- In regions characterized by a warm climate, temperatures of roof applications with water proof membranes on view can exceed 80 °C.

It should be noted that the absorption coefficient used for the simulation (and also in the real roof test) refers to a bituminous membrane with slate-grey finish. Higher levels of temperature will be reached when membranes of a darker colour are used.

This emphasises the importance to select an insulation material guaranteeing full functionality at temperatures significantly exceeding the maximum temperatures to be expected in end-use conditions.

- In all applications and for all climatic conditions, strong thermal variations have been registered within a relatively short period of time. As a consequence, the selection process of the most suitable thermal insulation material requires the calculation of the dimensional stability based on a range of temperatures close to end-use conditions.

  Furthermore, it is very important to evaluate the level of stability and cohesiveness of the whole water-proof kit in order to avoid that thermal stress causes distortions or little splits especially on the joints.

- As demonstrated by the tests according to the European harmonised standard hEN 13165, the physical and mechanical characteristics of rigid PUR-PIR foams guarantee fitness for use even under the most severe climate conditions.

Typical functional temperature resistance of PUR-PIR:	100-110 °C
Dimensional stability test temperature in the EN 13165:	48 h – 20 °C 8 h + 70 °C, 90 % UR

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