PU EUROPE
EXCELLENCE IN INSULATION
FEDERATION OF EUROPEAN RIGID POLYURETHANE FOAM ASSOCIATIONS

Factsheet n° 10

Efficient insulation

THE KEY TO EFFECTIVE THERMAL PROTECTION IN SUMMER

EXECUTIVE SUMMARY

Because of the changing climate, attic overheating in summer is getting more and more of an issue, affecting also Central and Northern Europe. As there are some common misunderstandings regarding the influence of thermal insulation on indoor temperatures, the Federation of European Rigid Polyurethane Foam Associations (PU Europe) commissioned FIW München to investigate this subject scientifically.

The energy efficiency and temperature conditions in residential buildings depend primarily on the sun shading, the thermal protection on the external structural elements, and ventilation. The heat storage capacity of the insulation layers plays a negligible role **[1]**. Practical tests clearly show that the thermal resistance of the insulation layer has a much greater influence on room climate in summer than the thermal mass of the insulation material. Relative to the other influencing factors (windows, shades, ventilation, effective thermal mass in the interior, standard of thermal protection, etc.), the heat storage capacity of the insulation material is of secondary importance.

Despite the simplified design of the experiment, the findings can be transferred to real building applications. Polyurethane thermal insulation boards offer much better thermal protection than wood fibre boards of the same thickness. This applies both in the warm and cold months of the year. Facings with high reflectivity and low emissivity on the polyurethane foam core can provide some additional help to keep the indoor air temperature lower and to minimise energy for cooling with air conditioning systems in summer.

There are no "summer insulation materials". On the contrary, insulation materials should perform as well as possible both in summer and winter. Highly efficient thermal insulation materials, such as polyurethane, provide optimal thermal protection, guarantee a comfortable living environment, and minimise energy consumption.

INTRODUCTION

Thermal insulation materials are installed in buildings in order to limit the heat transfer from the warm side to the cold side, both in summer and in winter. The only difference is that the heat flow in the warmer months is from the outside to the inside, and in the colder months from the inside to the outside. High performance insulation materials with extremely low thermal conductivity values are particularly effective in this respect. Up to this point, there is general agreement among experts.

When this subject is mentioned in the press, it is repeatedly claimed that insulation materials of greater mass and heat storage capacity are more advantageous in the warm summer months. Do some insulation materials perform better in summer than in winter?

HEAT STORAGE OR HEAT INSULATION?

The aim of thermal protection in buildings in summer is to keep interior temperatures at comfortable levels. Apart from the heat emitted by electrical appliances and persons, it is essential to limit the heat gains from direct solar radiation, ventilation and thermal transmission (walls and ceilings and floors). Windows without shades have the greatest influence on temperature conditions in summer **[2]**.

To understand the effect of thermal mass in buildings, it is important to realise that the temperature of the air and of structural elements fluctuates considerably over the day. This also continuously affects the intensity and direction of heat flow **[3]**. Structural elements absorb heat in the afternoon and emit it during the night. The storage and emission of heat by structural elements evens out the temperature peaks inside the building. Heavyweight constructions generally react more slowly to exterior temperature fluctuations than lightweight constructions. This is dependent not solely on the heat capacity of the structural elements, but also on the positioning and effectiveness of the thermal masses. Construction layers that are in direct contact with the interior air, which demonstrate a high heat storage capacity and are good heat conductors, act as heat buffers. Especially effective are solid, non-insulated interior walls, ceilings and floors with flagstones or tiled surfaces that absorb heat from the interior air in the middle of the day and thus cool the room. At night and in the early morning hours, the buffer cools down: the structural element gives off the heat it absorbed during the day.

Owing to their low thermal conductivity values and low mass (compared with solid structural elements), thermal insulation materials are not good at storing heat. After all, their job is to insulate and not to accumulate heat energy. No one would dream of making a hot water tank or a fridge out of wood (high heat storage capacity). A building with optimal thermal protection in summer and winter should have very good thermal insulation on the exterior in order to minimise heat gains through thermal transmission. Inside, thermal masses, such as solid walls, ceilings and floors are an advantage.

The claim that some products such as wood fibre insulation materials function simultaneously as insulators and heat stores is misleading. In fact, wood fibre insulation is not optimally suited to either purpose: firstly, wood fibre insulation with a thermal conductivity λ = 0.048 W/(m·K) transmits twice as much heat, for example, as high performance polyurethane insulation product with the thermal conductivity λ = 0.024 W/(m·K). Secondly, wood fibre insulation materials are not nearly as good at storing heat as solid structural elements, such as stone or concrete.

In buildings, thermal insulation and heat storage are complementary factors and should be viewed in tandem. Ideally, external thermal insulation (for example in roofs and on the rafters) should be installed such that the construction component layers on the inside exhibit higher heat storage capacity and thermal conductivity. Heavy insulation materials with moderate insulation properties that can store a little heat are not recommended.

WHAT EFFECT DO THE TEMPERATURE AMPLITUDE RATIO AND PHASE SHIFTS HAVE ON THERMAL PROTECTION IN SUMMER?

Over the course of the day, the exterior temperature fluctuates between a maximum value in the afternoon and a minimum value in the early morning hours. The interior air temperature mirrors the exterior temperature after a certain time lag. This lag is termed the "phase shift". In solid (heavyweight) buildings with large thermal mass, this delay between the maximum exterior temperature and interior temperature is greater than in lightweight buildings, as the heat is stored in the structural elements.

The temperature amplitude ratio (TAR) and the phase shift (φ) are sometimes indicated on individual structural elements or structural element layers. TAR and φ describe the theoretical time link between the temperatures of the exterior and interior surfaces. It is important to note that these purely theoretical values are calculated on the basis of boundary conditions that are not present in real buildings, and which therefore cannot be empirically verified.

In real buildings, the phase shift has no influence on thermal protection. It simply indicates the time taken for a temperature wave to travel from the outside to the inside. Of greater significance is the temperature actually reached on the inside, i.e. how much heat arrives at the inner surface – and this critically depends on the efficiency of the thermal insulation.

The relationship is quite easy to demonstrate: due to its low thermal storage capacity, a sleeping bag has only a small phase shift but will nevertheless keep you snug and warm on cold nights. Water, on the other hand, can store a lot of heat. But no one would dream of spending a night in a bath tub.

COMPUTER SIMULATIONS SHOW THAT HEAT STORAGE CAPACITY IN INSULATION MATERIALS IS IRRELEVANT

Using computer-aided thermal simulations it is possible to predict interior temperature fluctuations over the day in summer with a high degree of accuracy. The simulation technique enables us to compare different constructional designs with the same boundary conditions in a particular building. The observations are always specific to the individual case: the results are thus only valid for the model building selected. Simulation calculations are as a rule more informative than tests. In experiments, non-intended boundary conditions often play a greater role than the effects to be measured.

What factors have the greatest influence depends largely on the type of building being examined and the respective boundary conditions. In summer, wood frame buildings heat up more quickly than solid (heavyweight) constructions, provided there are no thermally active materials in the interior. In this type of construction, solid floors or cellar ceilings also have a greater influence on the interior temperature than the heat storage capacity of the insulation material. A computer-aided thermal simulation conducted by the **Fraunhoferinstitut für Bauphysik** showed that the different heat storage capacities of the insulation materials on the ground floor of a wooden house are of secondary importance due to the thermal effect of the concrete floor **[4]**.

The results of a simulation on a pitched roof using various insulation materials with identical coefficients of thermal transmission showed that any differences in the heat storage capacities of the insulation materials was of negligible importance given the same thermal transmission coefficient. The indoor temperatures differed at most by 0.6 K **[2]**. It is important to note that insulation materials with poorer thermal conductivity values must be applied in greater thicknesses in order to achieve an equivalent thermal transmittance.

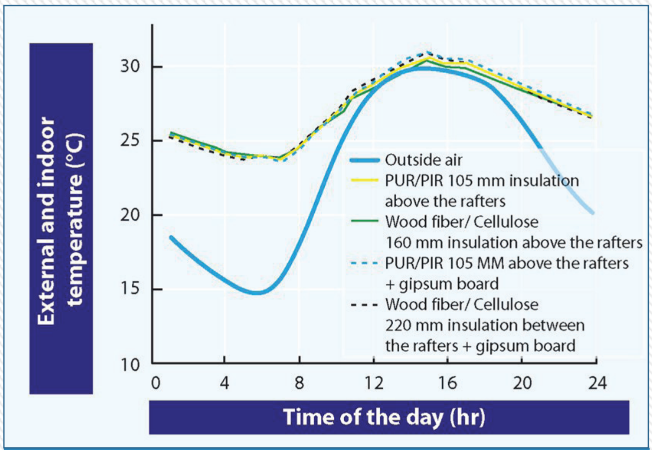

Diagram 1

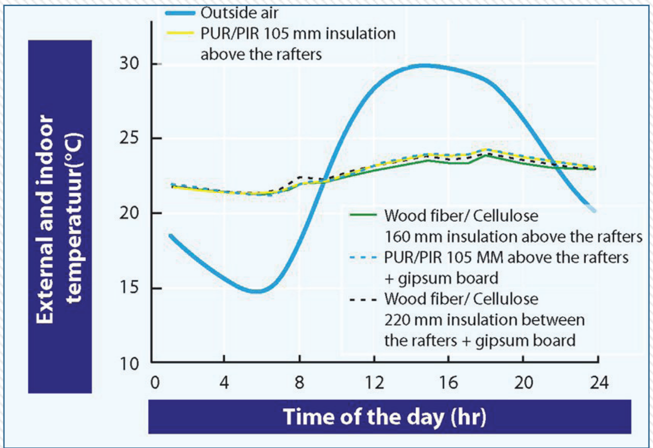

Diagram 2

SUMMER TEMPERATURE BEHAVIOUR IN THE MODEL

Sometimes, visitors to trade fairs and promotional events are shown a simple demonstration that is intended to support the theory "heat storage beats insulation", but which contains alarming conceptual and constructional errors **[5]**. The specimens, various 40 mm thick insulation boards, are placed in wooden boxes and warmed using infrared lamps. The trial generally lasts for between 10 and 20 minutes. In this time, sensors record the temperature changes on the underside of the topmost insulation board.

However, the demonstration results cannot be applied to real buildings. Top of the list of technical failings is that the air temperature in the wooden cases is not uniform. The insulation materials do not have identical facings, so that the different reflection properties lead to different temperatures on the upper surface. Some insulation materials are light-permeable, with the result that the temperature sensors are in the direct light path and consequently warmed. The heat dissipation to the sides and below is uncontrolled. The short test duration emphasises the short-term effects **[5]** and does not reflect the temperature curve over the whole day.

The simple demonstration and the short test duration therefore do not satisfy the demands made of a scientific experiment.

Recognising the errors inherent in this experiment, the FIW in Munich developed a model test that ensures identical boundary conditions for each specimen. It is then possible to derive statements concerning the behaviour of insulation materials in buildings.

The test design developed by FIW in Munich contains no thermal mass of note in the interior and has no transparent structural elements on the irradiated side. The heavily insulated test chamber is designed to exclude any heat gains or losses from the surroundings. A standard specimen thickness of 40 mm was chosen in order to minimise measuring errors resulting from the considerable temperature increase in the interior. This

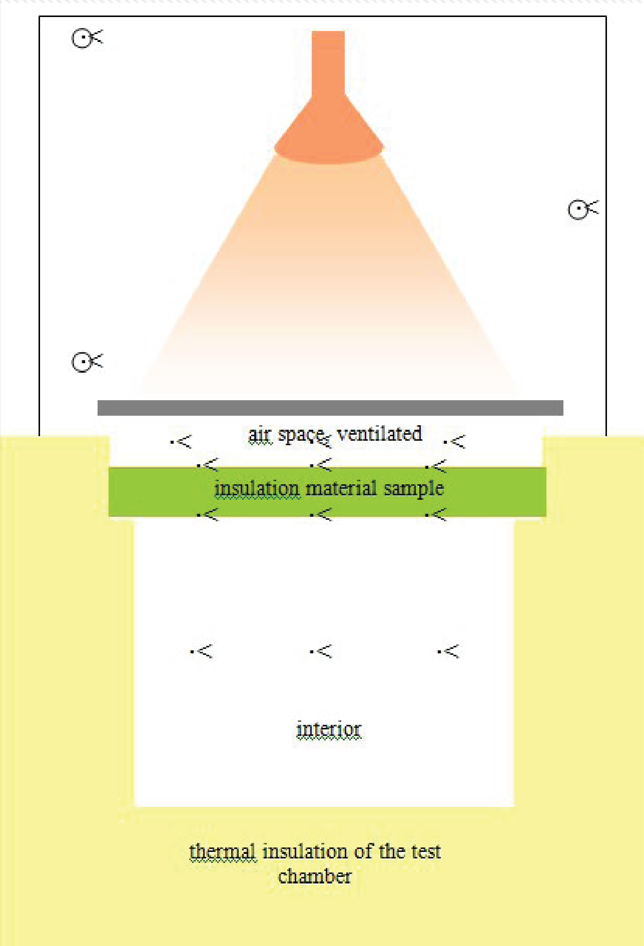

Diagram 3

Diagram 4

insulation thickness also allows for reliable measurement of the night-time cooling process. The test was carried out over 24 hours. In this time, the radiation intensity of the infrared lamp was regulated in accordance with the diurnal pattern (**Diagram 5**).

A comparison of the interior temperature curves reveals an initial delay in the increase in temperature in the case of the wood fibre sample due to its higher thermal mass (**Diagram 6**). As the test proceeds, this effect is offset by its lower thermal resistance, and the temperature curves approach each other after c. 6 hours. Subsequently, the temperature of the wood fibre rises more steeply. The maximum temperature for polyurethane is 1 Kelvin lower.

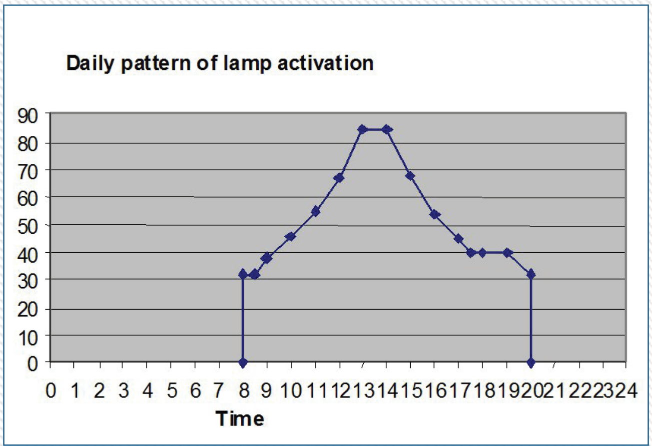

Diagram 5: Period of activation in % (100 % = always on; 0% = always off)

However, how we subjectively perceive heat not only depends on the maximum temperature achieved, but also on the

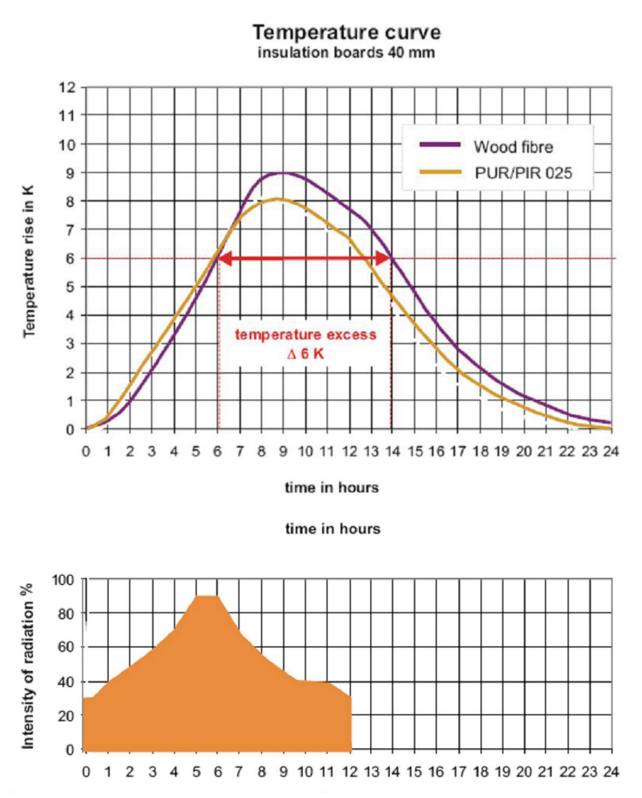

Diagram 6

length of time that a certain temperature threshold is exceeded. In Central Europe, we find interior temperatures of more than 26 °C to be outside the comfort range. For this reason, a temperature increase of 6 Kelvin was set as threshold value for the test. In the case of polyurethane, the length of time above the temperature limit of 6 Kelvin is 1.2 hours shorter.

The higher thermal mass of the wood fibre not only slows down the warming effect, but also produces a marked retardation in the cooling of the interior air; in other words it remains uncomfortably warm for a longer period.

Bibliography

[1] Wolfgang Feist, *Ist Wärmespeichern wichtiger als Wärmedämmen?*, Hrg. Passivhausinstitut, Fachinformation PHI 2000/4

[2] Industrieverband Polyurethan-Hartschaum e. V. (Hg.), *Sommerlicher Wärmeschutz*, 2004

[3] Martin H. Spitzner und Christoph Sprengard, *Summer indoor climate in attics: comparative tests on insulation materials taking into account instationary effects in a model test*, Untersuchungsbericht, 2006

[4] Gerd Hauser, *Holzfaserdämmplatten – Dämmstoffe als Wärmespeicher in Isoliertechnik*, 6-2006, pp. 38-44

[5] Martin H. Spitzner und Christoph Sprengard, *Durchführung eines Experimentes zur Oberflächen und Tiefenerwärmung verschiedener Dämm- und Baustoffe durch Bestrahlung mit einer Infrarotlampe*, Untersuchungsbericht, 2004