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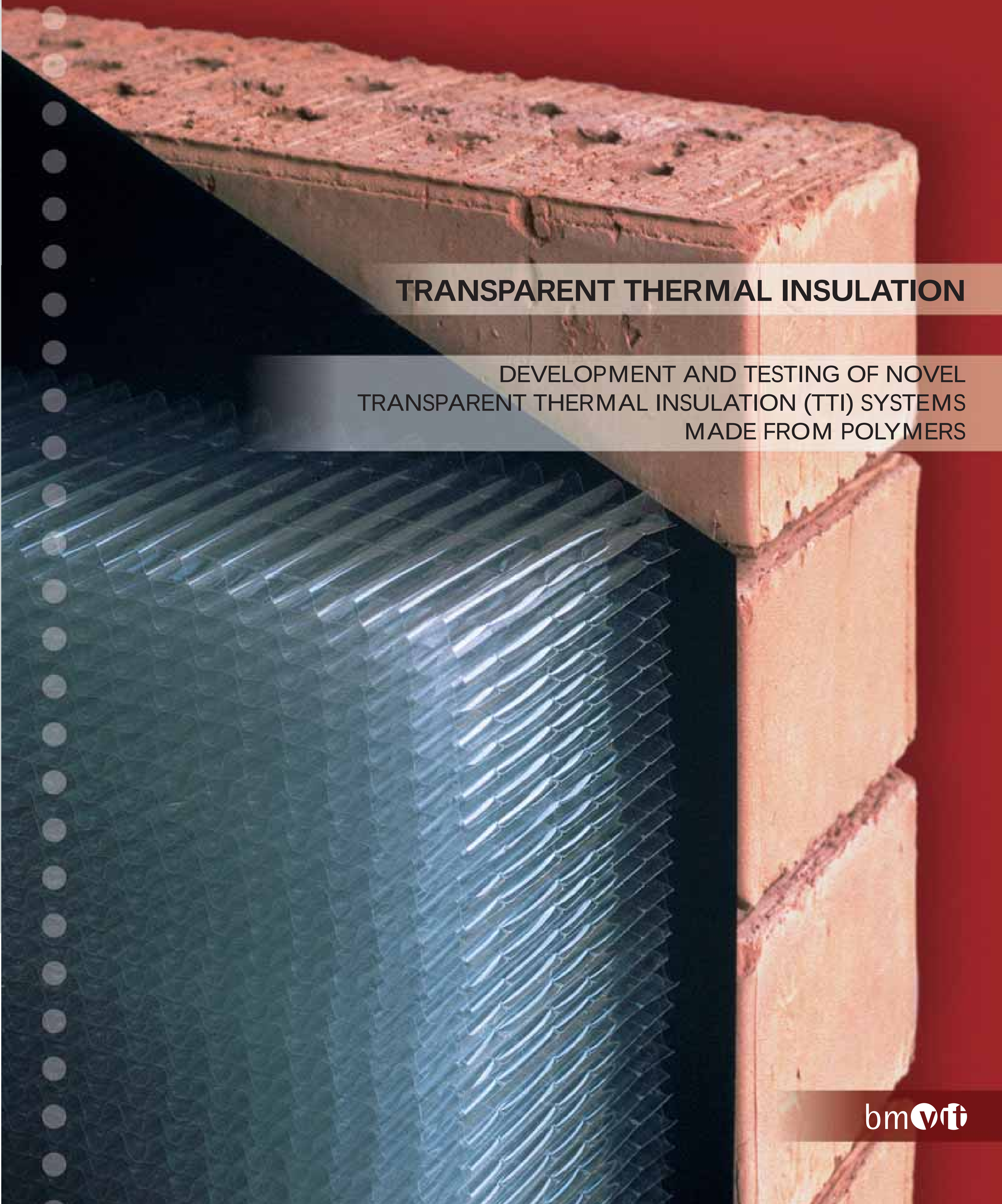


TRANSPARENT THERMAL INSULATION

DEVELOPMENT AND TESTING OF NOVEL TRANSPARENT THERMAL INSULATION (TTI) SYSTEMS MADE FROM POLYMERS

bmvit

NEW DEVELOPMENTS IN THE FIELD OF TRANSPARENT POLYMER BASED THERMAL INSULATION SYSTEMS

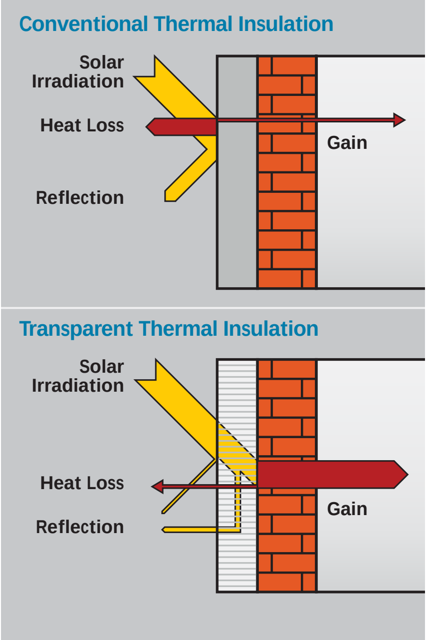
The increased use of renewable forms of energy constitutes one of the most important future-oriented strategies with a view to sustainable development. In the field of space heating, which accounts for approx. 35% of the total energy demand in Austria (as in other European countries), the use of solar energy is of particularly great importance. In this context, transparent thermal insulation systems are considered a promising innovative technology.

Conventional thermal insulation aims at reducing heat loss of a building on account of transmission. Transparent thermal insulation (TTI) relies on compensating heat loss with solar gains and, in addition, to use these gains for space heating. ***Transparent thermal insulation materials*** – in contrast to opaque thermal insulation materials, feature **two properties** that are highly important with a view to the energy balance of a building:

- highly efficient thermal insulation (i.e. low values for the thermal transmission coefficient Λ)
- high transmittance for solar radiation (i.e. high values for the total energy transmission coefficient g_h)

Today's commercially available TTI systems consist of translucent plastics, such as PC (polycarbons) or PMMA (polymethylmethacrylate) with either honeycomb or tubular structure normal to the absorber. However, their excellent thermal properties notwithstanding, they also show some deficits. The production process used (melt extrusion) causes weak points in the structure of the insulation material, which impair optical properties, in particular. The production process is highly complex and not very flexible concerning the use of different materials or the optimization of the geometric microstructure of the material.

Transparent Thermal Insulation
Principle of Action



Within the scope of research supported by funds provided by the Austrian Federal Ministry of Transport, Innovation and Technology (bmvit) and appropriated to technology emphases, the Institute of Polymer Technology of the JOANNEUM RESEARCH Forschungsges.m.b.H and the Institute of Materials Science and Testing of Plastics at the University of Leoben realized several projects aiming at the development and optimization of polymer TTI systems. The Fraunhofer Institute for Solar Energy Systems (Freiburg, Germany) also cooperated in these projects.

The projects focused on the development and production of novel TTI structures made from commercially available plastic foils as well as on a demonstration project in a single family home in Graz.

The following main objectives have been defined for the projects:

- Examination of a broad range of transparent types of plastic and selection of suitable polymer foils, taking into account the specific profile of requirements (resistance to aging, fireproofing, processing properties)
- Theoretical modeling and numerical optimization of lamellar structures perpendicular to the absorber with a view to thermal insulation and total energy transmission
- Elaboration of concepts for a process technology and the production of prototypes of optimized TTI structures adapted to polymers and based on commercially available plastic foils
- Verification and confirmation of theoretical calculations and modeling through analysis of model TTI structures.

The implementation of the research results is still in progress and relies on a prototype plant for the continual production of the novel structure. This stage of the project will soon be completed.

The planned demonstration project installed in Univ. Prof. Reinhold W. Lang's home in Graz will be realized later. As the planned demonstration object has been considered a very interesting example of a successful implementation of comprehensive concepts of solar technology and energy efficient measures, we want to present the concept of this building in the present paper, already.

Transparent thermal insulation materials

TTI materials owe their insulating effect, on the one hand, to a high air content and the separation of the air layers in very small volumes and, on the other hand, to materials with good absorption properties in the heat radiation range as well as to a low conductivity for heat.

TTI-SYSTEM WITH LAMELLAR HONEYCOMB PLASTIC STRUCTURES

Manufacture and optimization of production technology

Research within the scope of the projects aimed to develop innovative plastic structures that can be produced with economical methods, are suitable for various applications, can be installed in different ways, and meet the exacting requirements regarding thermal insulation and radiation conductivity.

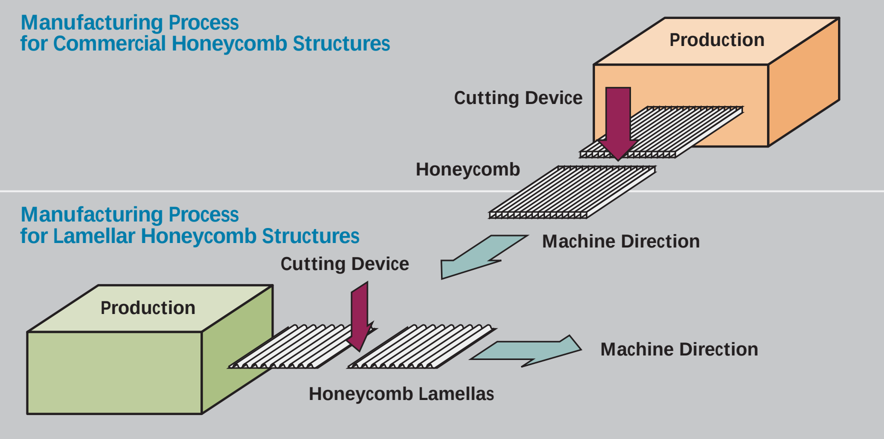
THE INNOVATIVE TTI-STRUCTURE

Research concentrated on the development of optically and thermally optimized, micro-cellular honeycomb structures based on commercially available polymer foils. In a forming process, the flat foils are given the required geometry and form a structure consisting of a great number of adjacent cells. These honeycomb lamellas are connected with each other and arranged in a plane, thus forming the basic element of the TTI structure.

The ***schematic representation*** shows the difference to the conventional production processes: A production plant forms the lamellar honeycomb structure, which consists of a flat foil serving as carrier layer and a wave-like foil, which provides for the cellular structure. Subsequently, the lamellar honeycomb structure, continuously produced in the machine direction (direction of feed), is cut to size by a cutting device.

The making direction provides for important advantages. Cutting to size of the TTI-structures is not done at the front surface that forms the visible surface parallel to the absorber, the foil is rather cut to the desired width of the TTI-module. This avoids common problems such as scatter loss at the edge of cut, insufficient quality of the cut edge, etc.

Manufacturing Processes for TTI Structures



Thus, the ***TTI-structures*** can now be produced seamlessly in any desired width; until recently, the process permitted only the production of smaller elements, the width of the elements depending on the geometrical arrangement of the nozzles of the production facility. In principle, there are two different basic processes for the production of endless lamellar honeycomb structures. The basic element for the TTI-structure can either be stapled or manufactured in the form of rolled structures.

Compared to TTI-structures manufactured by melt extrusion, **lamellar honeycomb structures** show the **following advantages:**

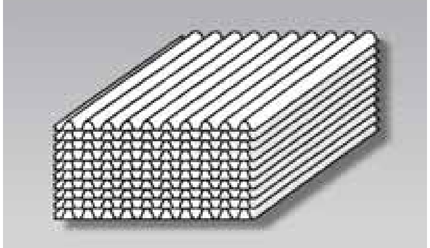
- The use of high-quality foils avoids structural defects on the surface of the TTI-structure.
- Manufacture is highly flexible regarding the type of plastic material and the dimensions of these TTI-structures.

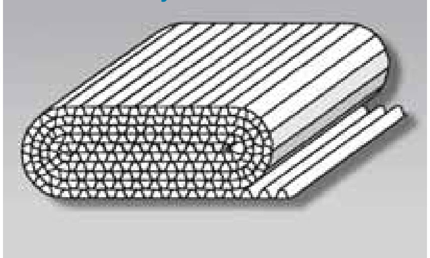
A patent for this novel honeycomb laminate structure has already been applied for in 1997, and has been granted, meanwhile. At present, work concentrates on the implementation of this technology in practice. The objective is to realize the continuous manufacture of lamellar honeycomb structures in a pilot plant including their adaptation for use in prefabricated modules or semi-finished products that can be easily installed on-site. This stage of implementation will soon be completed.

SELECTION OF MATERIALS

The projects also included test series to systematically identify the influence of type of plastic material and geometrical arrangement of the honeycombs

TTI-Structures





on the total energy transmission factor and on the heat transmission coefficient of TTI-structures. Research relied, both, on experimental examinations of different types of foil and on theoretical model calculations. Overall, a total of approx. 80 polymer foils were included in the program. The results have shown that, apart from PMMA and PC, Cellulose acetates (CA and CTA) are particularly suitable for use in the low-temperature range. Appropriate materials for process collectors include, amongst others, fluorine polymers, polysulfones as well as modified, high-temperature stable polycarbonate.
It also has been shown that, depending on the type of plastic, micro-cellular honeycomb structures reach optimum properties at a material fraction of 1.5 to 4.0 V% (percent by volume).

COMPARISON WITH COMMERCIAL STRUCTURES

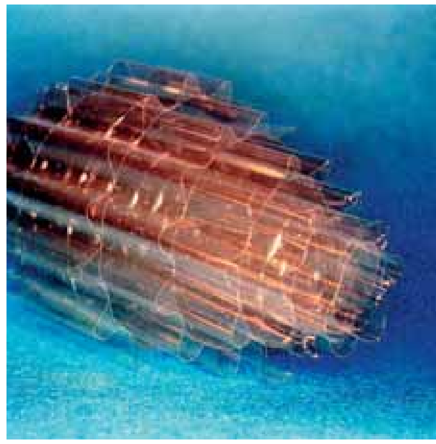
The diagram below shows a comparison between selected lamellar honeycomb structures (thickness: 10 cm, low-iron glazing on both sides) and commercially available TTI-structures concerning their respective total hemispheric energy transmission factors (g_h) and heat transmission coefficients (Λ).

The honeycomb laminates show g_h-values of about 0.55 to 0.60 and thus are better than the TTI-structures currently available on the market. Λ-values range from approx. 0.79 to 1.0 W/m^2K and thus partly exceed the values of currently available products. The two TTI honeycomb laminates made from CA-foils with different thickness reached particularly good results. They showed total energy transmission values as well as heat transmission values that were up to 30 percent better and, at the same time, material fraction was considerably lower.

COMPARATIVE ECO-BALANCING

The TTI facades (TTI-structure with facade structure, but without massive wall) developed in these projects were compared, in an eco-balance study, to existing and commercially available systems. Two well established methods (Swiss Ecopoint model and CML model) were used to evaluate the material balance data. The balance covered a range beginning with the extraction of raw materials to the manufacture of the components of the systems.

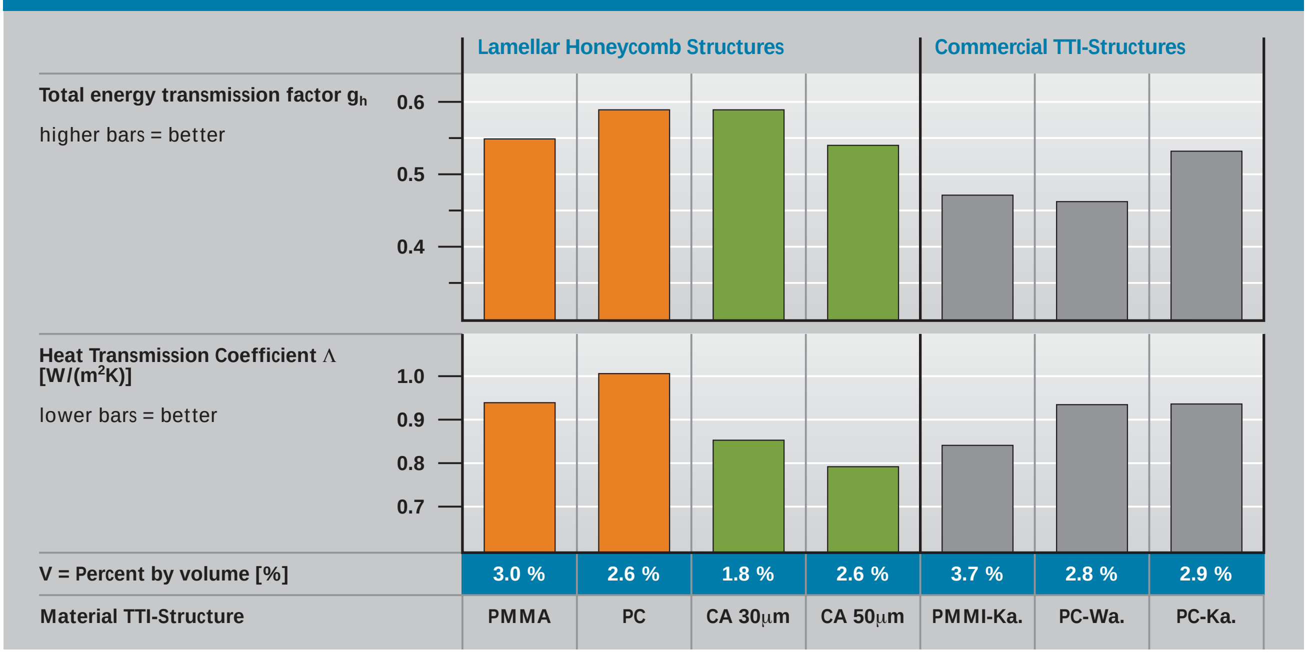
In order to identify the various performance levels of the individual systems, the eco-balance data were weighted by means of a quality factor, which also took into account the total energy transmission factor as well as the thermal insulation performance.



The studies included a total of ten different TTI systems, which differed considerably regarding their ecological evaluation. Thus, the systems with the highest and the lowest scores differed by a factor of 10 to 100, according to the Swiss Ecopoint system.

The systems based on CTA and PC TTI-structures, which were developed in the above-mentioned projects, yielded the best eco-balance results. Similarly positive results may be expected for PMMA TTI-structures. The most important benefit of these systems consists in the broad range of possibilities for facade design, which, in turn, is closely related to the newly developed TTI semi-finished products.

Comparison of Lamellar Honeycomb Structures with Commercial TTI-Structures



PRACTICE

ULTRA-LOW ENERGY SOLAR HOUSE IN GRAZ

Demonstration object for the application of innovative solar technology and measures aiming to reduce energy demand

The objective of Univ. Prof. Reinhold W. Lang's building project, a one-family home with office unit, (planning and implementation: Planungs und Bauges.m.b.H. Hegedys-Haas, Mitterlassnitzberg) consisted in exploring in practice the technological possibilities and the potentials of a full-fledged solar energy supply relying on the innovative use of plastics and polymer materials based on renewable raw materials. The type of construction and the selection of building materials were to take into account ecological and biological criteria.

The oblong, south-east/north-west oriented main wing of the building with plastered facades, wooden extensions and paneling, balconies and verandas stretches along a small creek running through the plot. The south-facing "solar" wing of the building intersects with the main wing of the compound, but is clearly detached; it has been energetically optimized through adapted geometrical design and appropriate inclination of surfaces. Here, the TTI-structure developed in the projects described above will be used, for the first time, in practice.

The TTI facade will serve as demonstration object for the innovative TTI system using a plastic honeycomb structure. In addition to the planned TTI wall, the "solar" wing also features a thermal collector with a steep tilt angle for high winter yields as well as roof-mounted photovoltaic modules with ventilation at the back. While the concept of the building does not follow the usual compact design of a passive house, energy efficiency criteria set forth for the passive house standard (space heating demand < 15 kWh/m^{2}a) were nevertheless achieved. After completion of the building a specific heating demand of approx. 12 kWh/m^{2}a may be expected.

Measuring programs for the building have been planned for a period of two years. A special data logging system has been developed and already been integrated into the building (see below) in order to evaluate the planned TTI system. Apart from the implementation of passive house energy criteria, the objectives included an efficient use of materials with a high proportion of building and other materials based on renewable raw materials as well as the use of plastics with a favorable eco-balance. In addition, the building concept comprises a great number of innovative ecological measures, such as the use of near-nature products for interior surfaces, biological measures such as a low-dust heating system, or the use of rainwater for the toilet and the washing machine.

ENERGY EFFICIENCY MEASURES

SPACE HEATING

- High-performance thermal insulation of the building envelope (reduction of heat loss through transmission). Opaque envelope surfaces ($k_{W,D}$ = 0.10 W/(m^{2}K), Windows (k_F = 0.80 W/(m^{2}K), Construction/components avoiding thermal bridges
- Airtightness of the envelope ($n_{50} \leq 0.6\ h^{-1}$)
- Controlled ventilation
- Appropriate zoning of individual rooms

POWER SUPPLY (DOMESTIC ELECTRICITY, DOMESTIC TECHNIQUE DEVICES)

- Utilization of natural light through architectural measures
- Energy saving appliances and lighting
- Energy saving domestic technique devices

SOLAR ENERGY COMPONENTS

SPACE HEATING AND HOT WATER

Passive use of solar energy

- Windows (orientation: southeast to southwest; approx. 23 m^2)
- Shading through projecting roof, balconies, and thermotropic layers
- Transparent thermal insulation (planned TTI wall, approx. 25 m^2 on the south facade)

Active use of solar energy

- Ventilation system with geothermal preheating and heat exchanger for fresh air/exhaust air (thermal efficiency 90%)
- Hot water buffer storage: 2.1 m^3, hot water stand-by storage: 0.3 m^3
- Low-temperature floor and wall heating system
- Backup heating based on compact heat pump with miniature geothermal heating system (1.2 kW$_{el}$)
- TTI flat collectors with highly selective absorber (planned)
- Backup hot water supply with compact heat pump

POWER SUPPLY

- 11 kW$_p$ grid-coupled photovoltaic system (surface area: 105 m^2, south-facing, tilt angle 30°)

DEMONSTRATION OBJECT AND MEASURING PROGRAM

The next step in the completion of the overall project will consist in the installation of the TTI structure on the wall of the demonstration building, the completion of the measuring system as well as the measuring program for the TTI wall over a period of two years.

At present, technical measures for the TTI facade include the wood panel construction, the roughcast and the absorber plaster work as well as preparatory work for the installation of the measuring surface for in-process scientific studies. The TTI materials CTA, PC, and PMMA chosen for the project were tested with a view to their adhesive strength on the absorber plaster.
All three materials showed very good adhesive power, even under conditions with increased temperature and moisture.

The measuring concept for solar irradiation, other climate data, and the yields to be expected in the demonstration object has been developed in cooperation with the Working Group Renewable Energy, Gleisdorf. The measuring system relies on climate sensors and sensors measuring the thermal behavior of the insulation systems. The sensor signals are transmitted to a data logger and recorded.

The examinations of the massive wall realized so far (still without TTI system) have demonstrated the flawless operation of the measuring system and also confirmed the results deduced from model building physics calculations for the black-plaster massive wall. For subsequent comparison with the TTI facade, measuring data collected on three cloudless days with high irradiation and three cloudy days with less irradiation have already been systematically analyzed.

TTI Measuring Surface at Demonstration Object (Without Plaster Work)

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PROJECT SPONSORS

The project **"Transparente Wärmedämmsysteme mit absorbersenkrechten Lamellenstrukturen aus Kunststoff"** (Duration: 1998 - 2000)
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INFORMATION PUBLICATIONS

The above-mentioned project has been described, amongst others, in two articles published in the journal "erneuerbare energie" (Issues 98-1 and 00-1).

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