*IEA SOLAR HEATING AND COOLING (SHC) PROGRAMME, TASK 20:
SOLAR ENERGY IN BUILDING RENOVATION*



# Transparent Insulation in Building Renovation

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INTERNATIONAL ENERGY AGENCY
Solar Heating & Cooling Programme

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# International Energy Agency (IEA) Solar Heating and Cooling (SHC) Programme, Task 20: Solar Energy in Building Renovation

If the use of solar energy is to mean that significantly less fossil fuel will be consumed, solar systems must be readily adaptable to existing buildings as well as new buildings. Under IEA SHC Programme Task 20: 'Solar Energy in Building Renovation', a number of the most promising solar concepts and systems for building renovation have been explored.

The first activity of Task 20 was the analysis of the performance of existing solar renovation projects that appear to be based on broadly applicable design concepts. Then on the basis of the information gained from these case studies, the participants investigated improved and advanced solar renovation system concepts with high potential for both energy savings and replication. Strategies for incorporating these concepts into the renovation process were developed for a number of specific projects.

The countries participating in Task 20 are: Belgium, Denmark, Germany, The Netherlands, Sweden, Switzerland and the USA.

## Acknowledgements


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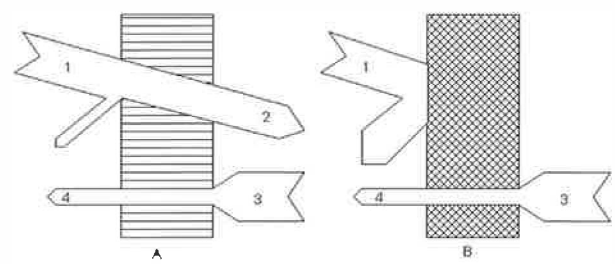
# Introducing Transparent Insulation (TI)

## Rationale for TI in solar renovation

Transmission losses account for about half or even more of the heat losses from a building. Heat is lost through walls and windows because of the limited insulation properties of these building elements.

These losses can be reduced by replacing old windows with novel glazing types having improved thermal insulation properties. However, these novel glazing types usually reduce solar heat gains.

Walls are normally insulated with lightweight, air-filled material. The level of insulation typically differs between countries and depends on national building codes and regulations. In practice, the reductions of transmission losses through the opaque parts of the building envelope are limited. Especially for walls, the practical limits of insulation are reached with 25–30 cm of today's available insulation material. Opaque – non transparent – insulation materials do not take advantage of solar energy.




*SOLAR THERMAL CHARACTERISTICS: **1** SOLAR ENERGY; **2** SOLAR HEAT GAINS; **3** HEAT ENERGY; **4** HEAT LOSSES. **A**: TRANSPARENT INSULATION; **B**: OPAQUE INSULATION*

## New concepts

In contrast transparent insulation (TI) allows a high transmittance of solar energy – direct and diffuse radiation – and has good thermal insulation properties. This unique characteristic of TI allows for new concepts of energy conservation and energy gain at the same time:

- As an insulation material for external walls, TI traps incident solar radiation, transforms it to heat by means of an absorber and stores the heat in the external wall. The heat passes through the massive wall (a wall with a high thermal mass) and is distributed passively into the building contributing to the heat energy (indirect solar gain).
- As fill material for advanced glazings, TI can improve the thermal and optical behaviour by reducing transmission losses with only slight degradation of solar gains. At the same time, incident light is diffused and dispersed, thereby improving the use of daylight. Depending on the application, this can reduce electricity demand for artificial lighting or can contribute to the building's heating needs as direct solar gain.

**Basic application of TI:**
- Solar wall heating
- Highly insulating glazings with light guiding properties

**Benefits of TI solar wall heating:**
- Walls with heat energy gains instead of transmission losses
- Improved comfort and lower heating requirements because of warm walls
- Simple, passive and self regulating heating system

**Benefits of TI glazing:**
- Cost effective light guiding system for improved light intensity distribution in rooms
- Increased daylight usage and heat conservation at the same time

## New materials

Research and development have resulted in a variety of TI materials, a few of which have reached the stage of commercial production. Some of these materials were derived from typical heat or noise insulation applications and consist of several transparent films with air cavities. Because of the high number of layers perpendicular to the incident light, solar transmission is reduced by multiple reflections. The most popular materials today are made from plastic (acrylic 'glass' or polycarbonate) and have a capillary or honeycomb structure. These materials have very high light transmission due to the light-guiding effect of the tubular structures. TI material made from plastic usually comes in ready-made plates of about 1 m$^2$.

Capillary materials made from glass are planned to be commercialized in the near future. They are manufactured as tiny, loose tubes and must be factory fitted into application-specific frames.

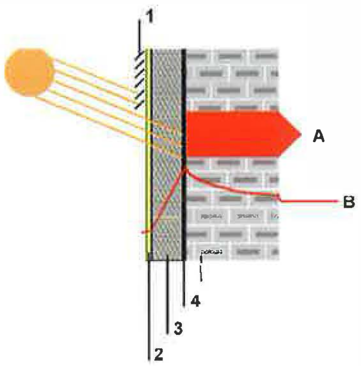
**Key properties of TI material**
- Low thermal conductivity ($\lambda$ < 0.12 W/mK)
- High solar transmittance (> 50%)
- Light weight (30–100 kg/m$^3$)

*GLASS CAPILLARY MATERIAL*

# Concepts

## TI WALL HEATING

Typical insulated building facades absorb some solar radiation at the outside surface. This part of the radiation is transformed into heat, but is immediately lost to the environment. Transparent insulation lets solar radiation pass through and reach the massive wall. Again, the radiation is absorbed and transformed to heat, but behind the insulation. For maximum absorption the wall should have a dark colour. The massive wall stores this heat energy and its temperature rises. Slowly, the heat energy passes through the wall to the inside, so that the inner surface of the wall warms up and contributes to the room heating as a large-area, low-temperature radiator. The insulating properties of TI prevent the generated heat from disappearing.




*PRINCIPLE OF TI WALL HEATING: **A** HEAT GAIN; **B** TEMPERATURE PROFILE IN WINTER. CONSTRUCTION: **1** SOLAR GAIN CONTROL; **2** TRANSPARENT COVER; **3** TI MATERIAL; **4** WALL*

**Advantages of TI wall heating**

- **Solar energy gains compensate all transmission losses from the wall that is covered**
- **An additional 30–100 kWh/m² of covered wall contributes to meeting the heating load of the building**
- **There is increased comfort due to warmer wall surface temperatures**
- **TI complements direct solar gains through glazing**

### Climate

Cold and sunny climates are most favourable for TI wall-heating applications. The usually long heating season in such climates can be reduced to just the winter months. Cool, but sunny, autumn and spring weather yields sufficient solar heat gains and comfort improvements to meet the requirements of the inhabitants of the building.

### Orientation

Because TI also works with diffuse radiation, the energy balance for a transparently insulated wall may be positive for all orientations over a heating season. However, north facades are not recommended in practical applications because of the economics. East and west orientations may be suitable, but today's system costs may dictate that only south oriented applications are used.

**Requirements for TI wall heating**

- **Needs a massive wall (ρ ≥ 1200 kg/m³), without insulation, as storage**
- **Most systems require solar gain control**
- **Available facades should be oriented south-east to south-west and should generally be unshaded by obstacles**

### Storage wall

The storage wall is a crucial component of the TI wall heating system. Mass is required to store the solar-generated heat energy. Good conductivity allows the heat to pass into the rooms. The materials for the storage wall must therefore have sufficient heat capacity. Concrete and limestone are best, although brick walls are also suitable. Any existing insulation reduces the solar gains and should be removed if accessible.

### Solar gain control

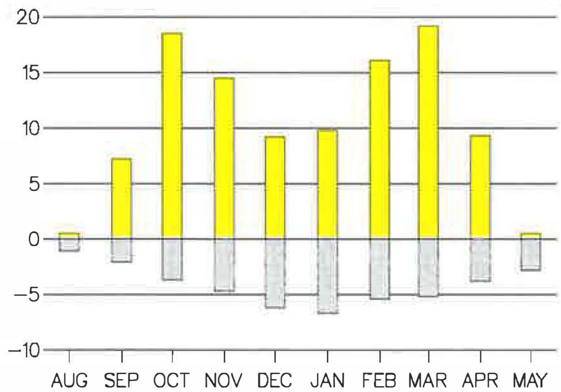
High-performance systems require solar gain control during the warmer months. This increases both complexity and system costs. A different approach can be followed with low-performance systems. They may not require solar gain control if only parts of the facade are covered.

### Local shading

The effect on heat gains of local shading by obstacles and overhangs must be taken into consideration. Reduction in solar access during the winter period should be avoided.

### Energy gain

Possible heat gains depend on various parameters, such as climate, location and building details. Solar energy gains of TI almost always meet all transmission losses through the wall. An additional 30–100 kWh/m² of wall becomes available to help meet the heating requirements of the building.




*ENERGY GAINS (YELLOW) OF A SOUTH-ORIENTED TI WALL. WITH SOLAR GAIN CONTROL COMPARED WITH ENERGY LOSSES (GREY) OF AN OPAQUE WALL WITH A U-VALUE OF 0.5 W/M²K (IN KWH/M² WALL AREA); LOCATION FREIBURG (GERMANY)*

### Window arrangement

Windows and TI walls interact as passive energy-gain systems. South-oriented windows and TI walls complement each other, but rooms with south-oriented windows (direct gain) may not fully profit from eastern TI walls. This is because the delayed heat distribution from the eastern TI wall coincides with the heat gain from the south windows.

### Suitable building types

Rooms that are frequently used in the evenings (living rooms) may profit most from TI wall heating. Furthermore, rooms with higher temperature levels are well suited (bathrooms). Kitchens and – to a lesser extent – offices usually have high internal loads and may not profit much from low-temperature wall heating.

In any case, TI walls should be as open exposed (e.g. no built-in cupboard) as possible to allow the heat radiation to provide increased comfort.

To profit from solar energy gains a certain range of room temperature swing should be tolerated.

**Building types well suited for TI wall heating application**

- Apartment buildings
- Single-family houses, detached and row (terrace) houses
- Senior citizens' residences
- Hospitals and nurseries
- Schools and kindergartens

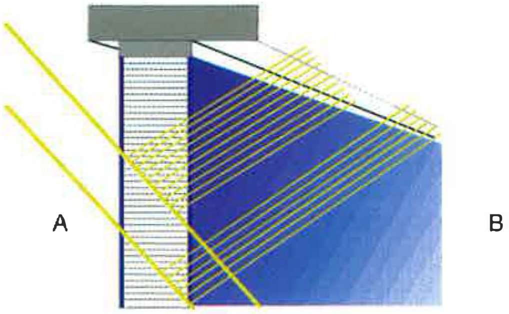
### Selection of buildings for TI wall heating

The application of a TI wall has a major impact on building renovation. TI walls cannot be added onto a project as easily as other solar system components, such as thermal collectors. It is therefore important to decide at an early stage in the design process whether to include TI walls. The following table may be helpful in making a first judgement on suitability.

| Criterion | Suitability for TI wall heating | | |
|---|---|---|---|
| | Good | Fair | Less suitable |
| Location | Open situation, high solar radiation during the heating period and/or low temperatures (e.g. mountain climate, location without fog, northern latitudes) | Limited solar radiation during heating season | Low solar radiation (e.g. foggy or generally overcast) |
| Orientation of the facade | South, south-west and south-east | West and east | North-west, north-east and north |
| External shading of TI wall (neighbouring building, trees, etc.) | No shading | Little shading | Significant shading |
| Self-shading due to building elements (e.g. balconies, roof, wide overhang) | No shading | Little shading | Significant shading |
| Form of building | Compact | Few juts and recesses | Complicated |
| Opaque facade parts | Large areas with no or only a few small openings | Medium-size areas with several, medium-sized openings | Small areas or areas with large openings |
| Facade structure | Regular placement of the openings | Few irregularities | Irregular placement of openings |
| Insulation level of candidate external walls | No insulation existing | Minimal insulation (2–4 cm of insulation material or air gap) | High level of insulation (> 4 cm) |
| Storage capacity of existing external wall | High capacity: concrete, limestone, clay etc. | Medium capacity: brick, cellular concrete, etc. | Low capacity: light construction, wood, etc. |
| Use of solar heat | Low internal loads | Medium internal loads | High internal loads |
| Fire protection problems (fire load of plastic materials) | Low-rise building | Building with three to four storeys | High-rise building |

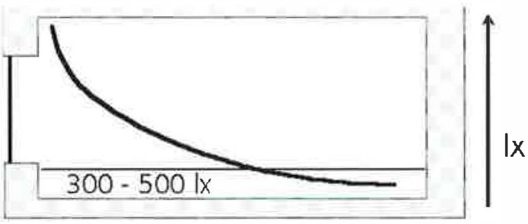
## TI glazing

TI material sandwiched between two sets of glazing forms an interesting element for improved use of daylight. These elements do not allow a clear view but are well suited to form translucent parts of walls. TI glazing offers several advantages for daylight use over standard double (low-E) glazing:



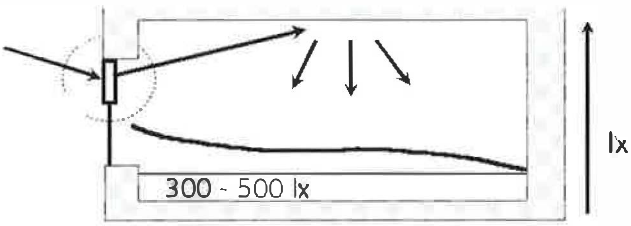

*LIGHT GUIDING PROPERTY OF HORIZONTAL TI STRUCTURES (**A** OUTSIDE; **B** INSIDE)*

**1** TI glazing is able to guide a portion of the diffuse light, with its hemispherical wavefront, into the building interior. This increases the depth of illumination without the need for artificial light.




*DISTRIBUTION OF LIGHT IN A ROOM WITH A SIDE WINDOW: TOO MUCH LIGHT CLOSE TO THE WINDOW AND NOT ENOUGH (< 300 LX) IN THE DEPTH OF THE ROOM*

**2** Light scattering properties of TI materials result in a more even light density distribution in the room and reduced contrasts.




*THE LIGHT INTENSITY CLOSE TO THE WINDOW IS REDUCED BECAUSE OF THE SMALLER AREA. A LIGHT-COLOURED CEILING HELPS TO REFLECT THE SCATTERED LIGHT TO THE WORKING AREA*

**Advantages of TI glazing**
- High light yield
- Low U-value
- Improved daylight quality
- Improved thermal and visual comfort

**Typical applications of TI glazing**
- Translucent walls of industrial buildings
- Glazed entrance halls of commercial and office buildings and schools
- Glazed staircases of apartment buildings
- Glazed walls of indoor swimming pools
- Windows and roof windows in libraries, galleries and art studios
- Windows in office buildings

**Typical parts of the building envelope suited for TI glazing**
- Top section of windows
- Parapets
- North facades
- Clerestories, sawtooth type of roof arrangements (north-oriented part)
- Atria

**3** The U-value of TI glazing is two to three times better than standard double glazing. Therefore, the glazing area may be increased without increasing the overall U-value of the facade. In this way the amount of light transmitted increases.

**4** Similarly, because of the improved U-value, the surface temperature of the inner glazing increases. Working places close to the glazed structure can therefore be utilized during the heating season without reduced comfort.

## Energy gain

In terms of energy, the improved use of daylight can reduce electricity demand for lighting. At the same time, TI glazing provides as much, or more, direct solar heat gain as standard glazing, but with reduced heat transmission losses.

## Beware of glare

Because of the 25% increased light density, TI glazing may lead to glare problems when applied at eye level. This must be considered particularly for areas exposed to direct solar radiation. TI glazings are therefore best suited for situations without direct solar radiation (north-oriented facades) or in locations that will not lead to glare problems.

# Architectural Considerations

## Design elements for TI wall heating

The application of TI on facades is still an uncommon design challenge, despite all the various demonstration projects in the past. In contrast to the well known, plain facade cladding or stucco materials, additional aspects are important with TI walls:

- Glass facades or plaster compound systems may be applied to the outer surface.
- A wall covered with TI may lead to a new partitioning and structuring of the facade.
- Joints to windows, corners, etc. may not be suited for standard construction solutions and must be considered carefully (e.g. cold bridges).
- The TI material and absorber may be visible through the transparent cover. Its elements are clear and self-explanatory.
- The projection of the different layers produces an impression of depth.
- Solar gain control systems usually add a design element.

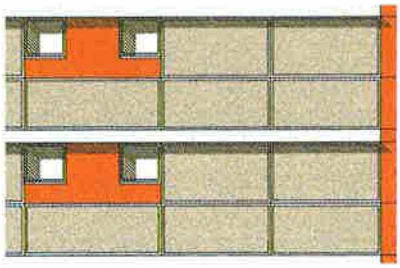
## Glazed facade elements

TI walls as glass facades allow an individual design for every component. The following table lists some possible design forms.

In a renovation situation, the openings of a facade are already given and will usually not be changed. These openings determine and limit the freedom of design for the arrangement of the TI facade. Larger coherent facades provide more possibilities for structuring the facade with TI and opaque facade parts. The design possibilities are then limited mainly by the dimensions of the components.

The following figures provide examples of facade design possibilities. They show a portion of a multistorey building facade. Windows and the coverage of the venetian blinds are shown. However, even within these restrictions the facade design leaves several possibilities for different emphasis.

| Component | Function | Design possibilities |
|---|---|---|
| Cover | Weather protection; transparent to sunlight | Different types of glazing possible: clear, etched, structured, coloured, etc. |
| Frame | Static element; joint | Dimension and colour of visible elements; various materials |
| Absorber | Converts light to heat | Some variation of colour; variation of materials (painting of the facade, metal, fibre concrete, etc.) |
| Variable shading | Solar gain control | Placement in front or behind glass cover; variation of blinds; shape, colour, unit dimensions |
| Fixed shading | Solar gain control | Placement in front or behind glass cover, variation of colour, limited variation of width and spacing of slats |



*HORIZONTALLY ACCENTUATED FACADE DESIGN*

*VERTICALLY ACCENTUATED FACADE DESIGN*

## Solar gain control

Shading systems for solar gain control may be crucial to the appearance of the TI facade. With an adjustable shading system, the facade changes its appearance according to the season of the year and to user requirements.

**Example: Sonnenäckerweg, Freiburg, Germany**

This eight-family house was built in the late 1950s and renovated in 1989. The renovation involved standard insulation measures on all facades, ceiling and cellar. Low-E blinds inside double glazing were also installed. In addition, 120 m² of TI was fitted to the south-west and south-east facades.

The annual heat demand before renovation was 225 kWh/m² of living area. After renovation the heat demand dropped to 43 kWh/m². The solar gains through the transparent building components amounted to 38% of the annual heating energy requirement; of this 22% was provided by the transparent insulation alone.

**TI facade characteristics at Sonnenäckerweg**

- **10 cm polycarbonate honeycomb TI in prefabricated wood frame modules**
- **Facade elements attached to a self supporting mounting structure**
- **Module-integrated roller blinds for solar gain control**

**Example: Affolternstrasse, Hedingen, Switzerland**

This building, with 11 apartments, was built in 1971. Some of the small apartments were combined to form larger ones during an internal refurbishment in 1991. In 1994 planning for an energy conservation project was started. The aim was to reduce the heat energy demand of the living area, which was 245 kWh/m².

*UNSHADED TI WALL HEATING FACADE*

The renovation included insulating the cellar and roof, replacement of the old double glazing with new windows having low-E glazing, new external sun protection (venetian blinds), insulation of external walls with 12 cm rock wool and fibre cement cladding. The south facade was covered with 31 TI facade elements with a total area of 63 m². The elements, which had insulated metal frames and integrated mounting structures, were prefabricated and attached to the wall in the same way as a rain cladding system.

*TI FACADE SHADED WITH EXTERNAL VENETIAN BLINDS*

**TI facade characteristics at Affolternstrasse**

- **10 cm acrylic glass capillary structure in prefabricated thermally insulated metal-framed modules**
- **Mounting in the same way as a rain cladding system**
- **External venetian binds for solar gain control**

The actual annual heat energy demand will be monitored and is expected to be around 40 kWh/m² of floor space.

### TI compound system for opaque walls

Common compound insulation systems can easily be combined with TI compound elements. Design elements are the size and shape of the TI facade portions and the arrangement within the facade. The colour and surface texture of the TI compound elements are given. However, the colour and surface structure of the surrounding opaque compound system may be varied (for construction details see page 12). Design elements are summarized in the following table.

| Component | Function | Design possibilities |
|---|---|---|
| Cover | Weather protection; transparent to sunlight | None (transparent plaster) |
| Frame | Static element; joint | Dimensions and colour of opaque insulation plaster |
| Absorber | Converts light to heat | Given by system |
| Shading | Solar gain control | Not required |

Solar gain control for the TI compound systems is to a certain extent inherent, because of the reflective properties for high positions of the sun (in summer). Limiting the size of the transparently insulated wall area is sufficient to prevent overheating during the summer months.

Area limitations and the system-inherent maximum dimensions of the TI compound elements lead to a frame-formation facade design. This opens a variety of possibilities.

*FACADE DESIGN EXAMPLE FOR A SINGLE FAMILY HOME*

### Example: Villa Tannheim, Freiburg, Germany

After being uninhabited for several years, this multifamily building, dating from about 1900, was chosen in 1994 to become the headquarters of the International Solar Energy Society (ISES). The three-storey building, which has 540 m² of heated floor space, required a complete renovation.

*VIEW OF THE WEST FACADE OF THE RENOVATED VILLA TANNHEIM*

The renovation included new glazing and window frames, opaque facade insulation combined with a TI compound system on the west facade, solar preheating for heating and domestic hot water and installation of new heating equipment. The annual space heating demand before renovation is not known, but was calculated to be approximately 250 kWh/m² per heating season.

The monitoring phase during winter 1995/96 showed an average space heating demand of 75 kWh/m² of heated floor area per heating season.

**TI facade characteristics: Villa Tannheim**

- **50 m² TI compound system with prefabricated polycarbonate capillary plates**
- **Mounting by gluing and combining with opaque compound insulation**
- **No external elements for solar gain control**

## Design elements for TI glazing

The most important difference between TI glazing and regular glazing is that TI offers no distinct view. However, the shapes of objects are visible and parts of the interior can be displayed when a building is illuminated at night.

*IN A CONVERSION OF AN OLD WAREHOUSE TO AN OFFICE BUILDING OPAQUE WALLS HAVE BEEN REPLACED WITH TI GLAZING TO ILLUMINATE MEETING ROOMS. (WWF HEADQUARTERS SWITZERLAND, ZURICH; PROJECT: COLE+ZIMMERMANN)*

In renovations, skeleton-type building structures may have the most interesting opportunities for replacing opaque walls with TI glazing. Other building structures may limit the application of TI glazing to replacement of existing glazed elements.

From a construction point of view, TI glazing has much in common with regular glazing. However, most of the TI glazing components are much thicker than regular glazing, requiring special frame designs. The low U-value of the TI system calls for a frame design with a low U-value in order to take full advantage of TI glazing systems.

*THE OVERALL RENOVATION OF A LABORATORY BUILDING INCLUDED REPLACEMENT OF THE SINGLE-GLAZED FACADE WITH TI GLAZING ELEMENTS. (LABORATORY BUILDING AT PAUL SCHERRER INSTITUTE, WÜRENLINGEN, SWITZERLAND; PROJECT: M. ERNI)*

Careful lighting design with TI glazing in renovation can lead to very highly improved situations. The use of modern computer technology and simulation techniques may help to find the best daylighting opportunities with TI.

**Example: Industrial Hall, Salzgitter, Germany**

This industrial assembly hall, 40,000 $m^2$ in area and 15 to 18 m high, had an energy consumption for space heating of about 350 kWh/$m^2$. In addition, artificial lighting was used excessively as a result of the aging of and pollution on the glazing. The main objective of this first step in the renovation was to improve the comfort of the workers. This mainly meant improvements in the thermal and daylighting situation. In the glazed part of the facade, this was accomplished by replacing single-pane glazing with cast-glass elements filled with 40 mm acrylic capillary plates. The U-value of the cost-optimized cast-glass element is 1.9 W/$m^2$K. Because of the air change losses (high air change rate) in the hall, a lower U-value at increased cost was not favourable.

Each side of the square-shaped building has a glazed facade area of almost 2000 $m^2$, resulting in a TI-glazed facade area of over 7500 $m^2$. This is being constructed in three phases between 1995 and 1997. Monitoring of the thermal and (day-) light performance will proceed during the whole renovation phase and will last through 1998.

Glare and overheating are not expected to pose any problems because the work areas are away from the facade and the high air-change rate will provide good ventilation of excess heat.

*FACADE VIEW OF LHB INDUSTRIAL HALL AT SALZGITTER.*

**TI facade characteristics of the Industrial hall**

- **7500 $m^2$ of cast-glass elements**
- **Cast-glass elements filled with 40 mm acrylic glass capillary plates**
- **U-value of transparent facade: 1.9 W/$m^2$K**

# Systems and Components

## Transom-mullion system from wood or metal

**Characteristics**

Prefabricated frame system, or one prepared on site, with columns (mullions) and cross bars (transoms) made of wood or metal, mounted on massive, black-painted wall (absorber).

Several type of fill-in are possible:

- Bare TI material covered with a single glass pane held by the cover frame. This results in a very high solar transmission because the radiation must pass through only one additional transparent layer. The U-value may be adapted to the requirements.

  *HORIZONTAL SECTION WITH BARE TI MATERIAL AS FILL-IN:*
  ***1*** *MASSIVE WALL WITH BLACK PAINT AS ABSORBER;*
  ***2*** *TI MATERIAL DIRECTLY ON MASSIVE WALL;*
  ***3*** *TRANSOM–MULLION WOOD/METAL SYSTEM,*
  ***4*** *COVER WITH SINGLE GLAZING;*
  ***5*** *SOLAR GAIN CONTROL WITH ROLLER BLIND*

- Prefabricated glass–TI–glass sandwich panels clamped into the cover frame. No handling of bare TI material on site is required. The U-value may be adapted to the requirements.

  *HORIZONTAL SECTION WITH TI PANELS:*
  ***1*** *MASSIVE WALL UNTREATED OR WITH BLACK PAINT AS ABSORBER, DEPENDING ON ITEM 4;*
  ***2*** *GLAZED PANEL FILLED WITH TI MATERIAL;*
  ***3*** *TRANSOM–MULLION METAL SYSTEM;*
  ***4*** *ABSORBER PLATE OR GLASS;*
  ***5*** *SOLAR GAIN CONTROL WITH ROLLER BLIND*

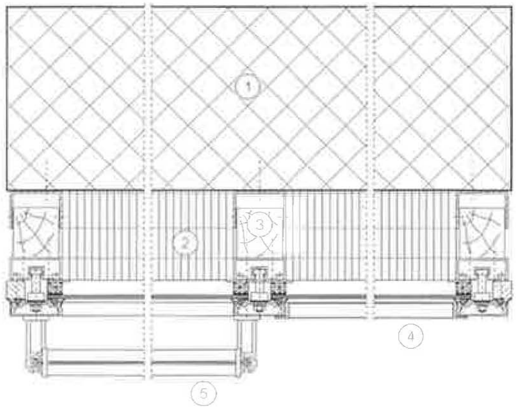
- Sealed TI glazing of thickness around 50 mm clamped into the cover frame.

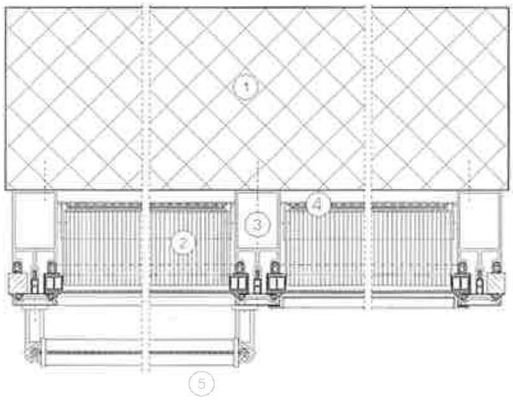
  *HORIZONTAL SECTION WITH SEALED TI GLAZING:*
  ***1*** *MASSIVE WALL WITH BLACK PAINT AS ABSORBER;*
  ***2*** *SEALED TI GLAZING;*
  ***3*** *TRANSOM–MULLION METAL SYSTEM;*
  ***4*** *SOLAR GAIN CONTROL WITH ROLLER BLIND*

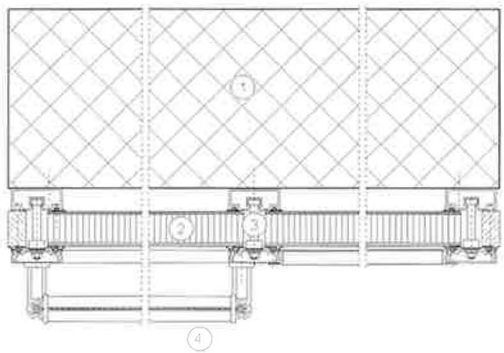
Solar gain control by external shading device, or by integrated roller blind or louvre behind a glass cover.

**Production**

Production follows standard transom-mullion facade procedure. Bare TI material is not suited for on-site construction. Factory prefabrication is recommended.



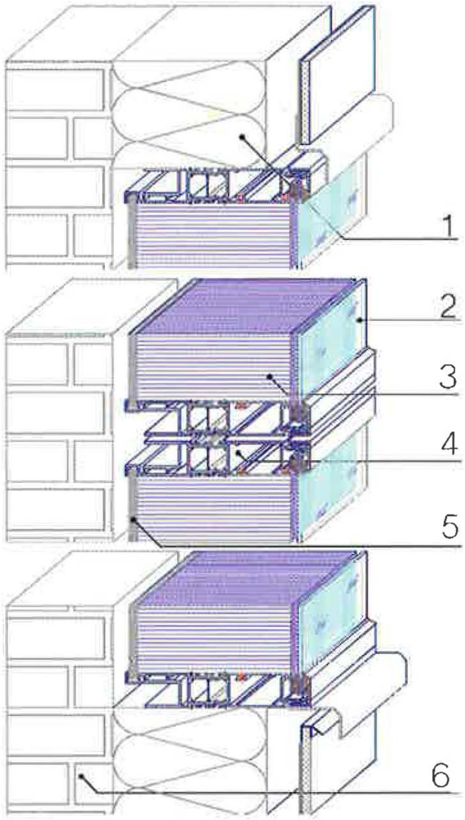
## Prefabricated TI wall element

### Characteristics

- Prefabricated facade element with wood or thermally insulated metal frame;
- Front cover of glass, back cover as integrated absorber or glass, using the massive wall as absorber;
- Maximum element size 1.2 x 3.0 m;
- Suitable for TI material of 80 mm to 140 mm thickness;
- U-value at the centre of the glass: 0.8 W/m²K; total energy transmittance $g_{dif}$ approximately 65% (element with 100 mm TI);
- Frame-integrated facade mounting structure;
- Solar gain control by external or module-integrated shading device.

### Production

Prefabrication requires detailed planning and facade design. Mounting of the support structure requires high precision. Subsequent mounting of the elements is simple and quick.




*TI WALL ELEMENT: **1** OPAQUE INSULATION; **2** ELEMENT COVER GLAZING; **3** TI MATERIAL; **4** THERMALLY INSULATED ELEMENT FRAME; **5** BACK GLAZING OR INTEGRATED ABSORBER; **6** MASSIVE WALL WITH OR WITHOUT BLACK PAINT AS ABSORBER (DEPENDING ON ITEM 5)*

## TI compound system

### Characteristics

- TI compound system with transparent plaster cover;
- Transparent elements made up of polycarbonate capillaries; must be framed with opaque insulation (expanded polystyrene or rock wool);
- 5 cm overlap of opaque plaster required;
- Maximum element aperture: 1.90 x 1.10 m; element depths: 80 mm, 100 mm, 120 mm, 140 mm;
- U-value: 0.8 W/m²K; $g_{dif}$: 45–50% (100 mm TI);
- Typical facade area covered with TI: 10–30%;
- No additional measures required for overheat protection when areas are limited.

### Production

Capillary plates are prepared in the factory, together with the transparent plaster cover and the border protection. These TI elements are glued to the wall by means of a mineral mortar, which serves as absorber. The overlapping opaque plaster both seals and secures the TI system.


*TI COMPOUND SYSTEM: **1** FIXING – GLUING WITH DARK MORTAR (ABSORBER); **2** INSULATION – CAPILLARY PLATES (POLYCARBONATE); **3** REINFORCEMENT – GLASS FABRIC AND TRANSPARENT GLUE; **4** PROTECTIVE COVER – GLASS PLASTER*

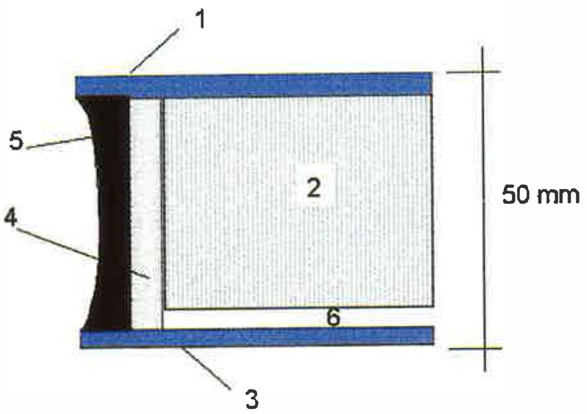
## Sealed TI glazing

### Characteristics

- Sealed double-glazing element;
- Acrylic glass capillary plate (40 mm);
- One glass has low-E coating;
- Rare-gas filling;
- U-value at the centre of the glass: 0.8 W/m²K; $g_{dif}$: 63%;
- Element and glass thickness depend on element size;
- Element size: minimum 1000 × 1000 mm; maximum 1200 × 2500 mm;
- Sealed cavity is pre-pressurized for the specific height above sea level of the application.

### Production

Sealed TI glazing can be mounted with in any framing system (wood or metal) that is suitable for the cross-section width of the element.




*SEALED TI GLAZING: **1** OUTSIDE GLAZING 5 MM; **2** TI MATERIAL – 40 MM ACRYLIC GLASS CAPILLARY PLATE; **3** INSIDE GLAZING 4 MM WITH LOW-E COATING; **4** SPACER; **5** GASKET; **6** RARE-GAS FILL*

## Cast-glass elements

### Characteristics

U-shaped cast-glass elements have been very popular as inexpensive glazing systems. Handling and framing is simple because of the inherent stability of the U-shaped elements. The transparency of cast glass is lower than that of float glass. The small width of the glass element (260–490 mm) reduces the light transmitting area.

Today two systems are available:

**1 Regular double-layer cast-glass facades:**

- Air cavity between the two glass elements is filled with TI material;
- U-value < 2.0 W/m²K; $g_{dif}$: 60%;
- On-site preparation and on-site handling of TI material.

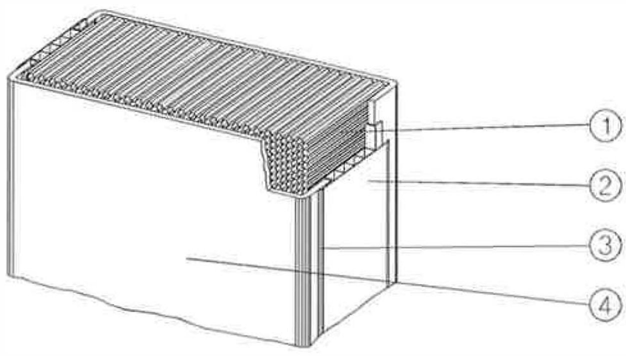
**2 Prefabricated elements:**

- Two glass panes are combined with a heat insulating web and are mechanically fixed to form an element; top and bottom are protected by a cover;
- TI material of up to 120 mm thickness can be used; – U-value 0.6–1.0 W/m²K; $g_{dif}$: 50–55%

### Production

System 1 is very well suited for direct replacement of existing double-layer cast-glass walls. System 2 usually needs a modification of the support structure as a result of the increased thickness of the cast-glass system.

Production, mounting and sealing between the elements is straightforward and uses well known technology.




*TI FILLED CAST GLASS ELEMENT: **1** TI MATERIAL; **2** INSULATING WEB, **3** SEALING AND JOINING RUBBER; **4** CAST GLASS*

## Solar gain control

Depending on orientation, application and type of building, TI walls require solar gain control for daylight and wall heating. Typically, this is realized with some sort of shading device. Shading devices can be roughly distinguished into two types (fixed and movable) and in the way in which they are applied (within the TI wall construction or external).

Mechanical shading devices can provide a significant cost factor and must also be considered from an architectural point of view. The following table gives an indication on the impact of mechanical shading on different aspects of a TI facade. In the future shading systems that are not mechanical are expected to become available. Most notable are systems that change light transmission depending on temperature or on electrical potential (thermochromic and electrochromic glazing systems, respectively). All these systems are being developed in combination with the glazing and will therefore be directly suitable for combination with TI. Other approaches are ventilated systems or combinations with active solar systems (solar collectors).

Beware: TI glazing in south, west and east facades or roof applications may also require overheat protection.

| | Shading systems | | | |
|---|---|---|---|---|
| | External | | Internal | |
| | Fixed | Adjustable | Fixed | Adjustable |
| Investment | Low | High | Low | High |
| Energy gains | Reduced | Max. | Reduced | Max. |
| Maintenance | Low | High | Low | high |
| Cleaning | Required | | Not required | |

*IMPACT OF MECHANICAL SHADING SYSTEMS FOR OVERHEAT PROTECTION ON TI FACADES*

## General considerations

### TI materials

Today's available TI materials are very fragile and susceptible to dust and mechanical destruction. TI materials are therefore not well suited for handling on the construction site. Most of the previously described systems use some form of prefabrication in a controlled indoor situation.

### Condensation

Most TI materials contain some amount of moisture and thus condensation can occur in unsealed TI components.

### Fire regulations

Except for glass capillaries, TI material is not fireproof. However, there are, as yet, no standard fire regulations for TI systems. Approval by the local building authorities depends on the construction, the type of building and the height of the facade (number of storeys).

# Economics

## Important aspects

Transparent insulation technology is currently in transition from research and demonstration to commercial application. Following the traditional cost development curve, it is expected that costs will soon drop as new materials and new systems become available and there are more participants in the market.

For the building owner three cost figures are important:

- Investment cost
- Maintenance cost
- Equivalent energy cost or the effect on building operating costs.

In addition, increase in occupant satisfaction due to a more comfortable indoor environment can be an important economic consideration (for example, tenants may be willing to pay higher rents, etc.).

### Investment

General information on capital costs is still difficult to derive. Most systems are still custom designed for specific projects. This is particularly true for renovation projects. However, for some systems the range of costs is known.

| System | ECU per m² |
|---|---|
| Transom-mullion systems with massive wall as absorber (including solar gain control) | 600-1000 |
| Prefabricated facade element with integrated absorber (including solar gain control) | 400–600 |
| TI compound insulation system (no solar gain control) | 250 |
| Cast-glass facades (no solar gain control) | 150–250 |

*SPECIFIC SYSTEM PRICES*

### Maintenance costs

Maintenance costs depend primarily on the type of facade and are not directly related to TI, although only 10 years' experience is available today. Maintenance costs are mainly associated with movable shading devices for solar gain control. As a rule of thumb, 4% of the investment must be calculated as the yearly maintenance cost for devices like venetian blinds. The expected lifetime is about 20 years.

For some systems the lifetime of the individual components may not be the same and it is to be expected that some parts will have to be exchanged within the lifetime of the facade. For example, metal facades have an expected life time of between 30 and 50 years. Typically, adjustable external shading devices would have to be replaced at least once during this period.

### Equivalent energy cost

For a rough comparison of different energy measures in general and for insulation systems in particular, it is possible to calculate the equivalent energy costs. Examples show that equivalent energy costs for TI systems may be in the range of 0.1 to 0.5 ECU per kWh and in the range of advanced opaque insulation systems (U-value < 0.2 W/m²K). These costs are expected to drop substantially as production volume increases and manufacturing and installation techniques improve. In addition, TI systems have many advantages that cannot be calculated in an equivalent energy price and may be already attractive for niche markets.

# Literature and Addresses

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## Other IEA SHC Programme Task 20 publications

**IEA SHC Programme 20 Brochures**

- Solar Energy in Building Renovation
- Solar Collectors in Building Renovation
- Glazed Balconies in Building Renovation
- Transparent Insulation in Building Renovation

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