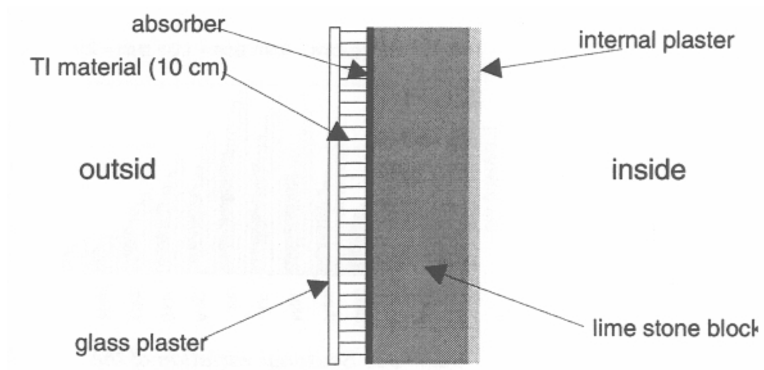
Application examples

- An exemplary demonstration building will be built as follow-up of the simulation activities if energy and comfort milestones are achieved in winter and summer
- Further application will be based on the demonstration project results

Modelling

Model description

- Residential building in heating dominated central European climate, no cooling considered
- Single zone building simulation model using TRNSYS
- Location Freiburg (Germany, climate data TRY 7), wall orientation south
- Overhang effect on incident radiation on the wall calculated with standard TRNSYS types



U-value of the opaque wall: $U_W = 1.26\ W/m^2K$

U-value of the TI-system: $U_{TI} = 0.94\ W/m^2K$

Total energy transmittance of the TI system (diffuse): $g_{dif} = 45\ \%$

Figure2: Set of parameters for simulation of the overhang

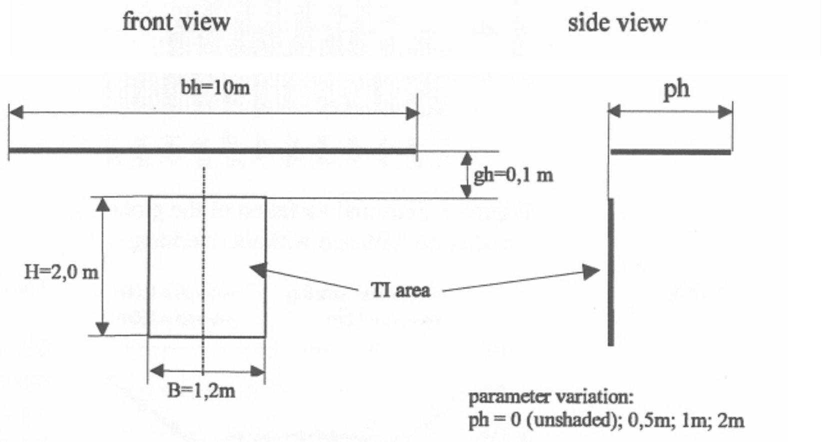


Figure 3: Sketch of the facade model and the physical properties assumed in the simulation analysis

Parameters

Dimension of the overhang ph

Evaluation Criteria

1. seasonal decrease of incident direct, diffuse and global radiation
2. seasonal change of the total energy transmittance of the TI system
3. seasonal reduction of solar gains as function time

Evaluation Tool(s)

TRNSYS 14.2

Evaluation Results

Results Criteria 1

Decrease in radiation

An overhang on a south oriented wall operates as seasonal filter for direct solar radiation. If the overhang is as wide as the absorber is high (ph= 2 m), direct radiation between April and August is decreased nearly 100%. The decrease in December is then about 23%. An overhang whose length is 50% of the absorber height (ph=1 m) is a compromise between summer direct gain control (comfort) and winter direct gain reduction (energy balance).

Diffuse radiation - assuming an isotropic sky model - is reduced without seasonal variation. Larger overhangs will have a greater effect on reducing solar gains. The large overhang (ph=2m) reduces the diffuse radiation by 40%, directly proportional to the reduction of the view factor of the sky.
Combining data for direct and diffuse radiation smoothes the seasonal control effect of an overhang. The large overhang (ph=2m) reduces the radiation in July by 61%, in December by 30%.

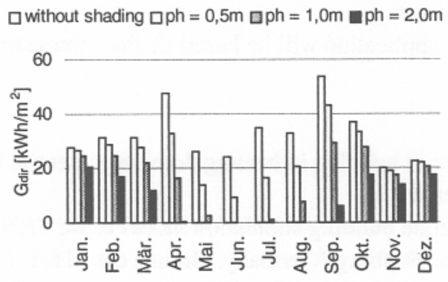


Figure 4: Seasonal variation of the direct radiation with and without overhang.

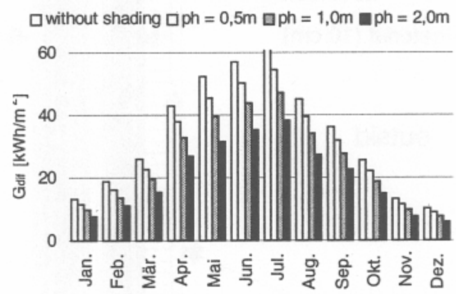


Figure 5: Seasonal variation of the diffuse radiation with and without overhang.

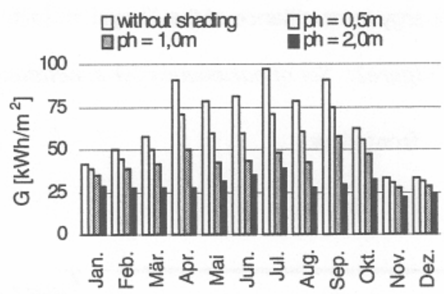


Figure 6: Seasonal variation of the global radiation with and without overhang.

Results Criteria 2

Total energy transmission

The effective solar energy transmittance g_{eff} is the ratio of the incident solar radiation transmitted trough the TI system. Due to the seasonal variation of the sun's position and the effect of the overhang, g_{eff} varies with the season. According to the diagram the seasonal change of g_{eff} is partly a counter effect to the seasonal effect of the overhang.

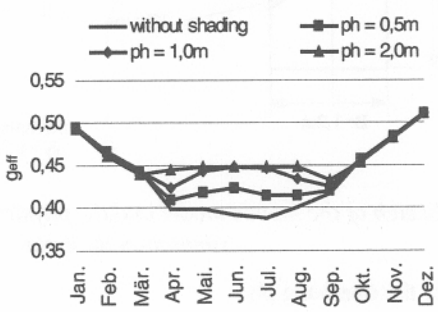


Figure 7: Seasonal variation of the monthly average solar energy transmittance.

Results Criteria 3

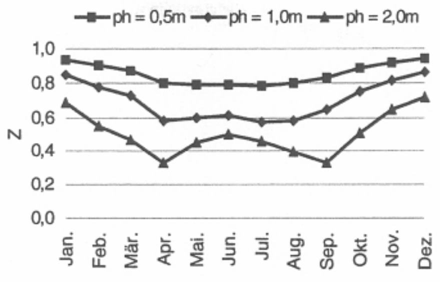


Figure 8: Seasonal variation of the monthly average solar shading factor.

Solar shading factor as function of time

Combining the effects of radiation control by an overhang and seasonal variation of the solar energy transmittance in a shading factor results in ,,Z,,, which describes the total effect of the investigated system design. Without an overhang, Z is constant and equal to 1.

Conclusions

Simulations show that passive solar gain control with seasonal variation is possible using an overhang. Unless the overhangs are properly sized, minimising the summer solar gains may also decrease wanted solar gains in the winter and result in increased heating loads. Therefore, the approach is a compromise to controlling both summer and winter gains.

Accepting 15% reduction of solar gains in the central winter months allows a reduction of solar gains in the order of 40% during summer (ph=1m). This describes a "typical" example for a 2 m high TI wall under a 1 m wide balcony. Comparing two cases with equal summer comfort (equal summer solar gains, June to August) allow for an increase of the active TI area by 40%. The winter solar gains over the whole heating season (September to May) will still be approximately identical as the specific gains per m^2 are reduced.

The main advantage is the change in the distribution of the gains over the heating season. More gains are available in the central winter months (40 % more area overrides the effect of 15% less gains) and less gains are available in spring and autumn (ref. results of criteria 3). Only project-specific simulations can determine if this shift benefits the building energy balance.

A parametric study for orientations other than south clearly underlines the strong limitation to south oriented walls.

In the cases of locations of higher latitude the seasonal control function is reduced due to the lower incident angle of the radiation.
Cost calculations were not part of the investigation. As the TI compound system is not designed to be used with active shading devices like blinds, the passive solar gain control can not be compared to an active control on an economical basis. Passive solar gain control allows an increase in the TI area without decreasing the summer comfort.

In the renovation case, the investigation provided the opportunity to compare the effect on building energy consumption resulting from a TI system mounted on walls with existing overhangs (e.g. balconies) compared to situations without shading.

9.6 Ventilated solar wall heating with TI (CH, D)

Specification

Concept description

Large area solar wall heating systems with transparent insulation material (TIM) need a solar gain control strategy to reduce comfort problems occurring outside of the heating season. Most of the applications implemented so far and most of the systems available use some kind of shading devices for this purpose. The advantages are the simplicity of the concept and the variety of the commercially available products (venetian blind etc.). The drawbacks are high investments and high maintenance cost for variable shading systems and reduced solar energy gains for fixed shading systems.

A different approach to prevent overheating is to purge the excess heat by means of ventilation air - a basic concept introduced already by Trombe during the invention of the solar wall concept in 1977. There are prototype products of TI wall heating systems available on the market using this concept of solar gain control.

This concept requires an absorber separated from the mass wall, a ventilation channel, and variable openings on the top and the bottom of the solar wall or the wall elements (see following graph). Solar gain control may be realised by natural or mechanical ventilation.

This system also allows for further improvement of the solar concept by using the warm air in the building's HVAC system or using a fluid based heat exchanger as an absorber (thermal collector absorber). Natural ventilation may then serve as overheat protection of the system.

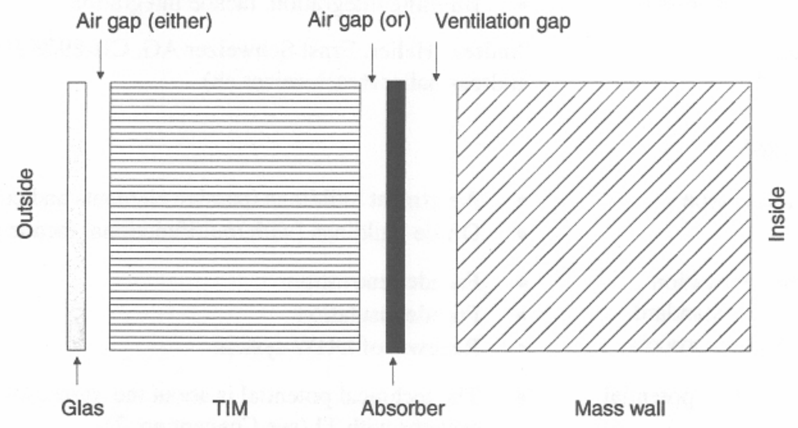


Figure 1: Principle section of the ventilated solar wall heating system.

Specific energy savings/energy gain

- Compensation of transmission losses of an external wall plus solar gains between 50 - 100 kWh/(m^2.a) (depending on mass wall material and climate).
- For combination with solar collector absorber for domestic hot water (DHW) systems additional gains of 200 - 350 kWh/(m^2.a) are expected.

Innovative aspects for renovation

- Improved integration in existing facades without changing the appearance for solar gain control (e.g. external roller blinds).
- Prefabricated wall elements developed for renovation applications and for use in combination with opaque insulation systems.
- Opportunity for multi-functional use of (limited) available facade area.

Critical aspects

- Optimal dimensions of TI material and air gaps
- Radiation and absorption properties of absorber
- Mechanical parts for closing and opening the ventilation gap
- Control of the ventilation openings for multi-functional systems

References

- P. Achard, R. Gicquel, European passive solar handbook, preliminary edition, 1986.
- G. Liersch, Untersuchungen des Energietransportes in einer konvektiv hinterlufteten transparenten Warmedammfassade, 1993.
- D.Schwarz, Two residential buildings with TI in Domat/Ems, Switzerland, realised as demonstration projects in 1996.

Development

Development status

Passive solar version with natural air ventilation for solar gain control: Qualified concept

- Prototype design of facade element with various absorber types under evaluation
- Cost effective solutions for operation of the ventilation openings are pending.

Multifunctional system with active thermal collector: Unqualified concept

Involved Systems / Components

- Glazed TI facade element
- Automated air flaps and control
- Solar thermal collector absorber

Type of companies involved in development

- Metal and facade construction company
- Consultant for fluid-dynamic calculations and facade testing
- Coating company for selective surfaces / absorbers
- Producer of air flaps and control systems

Required technical improvements / development focus

- Optimised absorber for glazed TI facade element
- Air channel and openings for natural ventilation
- Building integration, facade integration

Contact

Andreas Haller, Ernst Schweizer AG, CH-8908-Hedingen (e-mail: andreas.haller@eschweizer.ch)

Market

Building type

- Apartment buildings (passive elements and combined DHW systems)
- Office buildings (with multifunctional facade elements)

Main renovation reasons / Standard renovation process

- Facade renovation
- Facade insulation
- Renewal of DHW system

Application potential

- The technical potential is about the same as for other solar wall heating systems with TI (see Concept no. 7).
- Market potential limited by the achieved cost performance: A first estimate indicates that the current market potential is equivalent to other glazed solar wall heating system with TI (1 000 – 3 000 m^2 per year in Germany, Austria, and Switzerland).

Cost target

Total cost must be less than € 250 per facade element including gear and control.

Additional benefits

Improved winter comfort

Contractor/builder / additionally required experts

- Facade company
- Architect
- HVAC planner and plumber (multi-functional elements, only)

Application examples

To be built as follow-up of the development activities if cost and functionality goals are achieved.

Prototype Design

Construction

Total energy gained depends on transmission of transparent layers and absorption and emittance coefficients.

Layers	Prototype version: High inertia absorber	Prototype version: Selective absorber
Transparent layers	• low iron glass 4 mm as cover • air gap 3 mm • capillary plate (PC) 100 mm	• low iron glass 4 mm as cover • capillary plate (PC) 80 mm • air gap 23 mm
Absorber (measured values or producer information)	Fibre enforced concrete plate $\alpha = 0.72\ (\pm 0.05)$ $\varepsilon_{front} = 0.9\ (\pm 0.05)$ $\varepsilon_{back} = 0.9\ (\pm 0.05)$	Selective coated (NiCr) stainless steel $\alpha = 0.94 - 0.96$ $\varepsilon_{front} = 0.085 - 0.12$ $\varepsilon_{back} = 0.42\ (\pm 0.05)$

Prototypes base on existing thermally broken aluminium frame system for facade cladding and insulation system.

Design value for ventilation air gap between absorber and mass wall: 60 mm for channel height of 2.5 to 3.0 m.

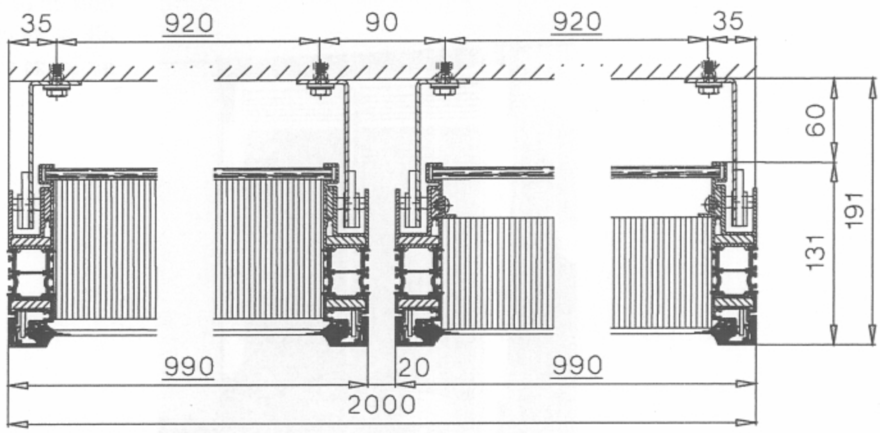


Figure 2: Horizontal section of the two prototype constructions: high inertia absorber on the left, selective surface absorber on the right.

Requirements for ventilation openings:

- Minimise pressure drop for natural convection air stream
- Minimise sensitivity to external air turbulence and wind pressure
- Full element width if possible
- Minimum height equals depth of ventilation channel
- Thermally insulated units (U-value < 2.0 W/m^2 K)
- Air tight in closed situation (equivalent to a window: a < 0.8 $m^3/(h.m.Pa^{v})$)
- Cost target: total cost must be less than E 250 per facade element including gear and control

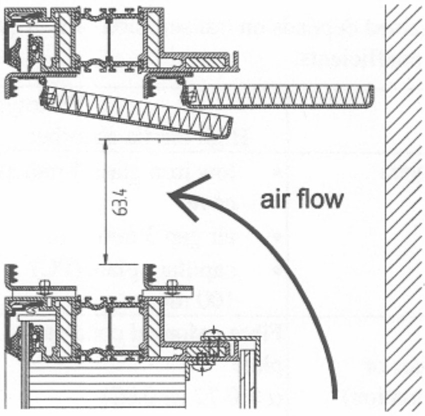


Figure 3: Vertical section of upper ventilation opening with double flaps (no gear included).

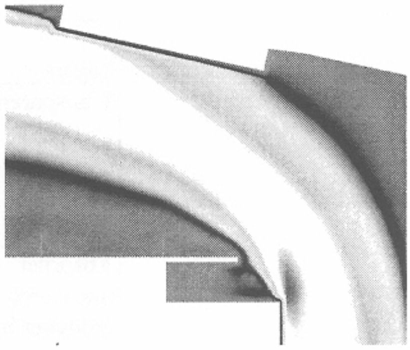


Figure 4: Simulated air flow pattern of upper ventilation opening: laminar air flow (light grey) with turbulent zones (dark shades) and static areas (dark grey)

Installation

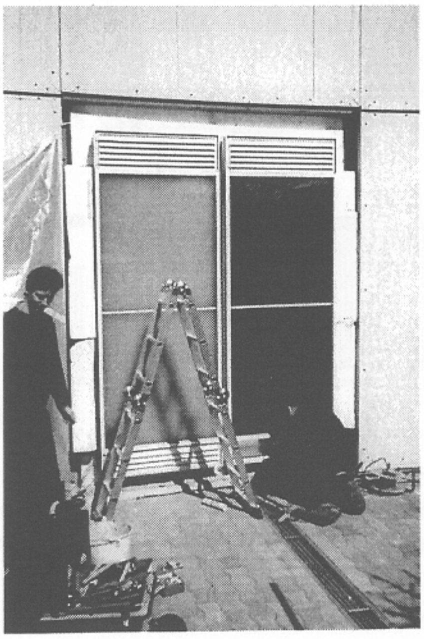


Figure 5: Prototypes during installation at the Fraunhofer ISE facade test site.

The ventilation openings at top and bottom of the elements are oversized to allow for experimental variation of the air inlets and outlets.

Prototype Evaluation

Result solar wall heating

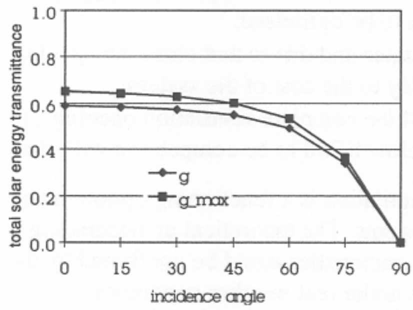


Figure 6: Transmission characteristics high inertia absorber.

Key characteristics

U-value and total energy transmission of prototype with high inertia absorber

- U-value = 0.78 W/(m^2.K) including frame
- g_max (centre of glass) = 0.65

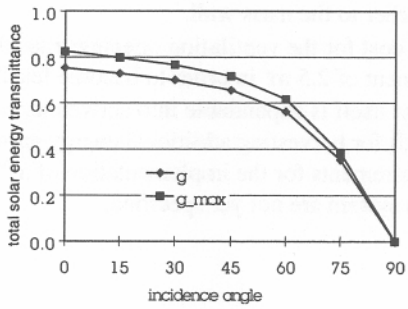


Figure 7: Transmission characteristics selective absorber.

Key characteristics

U-value and total energy transmission of prototype with metal absorber

- U-value = 0.72 W/m^2K including frame
- g_max (centre of glass) = 0.82

Result solar gain control

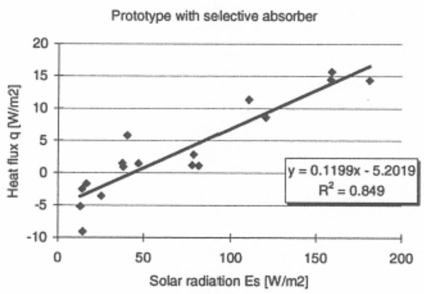


Figure 8: Evaluation of the energy transmission in ventilated mode.

Energy transmission in ventilated mode

For the selective metal sheet absorber with backside emittance of about 40%, the total energy transmission of the solar wall is below 12% in the ventilated mode. This is a sufficiently low factor to prevent overheating of larger solar wall heating areas during summer in central Europe.

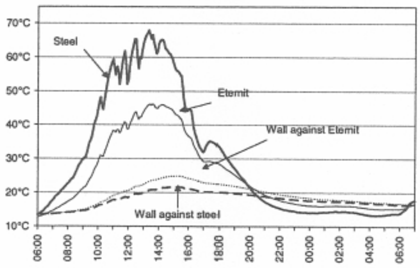


Figure 9: Temperature courses for a bright summer day.

Material parameter influence

A lower absorption coefficient and increased inertia result in Eternit absorber peak temperatures that are about 30°C lower than that for the selective steel absorber.

Despite the high temperatures of the absorber, the mass wall coupled to the steel absorber is cooler than for the Eternit absorber in the ventilated state because of the lower backside emittance of the steel absorber.

Cost estimation

- The cost increase for the basic facade element with a ventilation channel is low because only the mounting structure needs to be adapted.
- The cost for the ventilation openings for the prototypes is prohibitively high. This needs to be optimised.
- The mechanics and drives that close the openings in wall heating mode add considerably to the cost of the system.
- The cost of the complete ventilation openings, including mechanics and drives must be below € 250 to be competitive with standard external shading devices.

Conclusions

- Natural ventilation is a functioning option to control solar gains for solar wall heating systems. The theoretical understanding of the influence of the absorber surface characteristics could be confirmed by the measurements of the two prototypes under real weather conditions.
- At the time of reporting, the measured energy gains for solar wall system during the heating season without natural ventilation were not available. However, the performance is expected to be less than 10% below the performance of a solar wall where the absorber is directly coupled to the mass wall. Reduction is expected to be less than 10% compared to direct coupling of the absorber to the mass wall.
- Additional cost for the ventilation openings must be less than € 250 for a facade element of 2.5 m^2 in order to become feasible.
- The concept itself is expandable into active thermal collector systems (air or water based) for harvesting additional energy gains in summer. However, the design requirements for the implementation of a "hybrid" (combined passive and active) system are not yet specified.

9.7 Low cost TI wall heating system (CH)

Specification

Concept description

Transparently insulated (TI) massive walls form an efficient and attractive solar renovation concept by reducing energy requirements for space heating and improving comfort situation because of increased wall surface temperatures.

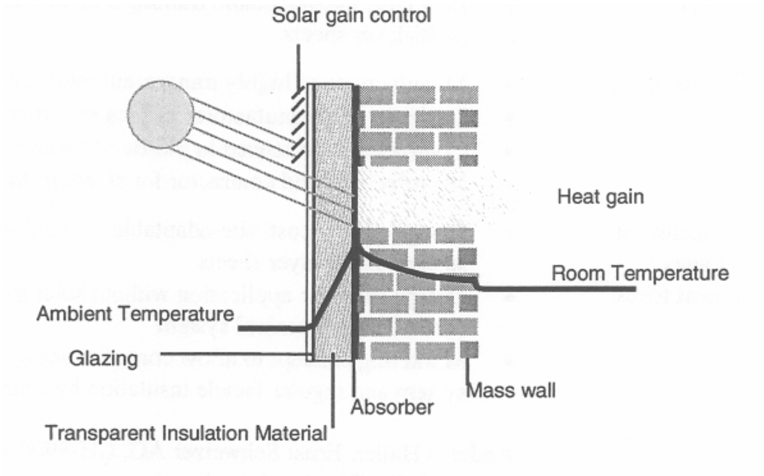


Figure 1: General principle of the solar wall heating system with TI.

The high investment cost of the high-performance glazed TI systems is a major hindrance for a more widespread application of this concept. Experiences demonstrate a few of the main reasons the high system cost:

- Expensive support structure for the currently used honeycomb or capillary TI materials.
- High planning and design costs, especially for renovations
- Most TI wall heating systems require additional craftsmen for mounting
- Need for solar gain control

In order to reduce total system costs a novel TI facade system will be investigated using mechanically sufficient stable and inherently weather protected TI material (multi-layer Macrolon® sheets).
The facade system needs to adapt to the usual dimension tolerances of on-site constructed building. A reduction in energy gains may be tolerated if investment cost can be sufficiently reduced.
Solar gain control may be avoided by covering only a part of the available facade area.

Specific energy savings/energy gain

Compensation of the transmission losses and additional gains of 40 - 80 kWh per m^2 of TI wall per hating season.

Innovative aspects for renovation

- Reduction of material (less framing, no glass panes)
- Application by traditional facade workers together with standard facade insulation
- Adaptation to building tolerances on the building site
- Reduced planning cost
- Use of existing distribution channels

Critical aspects

- Cost effective framing system
- Acceptance of the system by the facade insulation companies
- Acceptance of (plastic) facade material by architects and customers
- Conform to fire protection regulations because of the (uncovered) TI material

References

- IEA SHCP Task 20 brochure: Transparent Insulation in Building Renovation
- IEA SHCP Task 20 - Subtask E: Evaluation of Demonstration Projects

Development

Development status	• Qualified concept • Prototype design and evaluated prototype of TI component • No development for site-adaptable facade system pending
Involved Systems / Components	• TI elements from two or more stacked layers of multi-layer Macrolon@ sheets • Low cost, site-adaptable framing and facade mounting system for stacked multi-layer sheets
Type of companies involved	• Manufacturer of highly transparent multi-layer sheets • Designer and manufacturer of facade systems • Contractor experienced in plastic sheet handling (e.g. greenhouse builder) • Manufacturer and contractor for standard facade insulation systems
Required technical improvements / development focus	• Design of low-cost, site-adaptable framing and facade mounting system for stacked multi-layer sheets • Design rules for application without solar gain control or adaptation of low-cost solar gain control system • Marketing concept to allow commissioning of the improved solar wall heating system and regular facade insulation by a single contractor
Contact	Andreas Haller, Ernst Schweizer AG, CH-8908-Hedingen, e-mail: andreas. haller @ eschweizer.ch

Market

Building type	• Single family home • Apartment building • Industrial hall, storehouse • Public service building
Main renovation reasons / Standard renovation process	• Facade renovation • Facade insulation
Application potential	Market potential study for Austria, Germany and Switzerland: 70 million m^2 building facade insulation per year. • South oriented: 25 % of total; equals to 17.5 million m^2 • Suitable mass wall for solar wall heating: 30% of above; equals to 5.25 million m^2 • Unshaded area: 10% of above; equals to 525 000 m^2 per year
Cost target	Total cost must be less than E 280 per m^2 installed solar wall heating (without active solar gain control).
Additional benefits	Increased comfort for solar wall heating parts of the building envelope (e.g., specially suited for bathrooms)
Contractor / builder / additionally required experts	• Installation by regular facade insulation worker • No special experts required on site
Application examples	None up to reporting date

Modelling

Model description

Based on measured energy transmissions and U-values of multi-layer Macrolon® sheets, the energy gains of potential TI wall heating systems were evaluated for the following building model:

Heated floor space	170 m^2		
Footprint	100 m^2		
Volume	554 m^3	without attic	
Surface	420 m^2		
		U-value window	g
Window South	13.75 m^2	1.4 W/(m^2.K)	0.62
Window East	11.00 m^2	1.4 W/(m^2.K)	0.62
Window West	11.00 m^2	1.4 W/(m^2.K)	0.62
Window North	8.25 m^2	1.4 W/(m^2.K)	0.62
Opaque facade	154.00 m^2	0.30 W/(m^2.K)	
Roof	100.00 m^2	0.21 W(m^2.K)	
Basement	100.00 m^2	0.41 W(m^2.K)	
Solar wall heating	22.00 m^2	See below	See below

Parameters

TI variants and reference	Thickness [mm]	U-value [W/m^2.K]	g_h
Opaque insulation	100	0.33	0.00
2 stacked PC sheets	64	1.00	0.41
3 stacked PC sheets	103	0.7	0.27
Capillaries	105	0.9	0.60

Evaluation Criteria

Energy gains per m^2 solar wall heating
- for varying orientations of the TI facade
- for TI variants

Reduction of heat energy demand per heated floor area
- for varying orientations of the TI facade
- for TI variants

Evaluation Tool(s)

Monthly energy balance method with a proprietary static evaluation tool from Fraunhofer-ISE, Freiburg, Germany

Evaluation Results

Energy aspects

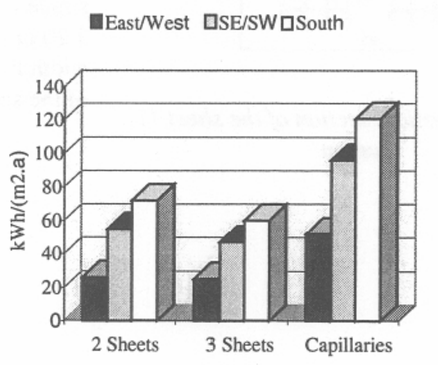


Figure 2: Energy gains per m^2 solar wall heating.

All variants of TI systems (for details see Parameters above) compensate the loss of the opaque reference system by approximately 30 **kWh/(m^2.a).**
In addition, all variants result in a net energy gain for orientations between East and West.
(These values are valid for the heating period from October to April in Freiburg, Germany)

Heat energy demand per m² heated floor space

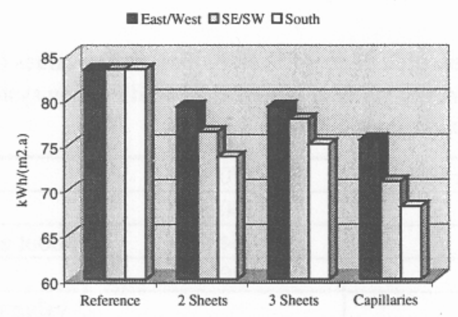


Figure 3: Heat energy demand per m² heated floor space.

Heat energy demand reduction is not as prominent (4% to 11%) because the solar wall heating area is only about 10% of the total facade area of the building model.

Conclusions

- The 2-sheet stack seems to be the optimal variant. The U-value of only one layer would not be sufficient (1.7 W/(m^2.K)). A stack of three sheets reduces the solar transmission too much.
- South orientation is the preferred application.

Prototype Design

Construction

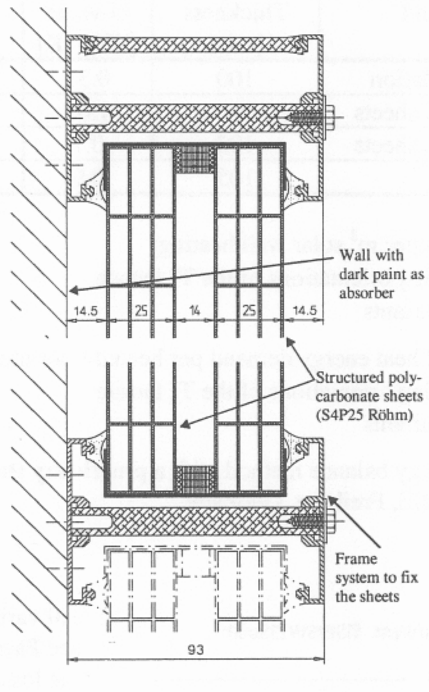


Figure 4: Vertical section of the sheet TI system.

A stack of two multi-layer sheets with a frame system is mounted in front of a dark coloured mass wall. The framing system must be sufficiently insulated by a thermal brake.
The framing system must allow a joint to the opaque insulation system and allow for service of the multi-layer stacked sheets without destruction of the adjacent opaque insulation system.

The spacers in the stack create an additional insulating air layer. A glue tape on top and sides seal the stack. The stack must be sufficiently open to moisture transfer at the bottom.

The practical maximum height of a single module is between 2.60 and 3.20 m (one storey). The maximum width is given by the available width of the sheet (980 mm).

Installation

Figure 5: Installation of the prototype.

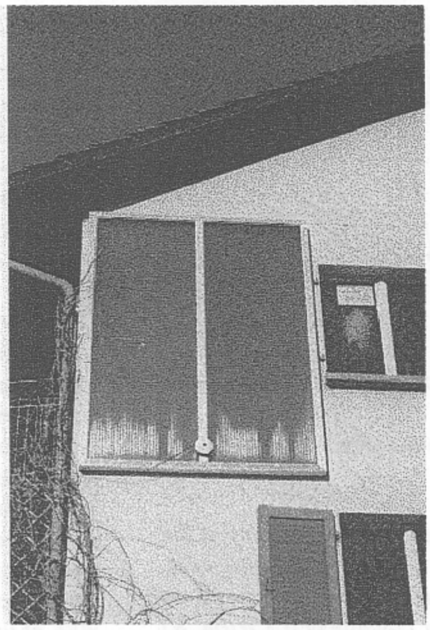


Figure 6: Test site of the prototype on a typical apartment building.

Mounting with prefabricated frames

A prototype of this solar wall system was installed on the south facade of a typical apartment building built in the early 1950s. The brick facade was painted black. Then the prefabricated frame for a double module was attached to the wall. The prefabricated stacked sheets were inserted into the base frame. A cover frame holds the sheets in place.

Aesthetics and moisture condensation

The aesthetics of the prototype installation may not be representative because there is no integration into the facade.

The condensation in the lower part can be eliminated by improved measures to avoid moisture accumulation in the cavities of the multi-layer sheets. (For the prototype the stack was sealed on all four sides. The bottom seal must be left out.)

Evaluation Results

Characteristic properties

U-value and solar efficiency

The characteristic properties of the solar wall heating system with the staked multi-layer PC sheets were calculated from the measured data. They were integrated to 5-day mean values. Every dot represents the energy transmission versus the climatic factor for a 5-day period. The regression curve results in a U-value of 0.48 W/m^{2}K at no solar incidence and a solar efficiency of 1= 18% (gradient of the 1st order regression).

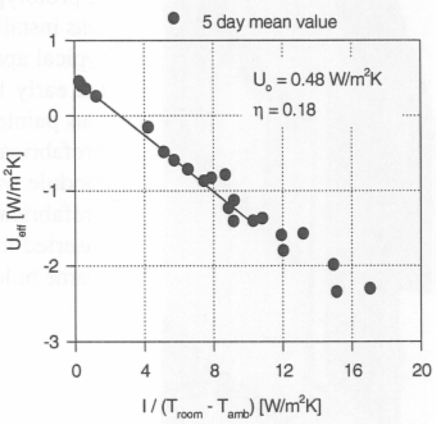


Figure 7: Regression plot of the mean values of measurement results allows the determination of the characteristic values of the system.

Comfort

Wall surface temperature

During prototype evaluation there was an extraordinarily long period (4 weeks) with very low radiation levels due to dense fog.

During this period the solar wall acted merely as "opaque" insulation resulting in a U-value of approx. 0.5 W/m^{2}K.

The inner wall surface temperature during this fog period was considerably lower than during the typical winter weather period. The graph shows the frequency of the temperature difference between inner wall surface of the solar wall and the room temperature. The inner surface temperature was equal to or greater than the room temperature more than 80% of the time.

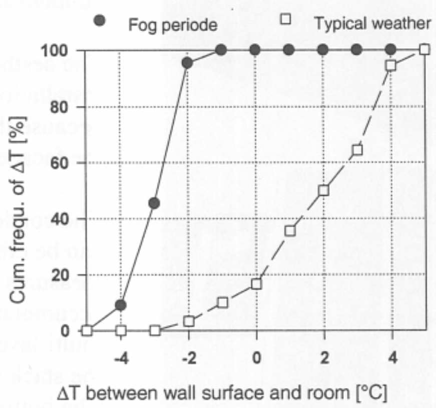


Figure 8: Cumulative frequency of the temperature difference between inner wall surface and room air for a wall with an equivalent U-value of 0.5 W/(m^2.K) and the solar wall prototype.

Cost

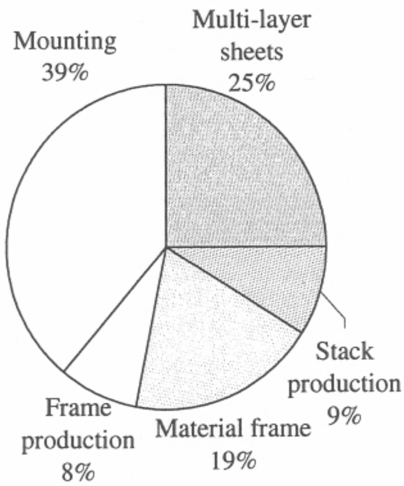


Figure 9: Cost split of the sheet TI system.

Cost split of the TI system for the solar wall heating based on the prototype system.

For small areas (10 to 15 m^2) the installation (mounting) contributes a large share to he overall cost. The preparation of the mass wall as an absorber is not included. Preparing the mass wall can be neglected for renovation projects because it would be required also for a standard facade renovation.
This also shows the potential for further cost reduction:

- Reduce fixed part of installation cost (e.g. mounting by the standard facade contractor).
- Material reduction for the multi-layer sheets.
- Cost reduction for the frame material.

TI system for solar wall heating	Investment cost [in €]	Yearly energy gains, south [kWh/m^2]
Prototype 2-stack multi-layer PC sheet	2 700	70
Glazed honeycomb system	5 400	120

Calculated investment cost of a small facade (12.5 m^2) with 5 identical TI modules based on the cost for the prototype and specific energy gains per heating season.
For comparison, the cost of a glazed TI system with the same size is given.

For both cases the same parameters are assumed (e.g. wall material).

Conclusions

The measurements of the prototype confirmed the calculated solar gains.

- The system has a cost reduction potential by optimisation of the framing system.
- The cost target of E 280 per m^2 seems feasible for large identical modules (> 2.5 m^2) in moderate quantities (more than 5 modules per order).

Over all conclusions

- This transparent insulation system for solar wall heating applications lowers the investment cost by approx. 50% compared to the known glazed systems.
- The cost reduction can be achieved mainly through a simplified construction for fixing the TI material to the facade.
- Energy gains are reduced to about 60% of a glazed system with honeycomb or capillary TI material.
- The reduced solar gains allow for applications without active solar gain control.
- The framing system allows the combination with and integration in any standard facade insulation system.

9.8 Elimination of thermal bridges with TI (NL)

Specification

Concept description

Transparent Insulation (TI) is most effective on non-insulated mass walls. TI applied to cavity walls may eliminate thermal bridges. In the solar renovation of the Brandaris in Zaandam, The Netherlands, the possibility of TI elements glued to the wall was studied.

The Brandaris is a high-rise multifamily building with 384 apartments. The building's long facade face east and west. There are structural thermal bridges in the cavity walls at the south facades because of the construction of the concrete floors.

Figure 1: View of the Brandaris apartment building

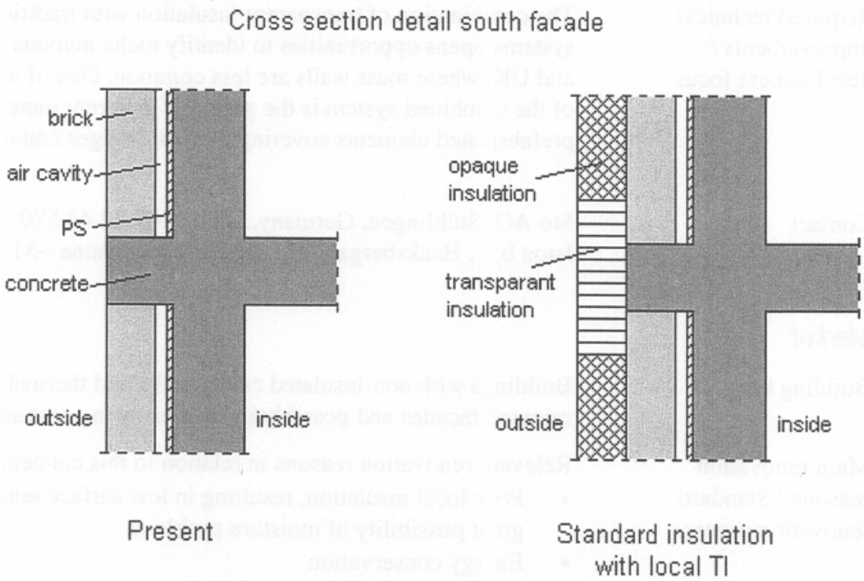


Figure 2: Cross section detail of south facade

Specific energy savings/energy gain	• Reduction of transmission losses of to 35 kWh per m length of exposed floor edge per heating season. • Solar gains of up to 10 kWh per m length of exposed floor edge per heating season.
Innovative aspects for renovation	The innovative aspects are • Use of passive solar energy to solve thermal bridge problems and improve thermal (winter) comfort with a solar energy net surplus without overheating in summer • Integration of transparent insulation with traditional exterior wall insulation systems on cavity walls
Critical aspects	Critical aspects are • Possibility of high local temperatures in the construction behind the TI during summer • Architectural considerations • Environmental aspects • Costs
References	Donze, G.J. a.o.; Renovatie Brandaris, Bouwfysica, vol.9, 1998, no. 1 (in Dutch) Knapen, M; Environmental considerations on materials in TI and possibilities for improvements, IEA SHCP Task 20, 1-98

Development

Development status	Transparent insulation as technology has passed its prototype phase. It has been applied in various shapes in a number of demonstration projects in Germany, Switzerland and Austria. In Germany the manufacturers Sto AG has launched a TI application which can easily be combined with EPS external insulation.
Involved Systems/Components	• Composite TI systems (Sto AG) • Exterior wall insulation systems
Type of companies involved in development	• Manufacturers • Architects • Building owners • Energy consultants
Required technical improvements / development focus	The combination of transparent insulation with traditional external insulation systems opens opportunities to identify niche markets in countries like Netherlands and UK, where mass walls are less common. One of the environmental drawbacks of the combined system is the gluing of different materials. The application of prefabricated elements covering thermal bridges could be seen as a solution.
Contact	Sto AG, Stuhlingen, Germany, phone +49 77 44 570 Iston b.v., Haaksbergen, The Netherlands, phone +31 743 575 473

Market

Building type	Buildings with non-insulated cavity walls and thermal bridge problems in south oriented facades and possibly in facades facing east and west
Main renovation reasons / Standard renovation process	Relevant renovation reasons in relation to this concept are • Poor local insulation, resulting in low surface temperatures on the inside and a great possibility of moisture problems • Energy conservation • Upgrading exterior

Application potential

There is a theoretically large potential for transparent insulation of south (and possible east and west) oriented linear thermal bridges in apartment buildings throughout Europe. The potential impact of the TI part is about 10%-20% to the total standard insulation area.

Cost target

The Dutch market would accept € 140 per m^2 where the costs of TI elements at the moment are about € 230 per m^2.

Additional benefits

Advantages of local TI are:
- Solar gains and energy conservation
- Solving thermal bridge problems
- Thermal comfort
- Improved architectural image

Contractor/builder / additionally required experts

- Architects
- Facade company
- Energy consultants

Application examples

None within The Netherlands yet

Modelling

Model description

The modelling was done for the abutting detail of the concrete floor to the end facade facing south.

Material characteristics:
- Characteristics of the existing detail

	material	thickness [mm]	conductivity [W/(m.K)]
wall	brick	100	1.2
	air cavity	50	-
	PS	15	0.045
	concrete	200	2.0
floor	concrete	200	2.0

- Characteristics of the existing structure:
- U-value of the opaque insulation: U=0.32 W/(m^2.K)
- U-value of the TI-system (100 mm TI): U=0.80 W/(m^2.K)
- Total energy transmittance of the TI-system (diffuse): g_{dif}= 45%

Simulation model for energy related simulations (CAPSOL and SECTRA)

Simulation characteristics:
- Inside: constant temperature of 20°C
- Outside: standard Dutch climate (Test Reference Year, De Bilt)

Simulation of temperatures in 5 nodes (output):
- Temperatures in the construction directly behind the TI in 4 nodes
- The inner surface temperature in node 5

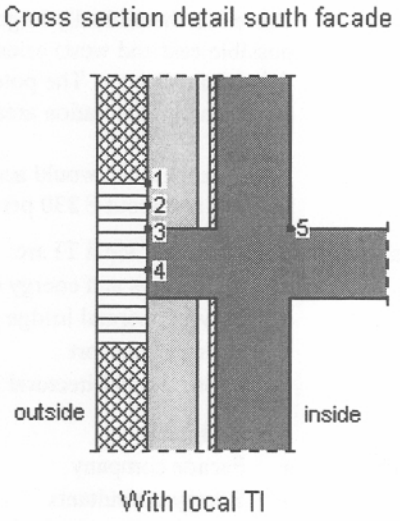


Figure 3: Schematic of simulation model with the evaluated temperature nodes.

Parameters

Specific set of parameters:

- Season: Winter, spring and summer
- Construction: Present detail, detail only with external insulation and detail with external insulation and local TI

Evaluation Criteria's

The evaluation criteria's are:

- Temperature inside the construction
- Reduction local heat flow

Evaluation Tool(s)

CAPSOL, a multi-zone transient heat transfer program (Physibel)
SECTRA, a 2-dimensional transient heat transfer program (Physibel)

Evaluation Results

Results Criteria 1
Temperature inside the construction

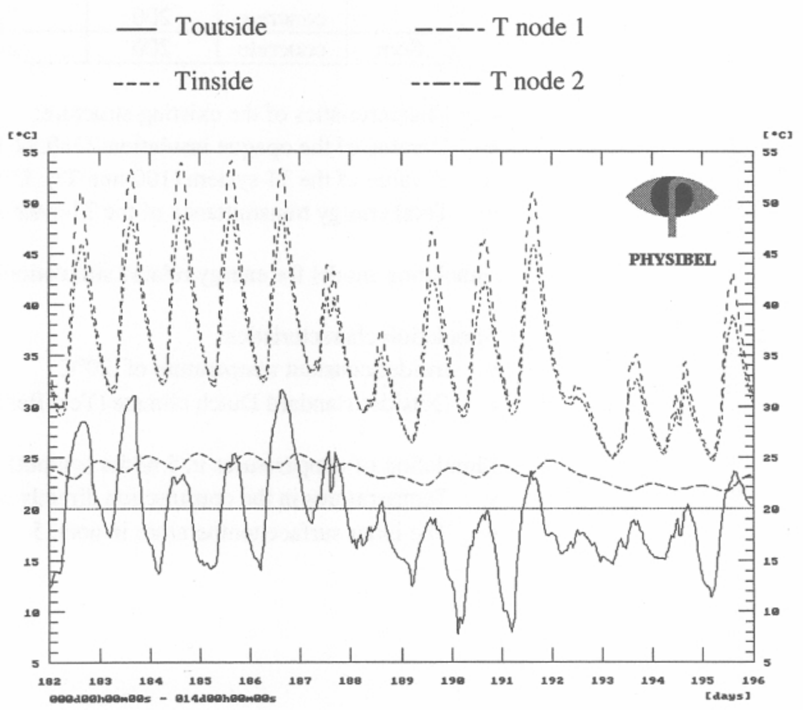


Figure 4: Temperature curve in construction, summer (1 Jul. – 15 Jul.); position of temperature nodes see figure 3.

Due to the angle dependent solar transmittance and the thermal mass of the building construction the difference between the highest temperatures in the construction is negligible during summer and spring. Possible materials stress effects and cracks in the outer shell are not expected from performed simulations.
In summer the time lag of the surface temperatures between the outside and inside of the construction is about 10 hours. This means that the highest temperature on the inner surface arises in the evening. The temperature fluctuation on the inner surface of the construction is about 10% of the outside surface. The inside surface temperature remains below the 25°C, so overheating during summer will not occur. During the winter period the inside surface temperature is minimum 18°C.

Results Criteria 2
Reduction local heat flow

According to the diagram the application of only standard external insulation reduces the heat loss during the heating season by 75% compared to the present situation.
Despite of the lower local insulation, the use of standard external insulation with 60 cm TI shows a positive heat gain over the total construction in the heating season.

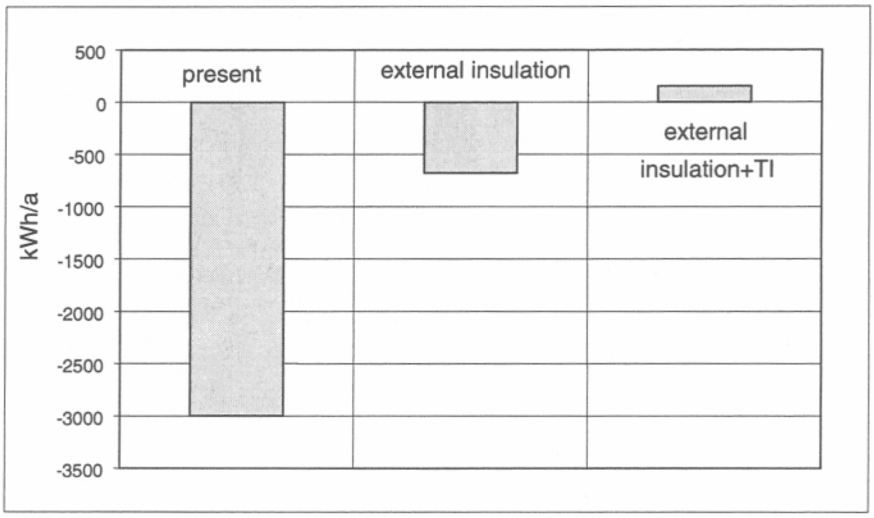


Figure 5: Heat flows over total construction in heating season

The specific heat flow reduction and the solar energy gains by the transparent insulation of the concrete floor sections can also be estimated like follows:

- Specific (linear) heat loss factor for the concrete floor edge exposed to the ambient: -- 0.5 W/(m.K)
- Heating degree days in Amsterdam: 3065 Kd
- Transmission losses: — 35 kWh per meter floor edge and heating season. It is expected that these losses will be compensated.
- Solar energy gains per meter floor edge: It is assumed that only the concrete (20 cm height) will actively store the solar energy. Thus 20% of the figure specified for solar gains of the TI wall heating system may be assumed (— 10 kWh per meter floor edge and heating season).

Conclusions

- Besides the application of TI on massive walls, TI can be used in combination with standard external insulation systems on south oriented cavity walls to eliminate linear thermal bridges.
- Depending on the situation before renovation, TI insulation of exposed concrete floor sections can save up to 100 kWh of heat energy per meter edge and heating season.
- Overheating during summer will not occur and instead of transmission losses there is a positive heat gain and an increase of comfort in winter. The cold bridge becomes a warm one!
- Due the frame-integration with standard external insulation systems and the possibility of reuse and recycling prefabricated TI wall elements with wood or thermally insulated metal frames are preferred instead of TI elements glued to the wall.

9.9 Facade integrated collector system (D)

Specification

Concept description

The proposed solar collector system is designed as an integral part of a compound insulation and finish system for building walls. The dark coloured surface of the plaster acts as an uncovered absorber for solar radiation. The plaster layer conducts heat to a plastic capillary piping system then transfers the heat to the domestic hot water (DHW) storage. A layer of insulation thermally separates the piping from the wall. The system collects solar gains and recovers part of the transmission losses of the building wall. Due to the absence of an absorber cover, the application is limited to preheating the water.

The development is part of a co-operation with industrial partners.

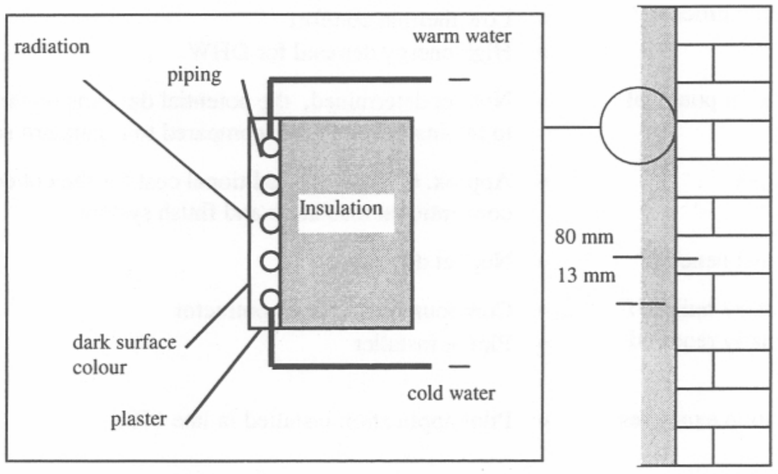


Figure 1: Basic system design of the facade integrated collector system.

Specific energy savings/energy gain

Results from testing the facade are available but not yet in a publishable format (finished diploma work).

Innovative aspects for renovation

- Installation as an integral part of a compound insulation and finish system
- "Low cost collector" (intention)

Critical aspects

- Fluid freezing in the collector tubes
- System costs
- Facade (absorber) colour

References

Diploma work at Fraunhofer ISE (DE): Untersuchung and Simulation eines Fassadenkollektors zur Brauchwasservorwarmung, Mathias Langer, 1996

Development

Development status

- Evaluated facade performance through simulation and monitoring in 1996
- A pilot application was installed as part of a building renovation in 1998. Performance will be monitored and analysed by Fraunhofer ISE under contract to the manufacturer.

Involved systems/ components

- Compound insulation and finish system
- Plastic capillary piping (standard part of cooling ceilings)

Required technical improvements/ development focus	• Basic system specifications and system layouts to be developed • Initial experiences with the system operation are needed to develop a reliable collector facade.
Type of companies involved in development	• Compound insulation and finish system manufacturer • Manufacturer of plastic capillary piping
Contact	• Fraunhofer ISE, Dipl.-Ing. Mathias Rommel (e-mail: rmmel@ise.fhg.de)

Market

Building type	• Residential buildings with west or south west (!) oriented external walls • Buildings having a central DHW system
Main renovation reasons / Standard renovation process	• Facade degradation • High heating energy demand • Low thermal comfort • High energy demand for DHW
Application potential	• Not yet determined, the potential depends on the ratio of system performance to the installation costs compared to a standard solar collector arrangement.
Cost target	• Approx. E 50 per m^2 additional cost for the collector compared to a conventional insulation and finish system
Additional benefits	• Not yet determined
Contractor / builder / additionally required experts	• Compound insulation contractor • Piping installer
Application examples	• Pilot application installed in late 1998

Experiments

Experiment description

• A facade collector with an absorber area of 13 m^2 was installed at a test house on the Fraunhofer ISE test grounds. The collector consists of:
— 13 mm blue coloured plaster (a=87%)
- 13 m^2 capillary piping made of polypropylene with an internal diameter of 1,5 mm
- 80 mm rock wool insulation
- 200 mm lime stone brick wall

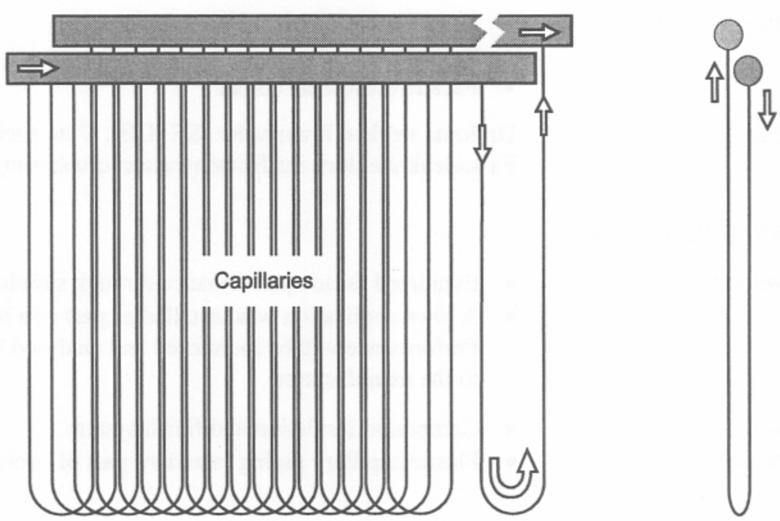


Figure 2: Principle of capillary piping.

- The collector was operated with a cooling unit to maintain a constant low collector inlet temperature

Results

- The optical efficiency of the collector was determined to be 56% (useful heat delivered per aperture area and insulation). This is about 25% less compared to standard glazed flat plate collectors. One reason for the lower performance is the relatively low absorbance of the facade colour (87% compared to 95% of a selective metal absorber). A second effect is the lower thermal conductivity of the plaster around the capillary piping compared to a metal absorber of a flat plate collector.
- The heat loss factor of the collector is determined to be approximately 10 W/(m^2.K) compared to 4 W/(m^2.K) for a standard flat plate collector. This increased heat loss is the direct consequence of the missing absorber cover.
- In low-flow operation the capillary tubes tend to non-homogeneous flow rates across the absorber area. This has a significantly negative effect on the overall system performance.

Conclusions

- The test results are in agreement with initial estimates.
- Improving the colour and the conductivity of the absorber has a high potential for increasing the collector performance.

Modelling

Model description

- Modelling was done with TRNSYS 14.2 using the measured collector efficiency function as input for type 1 (solar collector)
- Simulations were performed for the collector system "installed" at a 30-family apartment house in Freiburg, Germany, with a DHW demand of 35 litre per person per day. The collector is connected via an external heat exchanger to the stratified boiler. The boiler temperature in its upper part is maintained at a constant 50°C by back-up heat.
- Simulation data were also compared to the measured performance of the test facade. The comparison shows that the absence of an absorber cover resulted in strong fluctuations of the collector efficiency with the weather conditions. It is assumed that the annual results are in sufficient agreement with the simulations.

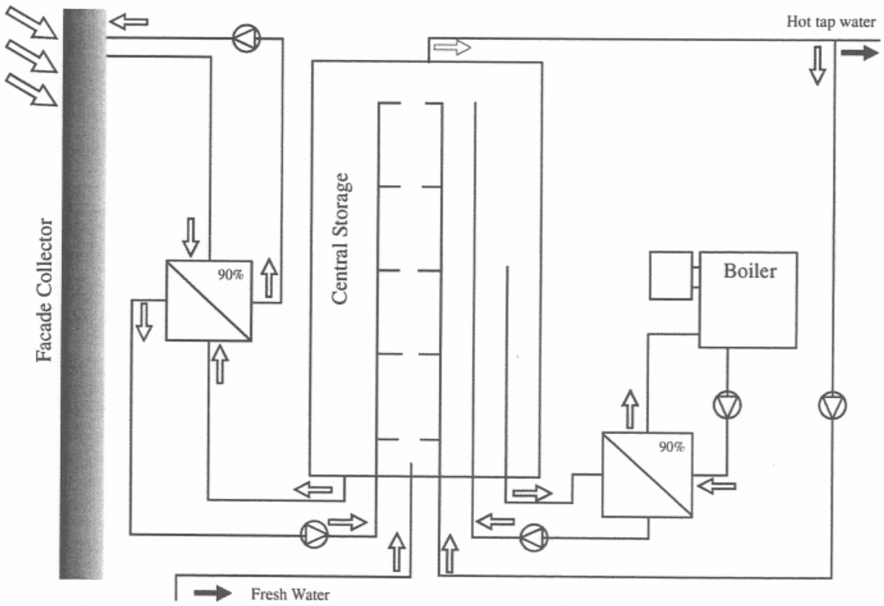


Figure 3: Basic system layout for the simulation.

Parameters	• orientation • temperature set point in the boiler • system economy
Evaluation Criteria	• energy savings
Evaluation Tool(s)	• TRNSYS 14.2

Evaluation Results

Results	• Using a south oriented and an absorber installation area of 1.5 m^2 per person, a solar fraction of 25% of the annual DHW demand can be achieved. • Compared to a south orientation, an orientation towards west decreases the solar fraction by only 9% whereas orientation towards east leads to a 24% decrease. The strong coupling of the absorber performance to the ambient temperature (high loss factor) results in a greater efficiency decrease for east-facing collectors compared to west-facing collectors. Maximum solar gains on facades oriented towards the west coincide with the highest daytime temperatures. • The collector yield is decreased by 25% in cases where the storage temperature is heated once a day to 60°C for hygienic reasons (legionellea). Therefore, other methods should be preferred for hygienic protection. • A comparison of the collector yield with costs and yield of a standard flat plate collector system leads to the conclusion that the upper cost range for the facade integrated collector is about € 50 per m^2.
Conclusions	• A full-scale pilot application was installed to verify the simulation results. This installation includes design modifications derived from the experimental investigation at the test collector (absorber performance, flow rate). The whole system design accounts for the fact that the collector is mostly preheating the water. Generally, it must be stated that this new product is in an early stage of development compared to standard flat plate collectors. The pilot application was installed on a facade of an existing building in late 1998. Measurements will be done under contract to the industry in 1999.

9.10 Solar air - double envelope (S)

Specification

Concept description

The described concept utilises solar heat for space heating by using a simple solar air collector in combination with a double envelope (e.g., a new facade placed at a distance from the existing facade). Solar heated circulates from the solar air collector, through the double envelope, and back to the solar air collector in a closed loop.

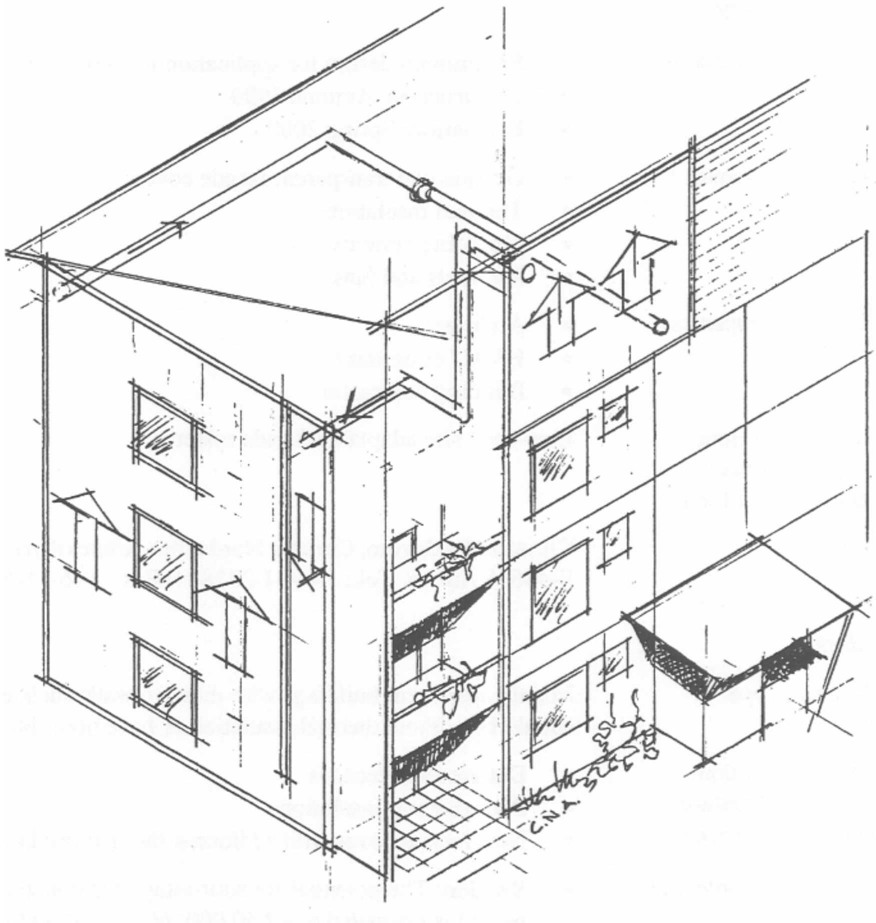


Figure 1: The illustration shows a schematic drawing of the solar air system with double envelope. Courtesy of C. Nordström.

The concept was developed based on the Solar House in Jarnbrott, Sweden, documented in IEA SHC Task 20 Subtask A. Considered improvements are:

- Vertical instead of inclined (roof) collector mounting to increase gains in autumn and spring.
- Simplify system for wall heating only and exclude summer operation for pre-heating DHW (air-water heat exchanger).
- Double envelope on north, west and east facades instead of all facades
- Guide the warm air to the bottom of the facade and extract the air from a top corner instead of the other way round.

Specific energy savings/energy gain

- Compensate part of the transmission heat losses, approximately 10-20 kWh per m^2 heated floor area.
- The project designers estimated that the required energy is small compared to the gains (see Jarnbrott project in references below).

Innovative aspects for renovation	Solar collector and double envelope design.
Critical aspects	• Air tightness - double envelope and collector • System control
References	IEA SHCP Task 20 brochure: Solar Collectors in Building Renovation IEA SHCP Task 19 "Solar Air Systems" Design Guidelines

Development

Development status	• Preliminary design for application in a renovation project. • Construction: Autumn 1999 • Evaluation: Spring 2000
Involved Systems 1 Components	• Opaque and transparent facade covers • Thermal insulation • Mounting systems • Air ducts and fans.
Type of companies involved	• Architect • HVAC consultant • Building contractor
Required technical improvements / development focus	Low-cost, site adaptable facade systems.
Contact	Christer Nordstrom, Christer Nordstrom Arkitektbyrå AB, Asstigen 14, S-43645 Askim, Tel.: +46-31-282864; Fax.: +46-31-681088: E-mail: cna@cna.se

Market

Building type	Mainly apartment buildings with massive walls such as concrete or brick. Walls should be without thermal insulation or have poor thermal insulation.
Main renovation reasons / Standard renovation process	• Deteriorated facades • Poor thermal insulation • New facade cover with additional thermal insulation
Application potential	• Sweden: The potential for roof-integrated collectors (based on renovation needs) is estimated to — 650 000 m^2 (according to IEA SHCP Task 20 Subtask A investigations). The potential for solar air collectors and double envelopes may be seen as a possible solution when the facades are suitable. The system requires about 5 m^2 of facade area per m^2 of collector area (rule of thumb). Assuming that the system can be applied on one third of the buildings suitable for collectors, the potential facade area amounts to — 1 000 000 m^2 for Sweden. • Europe: The potential is assumed to be larger in other parts of Europe, as uninsulated buildings are more common in less cold climates.
Cost target	The thermal gains are estimated to 100 to 150 kWh/a per m^2 collector area, which implies that the marginal cost (e.g. compared with traditional facade renovation) should amount to approximately £ 100 per m^2 collector or € 20 per m^2 facade.
Additional benefits	Increased thermal comfort due to increased wall temperature (indoors).
Contractor / builder / additional required experts	Supervisor for advice and quality check regarding air tightness
Application example	Gardsten, Goteborg, Sweden

Modelling

Model description	At the time of reporting no detailed model data was available. The model will be set up according to the project (see project design).
Parameters	Air flow, air velocity, pressure drop, temperatures, etc.
Evaluation Criteria	Energy gains per m^2 of collector and heated floor area. (Marginal) investment cost
Evaluation Tool(s)	TRANSAIR - IEA SHCP Task 19 Solar Air Systems

Project Design

Design description

The proposed system will be applied in a full-scale demonstration project in Gardsten, Goteborg, Sweden (THERMIE project):
The system will be applied on one multifamily building (concrete element walls) with 12 apartments (approximately 1000 m^2 heated floor area). A new roof will be installed and increased south-facing facade will be constructed. The new south facade will have about 70 m^2 of solar air collectors, divided in four sections. New north, east and west facades will be constructed (approximately 300 m^2) at a distance from the existing facade.
The solar collectors are connected via air ducts to the air space behind the new facade cover in four closed systems, one each for west and east facades and two for the north facade. Figure 2 shows the system applied to the west facade.

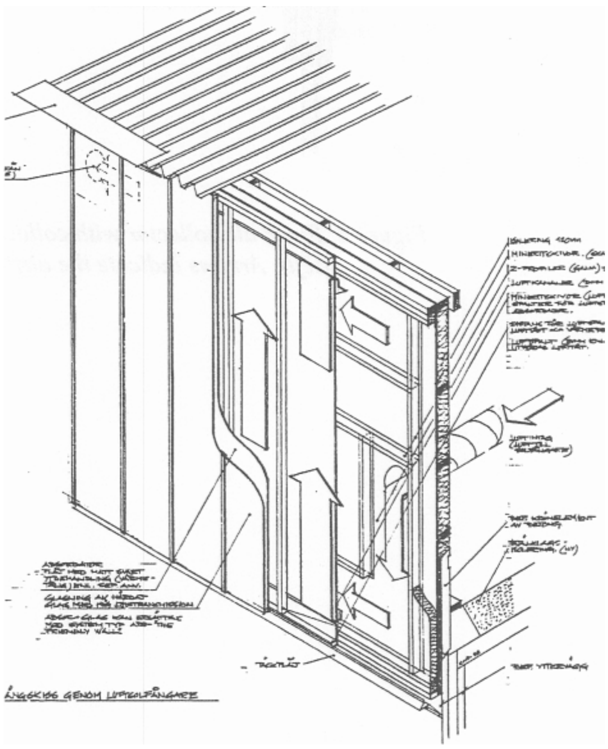


Figure 2: The reproduction of the blueprint shows the planned airflow of the west facade in 3-d view. Courtesy of C. Nordstrom.

Figure 3 shows two sections (supply and return air ducts) of the site-built collector, to be applied to the south-facing facade. The proposed airflow amounts to about 50 m^3 per m^2 of collector area.

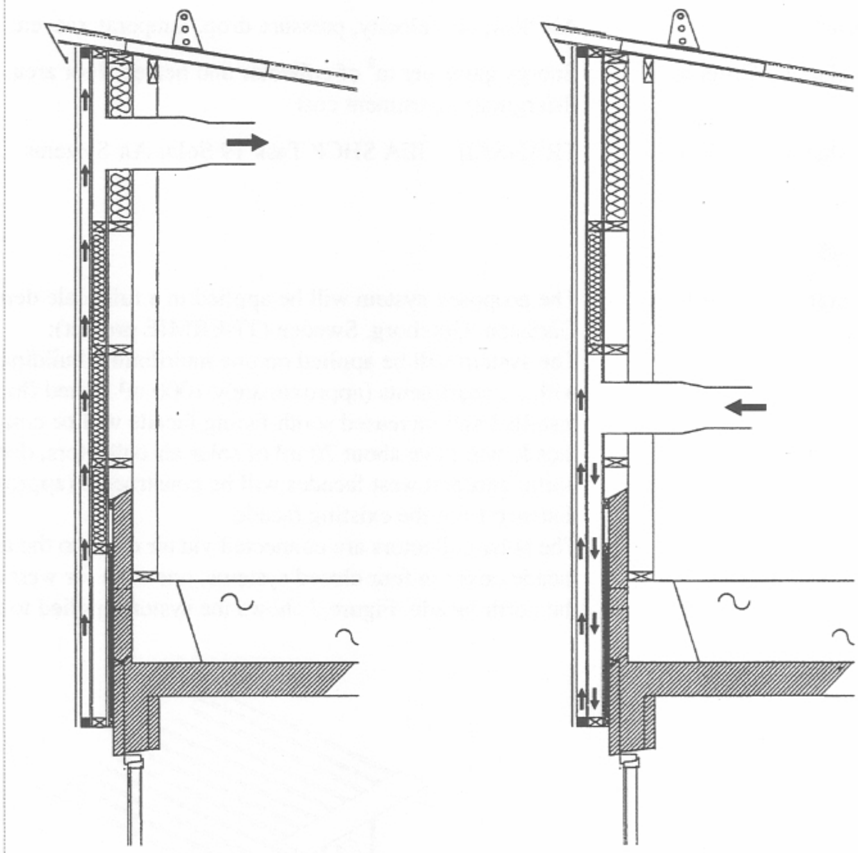


Figure 3: Solar air collector with collector supplies duct (right) and return duct (left). Arrows indicate the airflow. Courtesy of C. Nordström.

Design description (cont.)

Figure 4 shows a section of the north facade with the new facade cover including thermal insulation at a distance of about 50 mm from the existing facade (concrete elements). The air is guided from the air duct to the bottom of the wall and extracted from the opposite top corner of the double envelope section with another air duct.

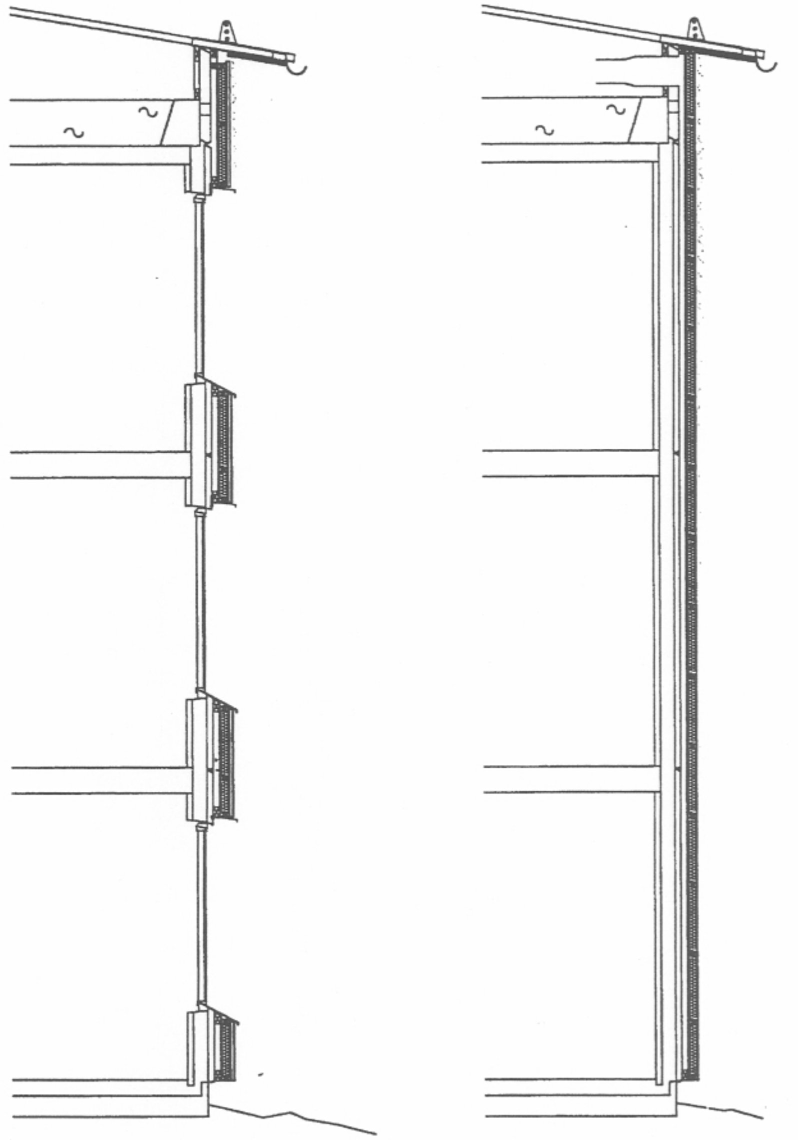


Figure 4: Double envelope: Facade part with windows (left) and closed facade part (right). Courtesy of C. Nordström.

Conclusions

- With the help of state of the art rule of thumb design rules it was possible to create a convincing design for a specific building.
- It seems possible for an ordinary building contractor to build the system within the given cost limits of the demonstration project.
- Evaluation will show what further work is required on the level of research and development.

9.11 Solar air system with building double envelope (CH)

Specification

Concept description

Circulating collector-warmed air through a hollow building envelope reduces heat losses through the building envelope. The system can work at a high efficiency due to the relatively cool temperature of the air returning to the collector.
In summer, a by-pass from the collectors to an air-water heat exchanger preheats domestic hot water.

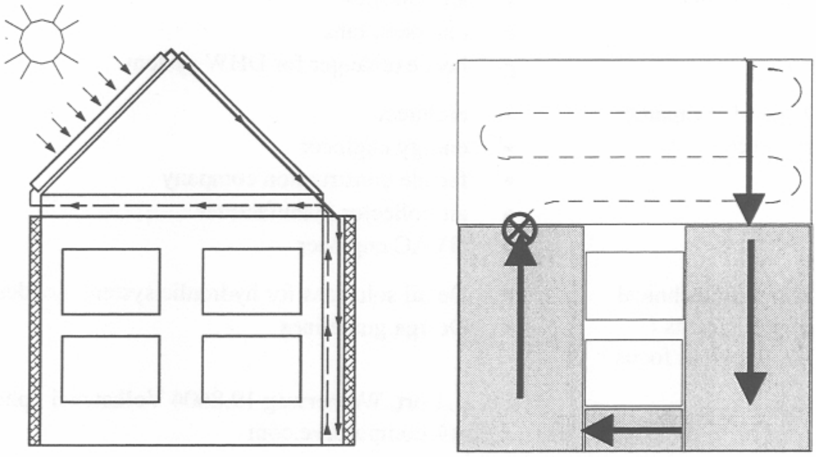


Figure 1: Hydraulic schematic. Air collectors on south oriented roof and airflow through north roof and north oriented facade.

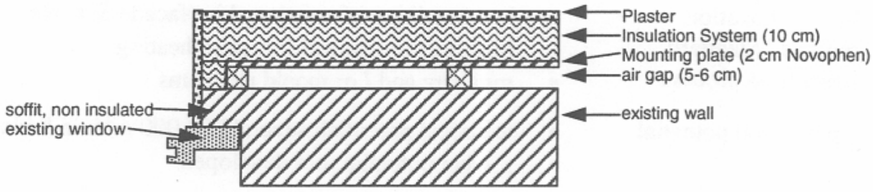


Figure 2: Horizontal section of a suitable double envelope construction.

Specific energy savings/energy gain

Energy savings for a well designed system (air gap 5-6 cm, insulation 10 cm, double envelope facade / collector area ratio = 5 / 1): approximately 100 kWh/(m^2.a) (area of absorber) in the Swiss midland

Innovative aspects for renovation

- Evaluation of concept for renovation of a typical Swiss apartment building from the 1960s to 1970s
- Evaluation for other climatic situations
- Optimisation of system parameters

Critical aspects

- Air tightness of the second skin
- Connection of ducts to facade cavity
- Hydraulic system: pressure profile
- Electricity consumption of fan

References	IEA SHCP Task 19: Solar air systems - Product catalogue S.R. Hastings, Solar air systems - Built examples; James & James (Science Publishers), 1999

Development

Development status	• air collectors and double envelope: Qualified concept and system model • summer operating mode with DHW production: proven concept
Involved Systems / Components	• double-skin facade / double envelope construction • air collector • dampers, fans • heat exchanger for DHW system
Type of companies involved	• architect • energy engineer • facade construction company • air collector manufacturer • HVAC engineer
Required technical improvements / development focus	• Detail solutions for hydraulic system, i.e. design of ducts, facade cavities, etc. • Design guidelines
Contact	Dr. K. Fort, Weiherweg 19,8604 Volketswil , phone +41 1 / 946 08 04, e-mail: k_fort@compuserve.com

Market

Building type	• small to medium sized multifamily houses • possible also for small office buildings • best suited for larger facade areas with few or no openings
Main renovation reasons / Standard renovation process	• bad condition of existing skin (facade & roof) • high energy demand for space heating • moisture and / or mould problems
Application potential	• technical potential: several 100 000 m^2/a in Switzerland • market potential: not developed
Cost target	Cost evaluation of the system is pending at the time of reporting
Additional benefits	• thermal comfort (higher wall temperature, no moisture) • preheating of DHW
Contractor / builder / additionally required expert	Not evaluated in project.
Application examples	• Hybrid solar house, Copenhagen • Solar House, Jarnbrott, Goteborg

Modelling

Model description	• Two stories • Flat roof • S-Facade: Width: 5 m, 12 m^2 windows (frame: 20%) • N-Facade: 5 m^2 windows • E-Facade: Width: 10 m, no windows • W-Facade: Climatic indoor conditions (adiabatic)

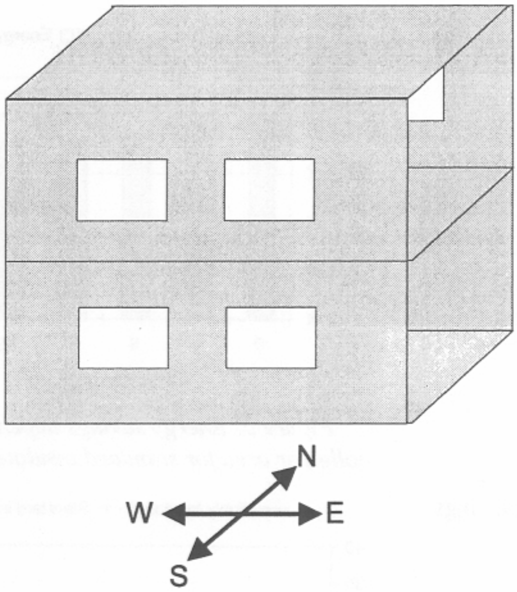


Figure 3: Shoebox model.

Insulation level of building:

U-value [W/m²K]	Highly insulated	Standard insulated
Roof	0.13	0.35
Wall with double skin facade	0.18	0.47
Other Wall	0.17	0.45
Window	1.60	1.60
Floor	0.19	0.44

Parameters
- ratio of air collector area to double envelope area
- orientation and tilt of air collector

Evaluation Criteria
- energy gains in function of the parameters
- hydraulic system
- performance

Evaluation Tool(s)
TrnsAir (IEA SHC Programme Task 19): Dynamic simulation tool for solar air systems based on TRNSYS

Evaluation Results

Energy savings

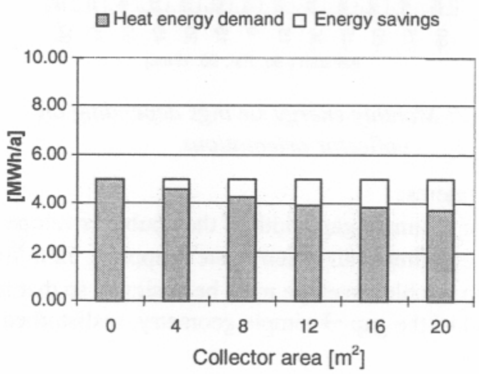


Figure 4: Energy savings depending on collector areas for highly insulated building.

Parameters:
- highly insulated massive building
- 60 m² double envelope
- collector orientation: South
- collector tilt: 45°

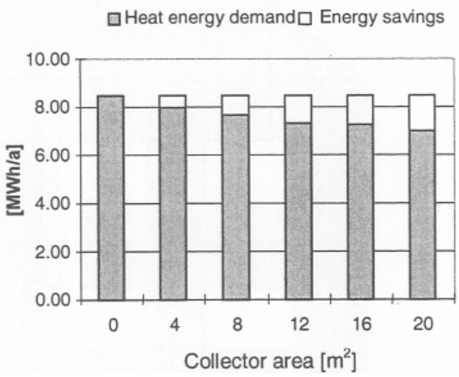


Figure 5: Energy savings depending on collector area for standard insulated building.

Parameters:

- standard insulated massive building
- 60 m² double envelope
- collector orientation: South
- collector tilt: 45°

Relative energy savings

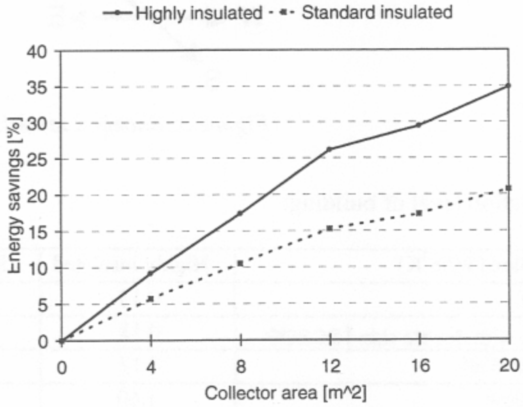


Figure 6: Relative energy savings depending on collector area for highly and standard insulated building.

Parameters:

- massive building
- 60 m² double envelope
- different insulation levels
- collector orientation: South
- collector tilt: 45°

The optimum collector / facade area ratio is around 1/5. The relative savings are higher for highly insulated buildings.

Monthly energy savings

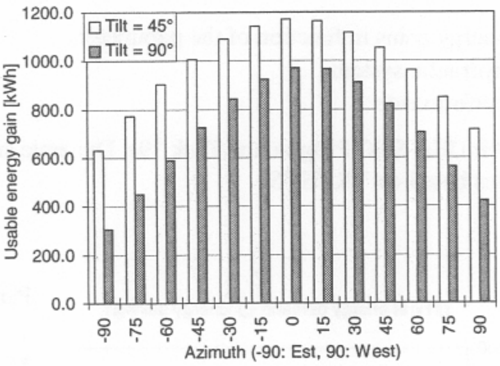


Figure 7: Monthly energy savings depending on collector orientations.

Parameters:

- massive building
- with 60 m² double envelope
- highly insulated
- collector area: 12 m²
- collector orientation: South
- collector tilt: 45°

Hydraulic System

Requirements:

- The optimum gap width of the double envelope is 5-6 cm.
- The optimum air volume rate is approx. 50 m^3/h per m² collector area.
- The double envelope must be designed so that the air is circulating in every part of the gap -3 simple geometry, undisturbed facade area.

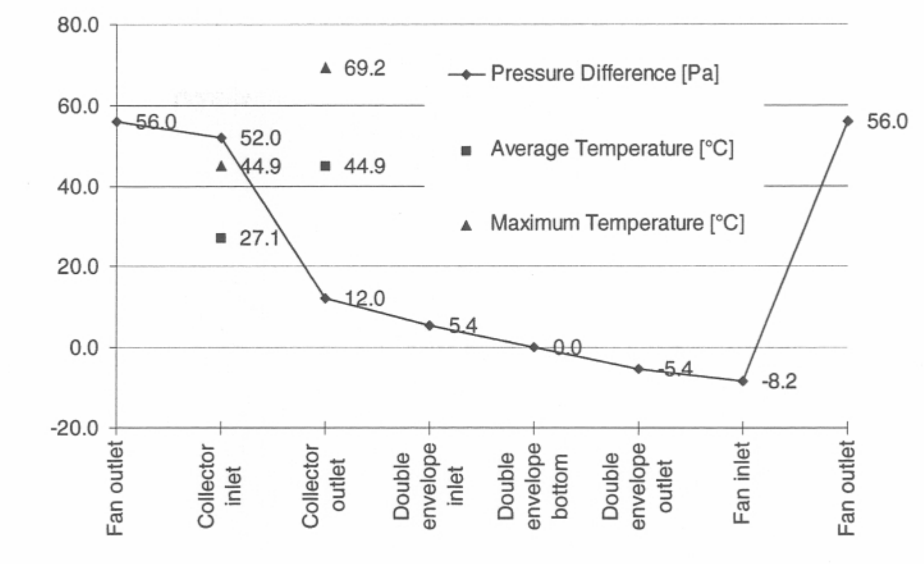


Figure 8: Pressure profile in Pa and average temperatures in °C of a typical system while fan is feeding the collector.

The bottom of the double envelope must be at atmospheric pressure to allow for drainage openings for condensed moisture. The pressure drop in the facade cavity must be minimal to avoid leakage.

Coefficient of performance / electricity consumption of fan

Heat energy saving per electrical energy demand for fan: factor of 15 to 25 (calculated value)

Conclusions

- The optimum collector / facade area ratio is around 1/5. The relative savings are higher for highly insulated buildings.
- The realisation requires relatively high planning efforts. Each project will have unique issues that must be studied individually. To reduce planning cost, the specific designs should be suitable to many similar buildings.
- Further guidelines for typical applications would be helpful.
- There are no specific standard products available for the double skin facade or the double envelope.

9.12 Roof windows with light ducts (US)

Specification

Concept description

Daylighting systems with advanced roof windows and automated lighting controls can decrease a building's energy consumption and increase occupant comfort. The Visitor's Centre at the National Renewable Energy Laboratory in Golden, Colorado, U.S.A., will incorporate this concept in its proposed renovation. Constructed in 1993, the Visitor's Centre is a single story building consisting of display space, conference room, and offices. Its electric lighting was modified in 1996 by replacing incandescent downlights with compact fluorescent downlights and T12 fluorescent lamps with T8 lamps and electronic ballasts. The areas to be renovated include the private offices and the main gallery corridor.

The proposed daylighting modifications will incorporate:

- Solar tracking roof windows with appropriate glazing that are properly sized and oriented to optimise the admittance of daylight relative to heat gains and losses from the windows.
- Automatic controls to operate the electric lighting systems when daylighting is insufficient to meet building lighting needs.
- Daylight distribution systems to help collect, transport, and distribute the light for maximum benefit.

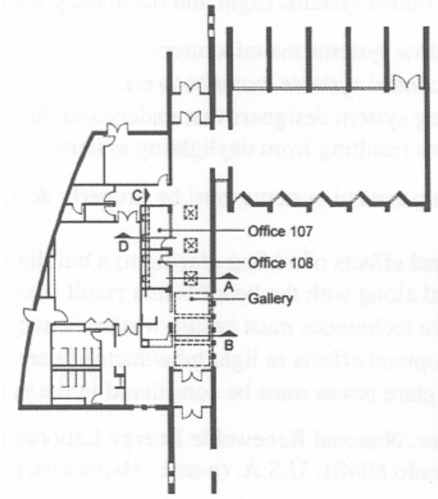


Figure 1: Floor Plan

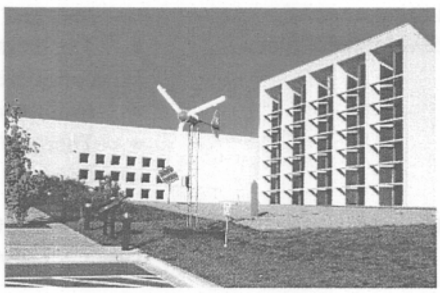


Figure 2: Visitor's Centre Entry

Specific energy savings/energy gain

Computer simulations show:

- Overall building energy savings would be 2 300 kWh while annual energy cost savings would be $(US)150.
- Office and Galley electrical energy savings would be 2 900 kWh.

Innovative aspects of renovation

Sun tracking reflectors mounted above the skylights increase early morning and late afternoon daylighting contribution.

- Sun tracking reflectors control glare problems by preventing direct beam radiation in the space.
- Interior reflectors spread and soften the daylight for increased comfort and illumination uniformity.
- Annual lighting energy savings more than compensates for increased winter heat losses and summer gains caused by the roof windows.
- Increases occupant comfort and satisfaction by providing natural lighting and an improved visual connection with the outdoors.

	• If sufficient glazing area exists, use of available daylighting can have a significant effect in a building retrofit situation without affecting the building envelope.
Critical aspects	• Must incorporate properly designed daylighting control system to achieve energy savings. • May require new roof penetrations for additional glazing area. • May adversely affect the building's heating and cooling loads if daylighting system is improperly designed.
References	• IEA SHCP Task 21 Daylighting in Buildings reports • Light Revealing Architecture, Marietta S. Millet • Concepts and Practice of Architectural Daylighting, Fuller Moore • Sunlighting as Formgiver for Architecture, William M. C. Lam

Development

Development status	• Skylights and controls commercially available. • System performance/limited characterisation. • R&D underway to develop integrated solutions/better performance (glazings).
Involved systems/ components	• Building roof window systems (glazings/louvers/trackers). • Light distribution systems (tube/duct/diffuser). • Lighting control systems (light and occupancy sensors).
Type of companies involved in development	• Roof window systems manufacturers. • Lighting control systems manufacturers. • Daylighting system designers that understand the lighting/thermal load interactions resulting from daylighting systems.
Required technical improvements/ development focus	• Daylighting control systems must be properly designed to ensure energy savings. • The thermal effects of adding glazing to a building envelope must be considered along with the benefits that result from daylighting. • Installation techniques must ensure window's integrity against weather. • Thermal/optical effects in light tube/duct/diffuser. • Potential glare issues must be considered in the system design.
Contact	Sheila J. Hayter, National Renewable Energy Laboratory, 1617 Cole Blvd., Golden, Colorado 80401, U.S.A. (e-mail: HayterS@tcplink.nrel.gov)

Market

Building type	Applicable to all building types. Energy savings potential more significant in daytime occupied commercial or industrial buildings where the daytime lighting loads are high and perimeter and/or roof exposure is significant. Solar access and local climate conditions must also be considered.
Main renovation reasons / standard renovation process	• Decrease energy use by building lighting systems. • Increase occupant visual comfort. • Standard renovation (re-roofing) or energy-efficient lighting upgrade typically does not consider integrating daylighting.
Application potential	High. Most commercial buildings contain interior spaces that do not have access to exterior glazing. Installing skylights is a relatively simple retrofit compared to other methods for increasing the building's glazing area. Baffled skylights maximise the amount of diffuse light allowed to enter the building to avoid glare issues. Electric lighting controlled to complement the available daylight decreases overall building lighting loads and lowers building energy and operating costs.

Cost targets

Not evaluated in general

Additional benefits

Improves occupant visual comfort, which, in commercial and industrial buildings, often increases productivity. Productivity benefits, while difficult to verify, will often far exceed the financial benefits of energy savings.

Contractor/builder / additionally required experts

The building designer can evaluate the energy savings potential and supervise the installation of daylighting systems. A window manufacturer often oversees the installation of new/replacement roof windows. The control system manufacturer may oversee the installation of new daylighting controls.

Application examples

- Schools in North Carolina
- Solar Energy Research Facility (SERF) – National Renewable Energy Laboratory (Golden, Colorado, U.S.A.)
- Thermal Test Facility (TTF) – National Renewable Energy Laboratory (Golden, Colorado, U.S.A.)

Modelling

Model description

This study focused on the daylighting renovation potential of the Visitor Centre gallery corridor and private offices (figure 1).

The proposed daylighting design for the gallery requires three 1.2 m by 1.2 m tracking mirrored skylights in splayed lightwells (figure 3) between the bank of windows at the southern end of the corridor and the gypsum wallboard soffit at the northern end of the space. This configuration allows uniform spacing of the skylights while avoiding conflicts with structural beams, fire sprinklers, and roof drains, which cannot be economically relocated for this project. Light reflecting baffles located within the lightwells will diffuse the light and prevent direct beam penetration into the gallery to prevent glare problems. A study of available energy-efficient skylights led to the selection of the So-Luminaire Daylighting System. This system includes a bank of four exterior mirrors mounted on a sun-tracking framework below the acrylic dome.

A light shelf (figure 4) with an indirect fluorescent lighting strip will be placed on the eastern gallery wall along the window bank at approximately 2.4 m above the finished floor. Daylight reflected off the light shelf onto the curved fabric reflector will emphasise the reception area at the Visitor Centre entry. The fluorescent lighting strip will provide similar indirect lighting at night.

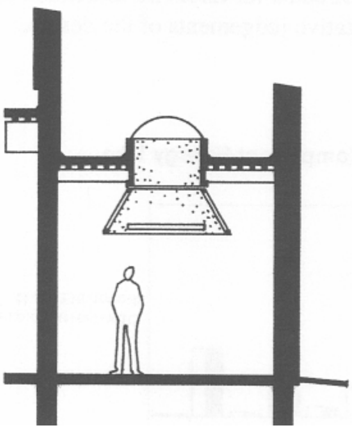


Figure 3: Gallery Skylight

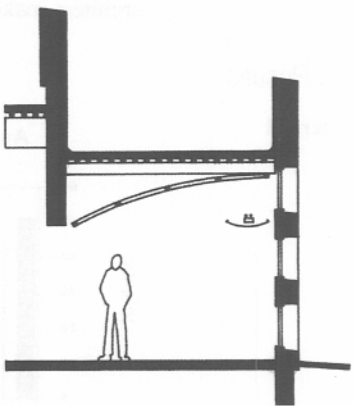


Figure 4: Gallery Reflector

The existing private offices need electric lighting while occupied because they have no access to daylight. A wall wash skylighting design will avoid major obstructions in the ceiling cavity to provide access to daylight while eliminating glare problems on the work. The west wall will be extended to the structural ceiling (figure 5) where two sun tracking 0.6 m by 0.6 m skylights will be installed.

Splayed reflectors will be used to diffuse and soften the light (Figure 6). This design will provide a pleasing wash of daylight across the major surfaces in the office.

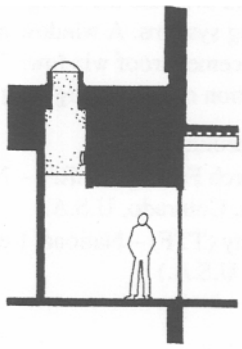


Figure 5. Office Section (West)

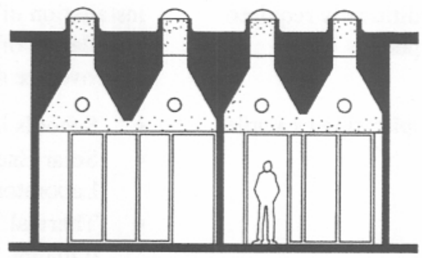


Figure 6. Office Section (North).

Simulations predict that only task lighting at workstations will be necessary during most daylight hours. Two compact fluorescent fixtures are proposed for each lightwell space below the skylights for use during evening and night hours. Two 1.2 m, single T8 fluorescent downlights are proposed for the drop ceiling near the east wall.

Parameters

- Daylight availability based on local climate and site conditions.
- Retrofit compatibility with existing construction and functions.
- Integration potential of daylight and electric lighting.

Evaluation criteria

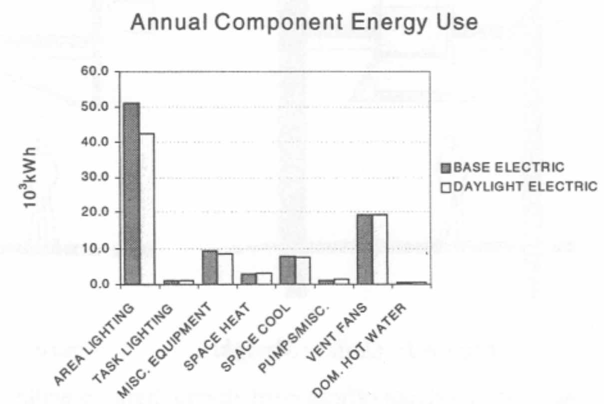
- Achieve annual energy savings at an acceptable renovation cost.
- Maintain adequate daylight and electric illumination levels.
- Improve user comfort and satisfaction.

Evaluation tool(s)

Computer lighting analysis, including horizontal illumination levels and grey- scab renderings, was conducted with Lumen Micro version 7.5 from Lighting Technologies. Energy analysis was modelled through DOE2 simulations using VisualDOE version 2.6 software from Eley Associates. A physical model at 4.2 = 1 m scale was constructed for direct measurement of illumination and to help the architect make qualitative judgements of the design.

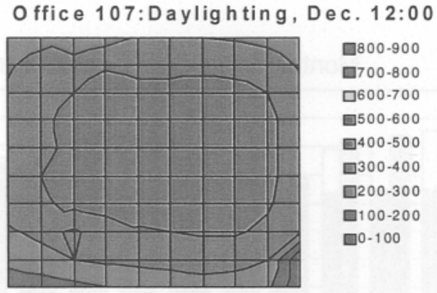
Evaluation Results

Results criteria 1

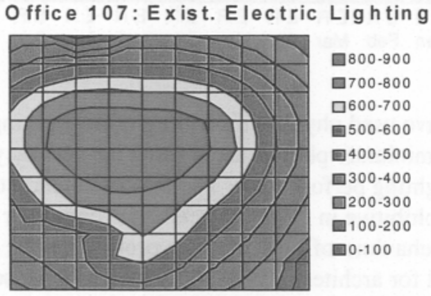


The VisualDOE analysis predicted the energy savings potential of a properly design daylighting retrofit. In this case, a slight increase in the heating and cooling loads was more than offset by electrical energy savings.

Results criteria 2

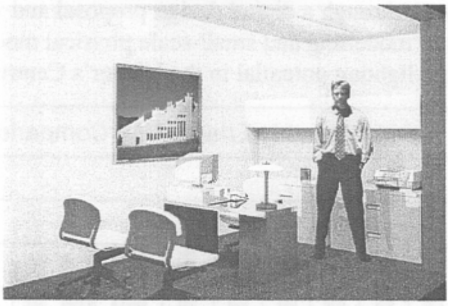


Physical model studies and computer simulations predicted adequate illumination levels in the gallery and offices. Under low daylight levels, supplemental electric illumination will be required.

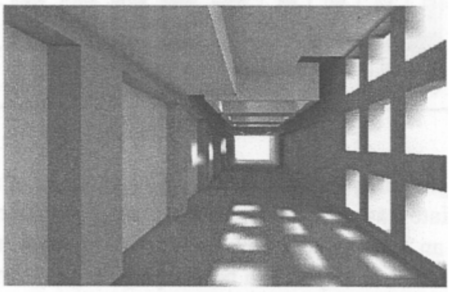


The graphs of the lux levels in the office predict uniform illumination with daylighting in December versus excessive illumination with the existing electric lighting.

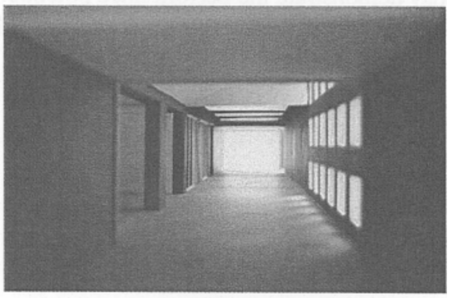
Results criteria 3



Lightscape visualisation studies allow designers to visually assess illumination from daylight and electric light. The image on the left shows the illumination in Office 107 with the proposed daylight and supplemental lighting for December 21 at noon.



The Lumen Micro program produces grey-scale renderings and luminance readings at any point in the image. This image shows the gallery daylighting at 10:00 on a clear December day.

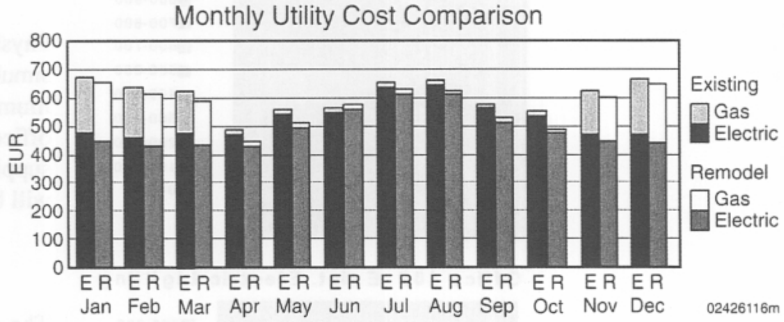


A physical model of the same space produces accurate illumination and a visual realism with sufficient detail. All three tools can help designers make appropriate decisions.

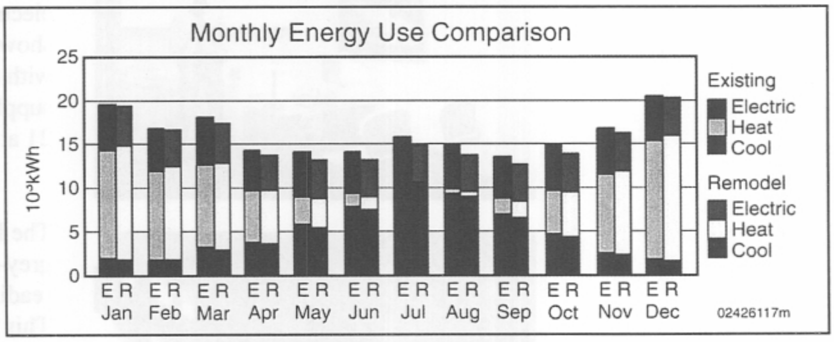
Conclusions

Implementing a daylight retrofit must be done with a careful analysis of the

Energy impact on the entire structure. Increasing the daylight in the Visitor's Centre and installing occupancy and light sensors will decrease building lighting loads. An annual energy analysis demonstrates the trade-offs between heat loss/gain and the electric lighting savings, similar to that shown for the Visitor's Centre.



Architects have used physical modelling of daylighting for centuries. Recent studies with miniature photosensors show the accuracy of physical modelling in predicting lighting performance. The cost of constructing detailed, large-scale models is prohibitive in most projects. New computer software that accurately models the behaviour of light in space promises to be a more accessible, cost-effective tool for architects. With tools such as Lightscape, designers and their clients can walk through a digital design proposal and visually assess the design. Both computer modelling and small-scale physical models were developed to analyse the daylighting potential in the Visitor's Centre project.



The most significant impediments to daylight retrofits are often the construction and system integration and cost issues. It may be difficult to place appropriate openings in an existing structure and to change the control system of the HVAC plant to work effectively with a new daylighting scheme. While an energy simulation may demonstrate the performance potential of a daylight remodel, a life-cycle cost analysis will show whether such an approach is economically justified.

9.13 Improved daylight for multi-storey housing (DK)

Specification

Concept description

The objective of the present concept is to increase the comfort through the use of direct sunlight reflected deep into the core of buildings. The utilisation of sunlight is a comfort issue and mainly based on the desire of having the quality of sunlight in the rooms rather than directly saving energy.

Sunlight is characterised having almost perfect parallel beams, giving the possibility to redirect the sunlight with plane surfaces having only marginally losses even over large distances. Typical systems consist of one or more moving minors following the Sun reflecting the sunlight towards one or more fixed minors pointing to the rooms or spaces where the sunlight is needed.

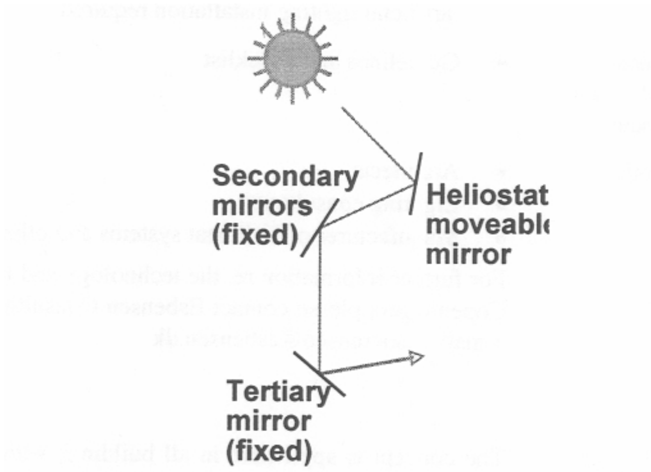


Figure 1: Light guiding principle with Heliostat mirror.

One pilot project is currently being carried out in the centre of Copenhagen (Project Prisme, Hedebygade 5-7) and the concept has proven being of interest to building owners having very deep multi-family housing blocks. In these the core of the building is often very difficult to utilise and giving attractive appearance due to the lack of daylight and sunlight at all times.

Specific energy savings/energy gain

Energy saving is of secondary relevance and part of the positive outcome of the concept. The amount is very dependent on the application and the solution. The amount of sunlight available is proportional to the area of the heliostat and for each subsequent reflection in minors approximately 2% of the sunlight will be lost.

Innovative aspects for renovation

The utilisation of heliostats for apartment buildings.

Critical aspects

- Unobstructed pathway of the direct sunlight
- User acceptance
- Project specific optical components

References

Transmitting Light to Dark Rooms, WREC 1996, R. Whhidi, G. Talehani, A. Afgami Rohani

Further general references: 5th OTTI seminar on innovative light technology, January 28./29.1.1999

See also the web-site of the manufacturer which includes examples: http://www.bomin.com/lighting.htm

Development

Development status	• The components for the moving mirror are already industrialised components up to a size of square size of 2.5 x 2.5m. • Additional secondary and tertiary mirrors are unique for most projects, since they have to be directly sized according to specific building geometry. Mirrors of glass can be bought in any size and bearings can be made. For smaller mirrors with weight less than 5kg, the bearings with 360° orientation can be found as standard tripod components from professional photography.
Involved Systems / Components	• Heliostats including electronic control system programmed for the location • Other mirrors designed from various materials such as polished anodised Aluminium or toughened glass mirrors. • Back up lighting required either via the reflecting system or as traditional artificial lighting installation required.
Required technical improvements / development focus	• Guidelines and checklist.
Type of companies involved in development	• Architects • Lighting consultants • Manufacturer of Heliostat systems and other optical systems and parts.
Contact	For further information re. the technology and the specific demonstration project in Copenhagen, please contact Esbensen Consulting Engineers, Mr. Henrik Sorensen: e-mail: h.soerensen@esbensen.dk

Market

Building type	The concept is applicable in all buildings with large distances from the facade to the core of the building, having roofs being exposed by sunlight and providing a vertical route for the light. Especially multi-family housing from the 1960ies period could benefit from this concept.
Main renovation reasons / Standard renovation process	The concept is to be regarded as a supplementary technology providing increased comfort of living in multi-family housing blocks. In the case of renovation establishing new vertical routes for heating, water etc. the extra effort establishing a vertical route for sunlight will be marginal compared to other building costs for establishing technical shafts etc.
Application potential	The application potential is mainly within, renovation of high-rise multifamily buildings with depths of 6 meters or more from the facade to the centre of the building - typically found in the high-density urban areas. Since the heliostat can be located away from the vertical paths, most buildings can be provided with direct sunlight to a secondary mirror.
Cost target	The cost target will vary from country to country and building to building, since the dominant factor is the potential increase in value of the building, when using the system to improve indoor comfort. In the evaluation of a specific project, this potential increase in property value should be carefully compared to the investment in mirror systems, heliostat and controls. A realistic target would be to balance this within the expected lifetime of the heliostat of 20-25 years.
Additional benefits	The direct sunlight will often give a subjective impression of light and friendly areas and potentially reducing the unfriendly and cold climate, especially in multi-family housing blocks of the 1960ies.
Contractor/builder / additionally required experts	• Manufacturer of optical components for advice to the contractor, both during planning, commissioning and fine-tuning of controls. • Service contracts with manufacturer are typical.

Application examples

So far the pilot project in Copenhagen is the only example of direct use of the proposed system in dwellings. Other building types (warehouses and shopping malls) have been equipped with similar systems for utilisation of sunlight:
Solar light pipe, CADDET IEA/OECD Demo 16, CA 90.011/3B.FO2, Telephone: +31 46 595 224/Telefax: +31 46 528 260
Solar Duct for Lighting and Ventilation Santa Amalia Building, Barcelona, Spain, WREC 1996, 0. De-Urrutia Dr. Architect, Pasaje Mulet 2, Bajos, 08006 Barcelona, Spain

Modelling

Model description

Due to the fact that daylighting experiments are scaleable, the proposed system was modelled in a physical model and evaluated with direct sunlight.
The model was designed so that the critical routes of the sunlight could be judged and measurements could be carried out. All surfaces and transparent parts were designed with the same reflectance and appearance as it was intended in full scale.
In the present model the sunlight was directed towards the bathroom and the kitchen, but all other rooms next the vertical shaft could in principal benefit from the direct sunlight.

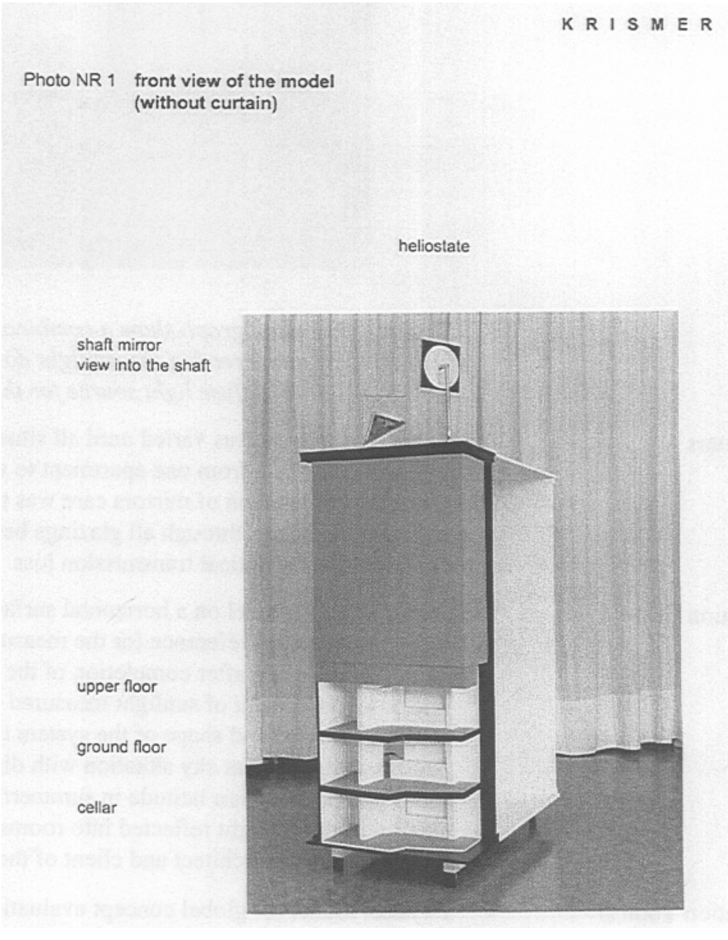


Figure 2: Picture of the model for the evaluation of the light conditions.

The model was designed so that the lighting conditions could be documented both with photographs and measurements. Three different possibilities for design of shaft and tertiary mirrors were tried out in the same model.

KRISMER

Photo NR. 7 **ground floor with glassing walls adjoining the shaft**

$E_{h\,bath} = 530$ lx (horizontal illuminance in the bathroom)
$E_{h\,kit} = 500$ lx (horizontal illuminance in the kitchen)

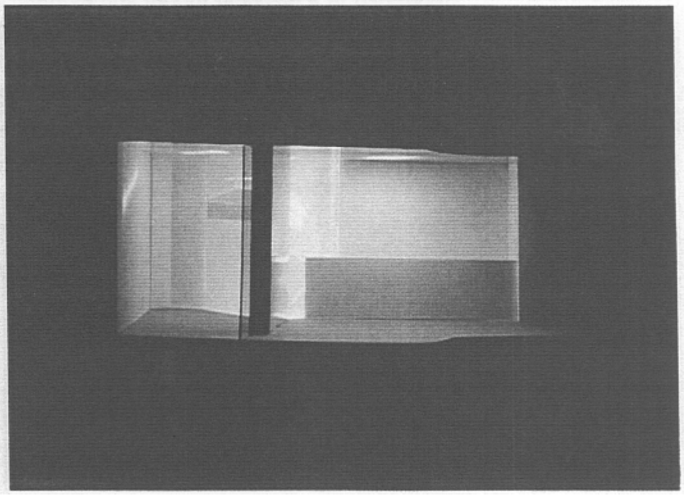


Figure 3: The photograph show a combination of a translucent wall in the bathroom (left) and directing the sunlight down the walls of the shaft to give a diffuse light source for the apartments.

Parameters

The location of mirrors was varied until all situations of direct glare and possibilities for looking from one apartment to another was completely avoided. When varying the location of mirrors care was taken to aim for having perpendicular sunbeams through all glazings between the shaft and bathrooms in order to minimise the optical transmission loss.

Evaluation Criteria

The primary lighting level on a horizontal surface 80 cm above the floor in the bathing room is used as reference for the measurements in the scale model and will be repeated in full scale after completion of the renovation.

1. The absolute amount of sunlight measured in lux on horizontal surfaces. In the layout of the size and shape of the system the desired illumination level is min. 200 lux during a clear sky situation with direct sunlight level between 9 a.m. and 3 p.m. at the given latitude in summertime.
2. Quality of the sunlight reflected into rooms: flickering, glare and the subjective judgement by the architect and client of the quality of the system.

Evaluation Tool(s)

- Physical model for global concept evaluation and illumination levels
- RADIANCE for parametric variations of the transparent parts, shaft interior etc.

Evaluation Results

Results Criteria 1

Illumination was measured with different layout of mirrors in the shaft. In all situations values above the desired 200 lux where achieved in the models. Because the glazing between the vertical shaft and the bathrooms and kitchens have to be of high fire-resistance, the area of the transparent and translucent parts had for economical reasons to be limited. The solution chosen was therefore a combination of the solutions shown below. Between the bathroom and the shaft translucent glass-bricks and 0.5 m^2 clear double-glazing was installed. The glass-bricks give a pleasant diffuse light and a direct spot of sunlight is directed towards the ceiling in the bathroom. In the kitchen clear glass was integrated above the main working place, providing a spot of sunlight.

Results Criteria 2

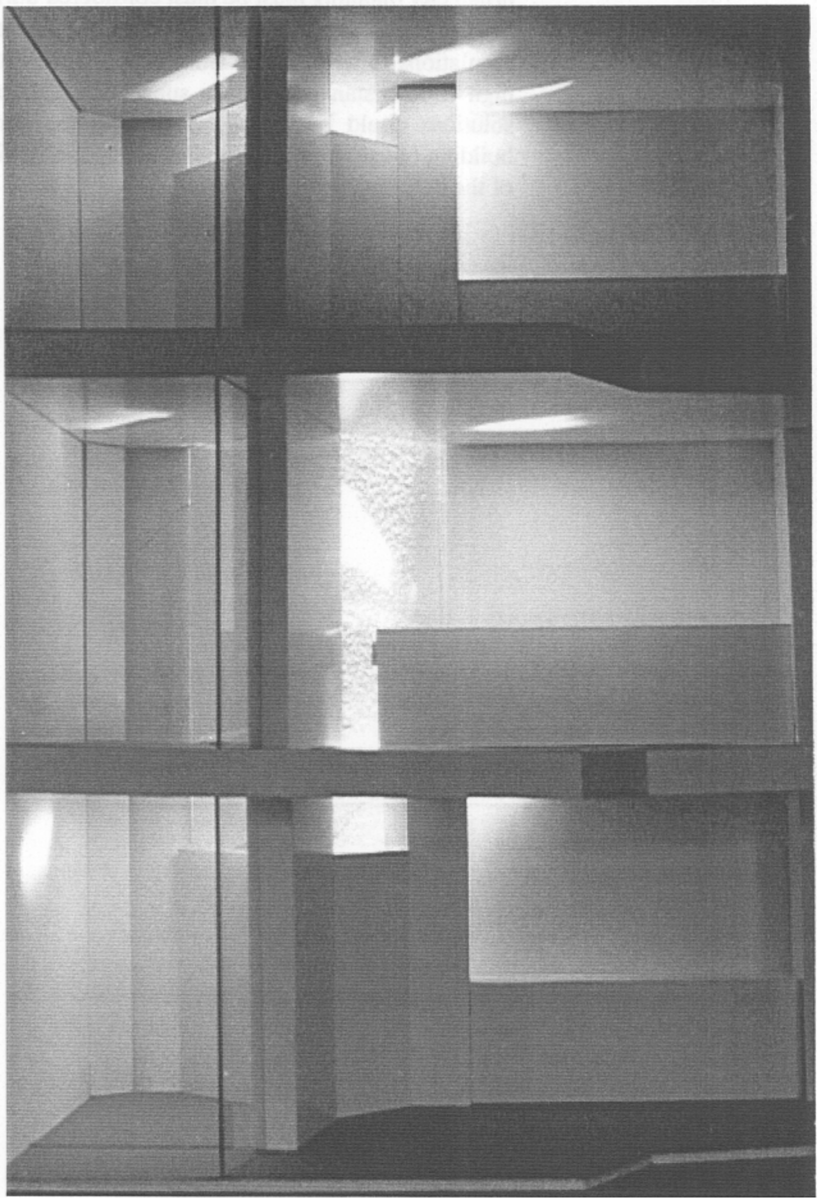


Figure 4: Picture from scale model showing the different options that were combined to the final solution. In the upper situation the sunlight is reflected to the ceiling of the bathroom and the ceiling of the kitchen (the picture is taken from a relatively low viewpoint. In the middle situation the openings to the shaft from the bathroom and kitchen are larger and the mirrors are adjusted so that the sunlight expose the texture of the back wall of the shaft. In the bottom situation the sunlight in the bathroom is directed more horizontally towards the back wall and the kitchen is receiving a relatively smaller part than in the top situation.

Conclusions

- The good visual performance and illumination values of approx. 400 lux in clear sky conditions in the model experiments indicate that the system will perform as predicted and expected during the concept development phase.
- The levels of sunlight achieved in the scale models show that the system within the building blocks can be quite compact, e.g. a shaft of 1.5 x 1.5 could be sufficient for providing sunlight to 2 rooms in 8 apartments.
- Since the costs are rather high, in the present project around € 55 000 for the heliostat and mirrors incl. mounting and approx. E 25 000 for the shaft with fire resistant glazing, the systems must only be considered for buildings where the improvement of lighting conditions can afford this investment.
- Local regulations, for example maximum building heights and other issues in urban city planning must be must considered during the planning phase.
- During the design process it is very important to be aware of the fire design regulations to be followed since both translucent and transparent glazing with high fire-resistance can be a substantial cost of the whole system. Cheaper solutions could be established having the vertical of sunlight outside the building (no shaft needed) and directing the sunlight horizontally into the depth of the building.

Annex

A.1 Task 20: Solar Energy in Building Renovation

In Subtask A, **Evaluation of Existing Building Applications,** the participants described and evaluated 15 existing solar renovation projects in six countries. The majority of these projects involved the multifamily building applications. Experiences concerning the different aspects of renovation, such as the various solar features employed, the renovation process itself, and occupant reactions were summarised in a working document, that was completed in October 1994.

In Subtask B, **Development of Improved/Advanced Renovation Concepts,** the participants developed an overview of many solar renovation possibilities, including strategies for heating, cooling and daylighting with different elements and for different types of buildings. The most interesting concepts were further analysed and computer simulations were completed for many systems. The market conditions for the different concepts were also investigated. A technical report was printed in January 1997.

In Subtask C, **Design of Solar Renovation Projects,** a common framework for reporting and evaluating design of solar renovation projects was developed and 16 projects from seven countries were reported. Experts examined the design process and the system concepts. The technical report was ready in July 1998.

Subtask D, **Documentation and Dissemination,** activities were devoted to synthesising and documenting information obtained from the other Subtasks. Four brochures were produced for different audiences. One overview brochure to catch the interest of solar renovation and three more technical brochures on different concepts: *Solar Collectors in Building Renovation, Glazed Balconies in Building Renovation* and *Transparent Insulation in Building Renovation.* The Experts also actively reported on solar energy in building renovation and the Task 20 work at international and national conferences, symposia and workshops.

In Subtask E, **Evaluation of Demonstration Projects,** an evaluation of the monitoring of seven of the demonstration projects from Subtask C was completed. Additional seven new projects were also included in this evaluation. Comparisons of the results from the projects were made for the different solar renovation technologies both according to energy performance and costs. Other aspects such as reasons for renovation, added value, lessons-learned, conclusions and recommendations were included in the analysis. The results will be published in a brochure, *Solar Renovation Demonstration Projects – Results and Experience,* in the same series as the brochures from Subtask D.

In Subtask F, **Improvement of Solar Renovation Concepts and Systems,** new and innovative solar renovation concepts are developed. Thirteen concepts are described, modelled, and the performance simulated. The report includes summaries and comparisons from all concepts together with summary, results conclusions and recommendations. All the concepts are described in detail.

Subtask G, **Dissemination of Results,** will organise the publishing of the Subtask E brochure. A slide set on CD-ROM will also be available. This CD-ROM represents a variety of the projects and concepts studied in Task 20. The national and international dissemination will be reported in a Dissemination Management Report within this Subtask.

A.2 Task 20 Participants

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A.3 IEA Solar Heating and Cooling Programme

The International Energy Agency (IEA) was established in 1974 as an autonomous agency within the framework of the Economic Cooperation and Development (OECD) to carry out a comprehensive program of energy cooperation among its 24 member countries and the Commission of the European Communities.

An important part of the Agency's program involves collaboration in the research, development and demonstration of new energy technologies to reduce excessive reliance on imported oil, increase long-term energy security and reduce greenhouse gas emissions. The lEA's R&D activities are headed by the Committee on Energy Research and Technology (CERT) and supported by a small Secretariat staff, headquartered in Paris. In addition, three Working Parties are charged with monitoring the various collaborative energy agreements, identifying new areas for cooperation and advising the CERT on policy matters.

Collaborative programs in the various energy technology areas are conducted under Implementing Agreements, which are signed by contracting parties (government agencies or entities designated by them). There are currently 40 Implementing Agreements covering fossil fuel technologies, renewable energy technologies, efficient energy end-use technologies, nuclear fusion science and technology, and energy technology information centers.

The Solar Heating and Cooling Programme was one of the first lEA Implementing Agreements to be established. Since 1977, its 20 members have been collaborating to advance active solar, passive solar and photovoltaic technologies and their application in buildings.

Australia	Finland	Norway
Austria	France	Spain
Belgium	Italy	Sweden
Canada	Japan	Switzerland
Denmark	Mexico	United Kingdom
European Commission	Netherlands	United States
Germany	New Zealand	

A total of 26 Tasks have been initiated, 19 of which have been completed. Each Task is managed by an Operating Agent from one of the participating countries. Overall control of the program rests with an Executive Committee comprised of one representative from each contracting party to the Implementing Agreement. In addition, a number of special ad hoc activities--working groups, conferences and workshops--have been organized.

The Tasks of the IEA Solar Heating and Cooling Programme, both completed and current, are as follows:

Completed Tasks:

Task 1	*Investigation ofthe Performance ofSolar Heating and Cooling Systems*
Task 2	*Coordination ofSolar Heating and Cooling R&D*
Task 3	*Performance Testing ofSolar Collectors*
Task 4	*Development ofan Insolation Handbook and Instrument Package*
Task 5	*Use ofExisting Meteorological Information for Solar Energy Application*
Task 6	*Performance ofSolar Systems Using Evacuated Collectors*
Task 7	*Central Solar Heating Plants with Seasonal Storage*
Task 8	*Passive and Hybrid Solar Low Energy Buildings*
Task 9	*Solar Radiation and Pyranometry Studies*
Task 10	*Solar Materials R&D*
Task 11	*Passive and Hybrid Solar Commercial Buildings*
Task 12	*Building Energy Analysis and Design Tools for Solar Applications*
Task 13	*Advance Solar Low Energy Buildings*
Task 14	*Advance Active Solar Energy Systems*
Task 16	*Photovoltaics in Buildings*
Task 17	*Measuring and Modeling Spectral Radiation*
Task 18	*Advanced Glazing and Associated Materials for Solar and Building Applications*
Task 19	*Solar Air Systems*
Task 20	*Solar Energy in Building Renovation*

Current Tasks and Working Groups:

Task 21	*Daylight in Buildings*
Task 22	*Building Energy Analysis Tools*
Task 23	*Optimization ofSolar Energy Use in Large Buildings*
Task 24	*Solar Procurement*
Task 25	*Solar Assisted Air Conditioning ofBuildings*
Task 26	*Solar Combisystems*
Working Group	*Materials in Solar Thermal Collectors*
Working Group	*Evaluation ofTask 13 Houses*

To receive a publications catalogue or learn more about the IBA Solar Heating and Cooling Programme visit our Internet site at **http://www.iea-shc.org** or contact the SHC Executive Secretary, Pamela Murphy Kunz, Morse Associates Inc., 1808 Corcoran Street, NW, Washington, DC 20009, USA, Telephone: +1/202/483-2393, Fax: +1/202/265-2248, E-mail: pmurphykunz@compuserve.com.