FAÇADE INTEGRATION OF POLYMERIC SOLAR COLLECTORS

M. Meir, Ø. Mathisen, A. Olivares, J. Rekstad, J.A. Schakenda
University of Oslo, Department of Physics, P.O. Box 1048, Blindern, N-0316 Oslo, Norway
Tel.: +47 228-56469, Fax: +47 228-56422, E-Mail: mmeir@fys.uio.no

F. Fiedler
Solar Energy Research Centre SERC, Dept. of Mathematics, Natural Sciences and Technology,
Dalarna University College, S-7188 Borlänge, Sweden

S. Kahlen
Polymer Competence Centre Leoben, Parkstrasse 11, A-8700 Leoben, Austria

Abstract – The present paper examines building integrated solar collectors with absorbers of polymeric materials. Efficiency measurements of façade-integrated collectors with non-selective black and spectrally selective coloured absorbers are carried out. The performance of the polymeric absorber was compared with solar glass and polycarbonate twin-wall sheets as collector cover. Simulations demonstrate a high solar fraction for a solar combisystem with façade collectors for a well-insulated house in a Nordic climate. Two examples of house concepts with façade collectors are presented which address a new type of customer than the solar enthusiasts with special interest in renewable energy.

1. INTRODUCTION

In the last decade, combined solar systems for domestic hot water preparation (DHW) and space heating (solar combisystems) experienced a considerable market growth in the middle and in northern Europe (Weiß, 2003). Requiring larger collector areas, building-integrated collector installations become a natural choice for solar combisystems.

Traditionally, solar collectors have been mounted on roofs. Due to the low declination of the sun during the heating season from the middle of September to the middle of March, the integration into the façade represents an obvious alternative to roof integration at high latitudes. The façade integration opens new opportunities for decision makers, building planners and architects by introducing coloured absorbers. Façade collectors can be seen as multi-functional building modules, providing energy, new possibilities of façade design and surface protection for the building. Within the EU-project Colourface, spectrally selective paints were developed for metal absorbers and demonstrated in pilot projects (Müller et al., 2004).

The changed building physics for collector façades has been studied by Bergmann et al. (2002) for installations in Austria and recommendations for planners and installers have been worked out (Müller et al., n.d.). Colours on metal absorbers for installations on flat or inclined roofs in Mediterranean climate were studied with regard to performance and aesthetics (Tripanagnostopoulos, 2000).

The present work studies the façade integration of polymeric collectors for a Nordic climate. Different collector covers and different paints on the polymeric absorber were investigated. The collector is part of a drain-back system with water as heat carrier. The study is carried out within the project Competitive Solar Heating Systems for Residential Buildings (REBUS), financed by Nordic Energy Research (www.nordicenergy.net). REBUS is collaboration between research institutes and industries in Denmark, Norway, Sweden and Latvia on research, development and demonstration of solar combisystems. The aim of the REBUS project is to develop solar heating systems, which are attractive to buyers and cover up to 50 % of the annual heat demand.

The first part of the present work presents laboratory studies on façade-integrated collectors with black, selective and non-selective, coloured absorbers. The performance was investigated with glass and polycarbonate as collector cover. Consequences for the solar heating system design by introducing façade collectors are discussed.

Further, two examples of residences with façade collectors are presented, which address a different type of customer than the conventional energy concerned solar enthusiast.

2. POLYMERIC FAÇADE COLLECTOR

2.1 Drain-back design

The polymeric collector has been designed as a part of a drain-back system. In Europe, drain-back systems are installed in the Netherlands and in Norway. In the Dutch system design, the solar loop normally contains a heat carrier with antifreeze additives. In Norway, the installed systems are almost exclusively polymeric solar collectors with water as heat carrier in the solar loop. The heat buffer storage in the Norwegian design (Solarnor) is non-pressurized with typical volumes of 0.05 m^3 to 0.10 m^3 per square meter collector area. There are normally no intermediate heat exchangers between the heat storage volume, the solar loop and the heat distribution loop for space heating (e.g. floor heating loop). The hydraulic scheme is shown in Fig. 1. When the solar system is not inoperation, the absorbers are filled with air and the heat carrier (water) is drained to the storage. For the flow of the heat carrier, several collector modules are connected in parallel.

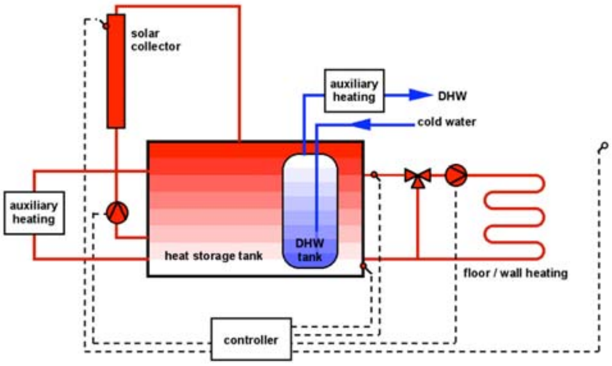

Fig. 1. Hydraulic scheme of a solar heating system with drain-back design and polymeric façade collectors.

2.2 Façade integration

For the façade integration of drain-back collectors, the location of the heat storage tank determines normally to which level over ground level the façade can be covered by solar collectors. A complete draining of the solar system is -in the most simple system design- secured when the lower end of the collector façade is above the storage level. This limitation is normally given in one-storey buildings without basement where the technical room is commonly placed. The limitation can be overcome when forced drain-back is introduced (e.g. support by pressurized air) instead of drain-back caused by gravity.

2.3 Polymeric collector

The absorber and the collector cover consist of polymeric materials (modified NORYL®, PPO/PS blend; polycarbonate) and are sheets with an internal twin- or multi-wall structure. Due to the properties of polymeric materials, the system design avoids high operation- and stagnation temperatures. This includes e.g. that the heat carrier's volume flow is with typically one litre per minute per square meter collector area rather high compared to conventional metal absorbers. The heat carrier volume in the collector is approximately 3 litres per minute and per square meter collector area. The development of the polymeric material is carried out by General Electric Plastics in collaboration with Solarnor AS and the University of Oslo, and is reported in (Meir et al., 2003). The most recent PPO/PS blend is part of a study, which investigates various candidates for solar absorber applications with regard to the performance properties on time and temperature (Kahlen, 2005).

2.4 Coloured absorbers

The polymeric material of the present absorbers principally opens the possibility to choose the colour as a property of the bulk material for extrusion. This is feasible when a certain production volume for the coloured absorber is given.

In the present studies, the absorbers were coloured by a Thickness Insensitive Spectrally Selective paint (TISS) in the colours green and blue (Köhl, Orel et al., 2003). The TISS paints were demonstrated for conventional metal absorbers within the EU-project Colourface (Müller et al., 2004). The TISS paint coatings could be applied on the polymeric absorbers without surface priming. The coatings revealed good adhesion and no visible degradation since the installation one year ago.

The absorptance for the unpainted black absorber and for the colours green and blue, were measured with an spectrophotometer model 746 from Optronic Laboratory, USA owned by the Solar Energy Research Centre (SERC) at Högskolan Dalarna in Borlänge, Sweden. The absorptance spectra are shown in Fig. 2 for the wavelength range of 350 nm - 2500 nm. The uncertainty of the absorptance measurements is approximately 1 %. The emittance TISS paint coatings on metal absorbers was reported by Köhl (2004) and was $\varepsilon_{green}(373\ K) = 0.45$ and $\varepsilon_{blue}(373\ K) = 0.40$.

The weighted solar absorptance (Duffie and Beckmann, 1991) of the various colours is listed in Table 1. The table compares the absorptance of TISS paints with commercial non-selective alkyd-based paints, which were applied and tested earlier (Meir, 2004; Svåsand, 2003).

Table 1. Solar absorptance of the coloured and black polymeric absorbers.

Colour	Absorptance for λ=350-2500 nm
Black, non selective	0.94
Green TISS, 9	0.81
Blue TISS, 8	0.82
Green non-selective	0.92
Blue non-selective	0.83

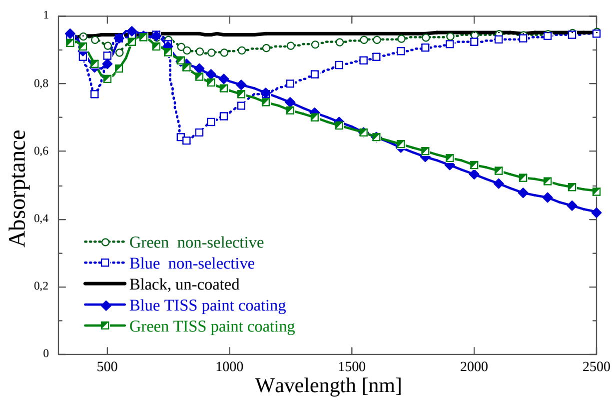

Fig. 2. Absorptance of the un-coated black absorber, of the absorber coated with green/ blue TISS paints and with non-selective green/blue paints.

2.5 Collector cover

The present polymeric collector is commercially available with polycarbonate (PC) twin-wall sheet of 10 mm thickness and rectangular structure as collector cover. As glass façades are very common for larger and commercial buildings, the performance of the collector with black NORYL® absorbers was also investigated with solar glass EUSOL-T/4.0 mm from EUSOGLA. The physical properties of both collector covers are compared in Table 2.

PC twin-wall sheets are available in dimensions, which correspond to the polymeric absorber. Further advantages are the low weight for the transport and the handling during the installation.

Table 2. Physical properties of the collector cover: PC twin-wall sheet of 10 mm thickness and solar glass of 4 mm thickness.

Collector cover	**PC twin-wall sheet**	**Solar glass**
Thickness [1] [mm]	10	4
Transmittance, solar spectrum[1]	0.86	0.91
Weight[1] [kg/m^2]	1.7	10.0
Refraction index, T=25ºC	1.59[1]	~ 1.50
Thermal expansion [K^{-1}]	10^{-5}	~ 3 x 10^{-6}
U-value [2] [W/(m^{-2} K)]	3.5	~ 6.0

[1] The values refer to the PC twin-wall sheet LEXAN LTC10/2RS from GE Plastics and to solar glass EUSOL-T/4.0 mm from EUSOGLA respectively.
[2] Refers to the application in window glazing.

2.6 Building Physics

The thermal performance of a building will be considerably influenced by large areas of integrated facade collectors. It concerns the design of the facade construction, passive gains and the temperature- and humidity conditions in the construction. Studies with the polymeric collector were done on a test facade (Meir et al., 2004).

3. COLLECTOR PERFORMANCE

3.1 Experimental set-up and measurements

The collector-performance measurements were carried out at the Sol-lab, a small test laboratory at the University of Oslo from summer to autumn 2004. Following collectors were tested:

- Black, uncoated NORYL absorber, cover: 10 mm polycarbonate twin-wall sheet
- Black, uncoated NORYL absorber, cover: solar glass EUSOL-T/4.0 mm
- Absorber coated with blue TISS paint, cover: 10 mm polycarbonate twin-wall sheet
- Absorber coated with green TISS paint, cover: 10 mm polycarbonate twin-wall sheet

The different collectors were mounted on the south-facing façade (tilt angle: 90°; azimuth: 18°). The efficiency was determined with the calorimetric method (Svåsand, 2003), collector area: 1.7 m^2, heat storage volume: 81 litres. The stagnation temperature was determined from separate measurements.

3.2 Results

As expected, the façade collector performs somewhat better with the glass cover at small values for $(T_c\text{-}T_a)/I$ while the collector with PC cover performs better at large values for $(T_c\text{-}T_a)/I$. A solar combisystem with the polymeric absorber is designed so that the typical range of operation for the $(T_c\text{-}T_a)/I$-value lays between 0.02 (K m^2)/W and 0.06 (K m^2)/W. In this range, the efficiency is in the same order for both cover materials. The selection of solar glass or polycarbonate as collector cover will be more dependent on the design of the façade, aesthetics, material and installation choice and costs.

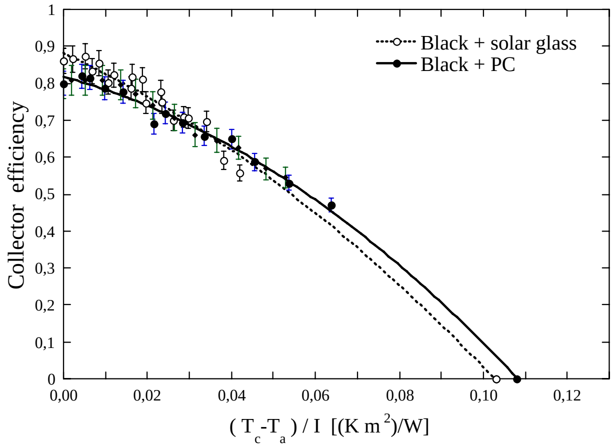

Fig. 3. Measured collector efficiency of the black, uncoated polymeric absorber with two different collector covers: 10 mm polycarbonate twin-wall sheet and 4 mm solar glass.

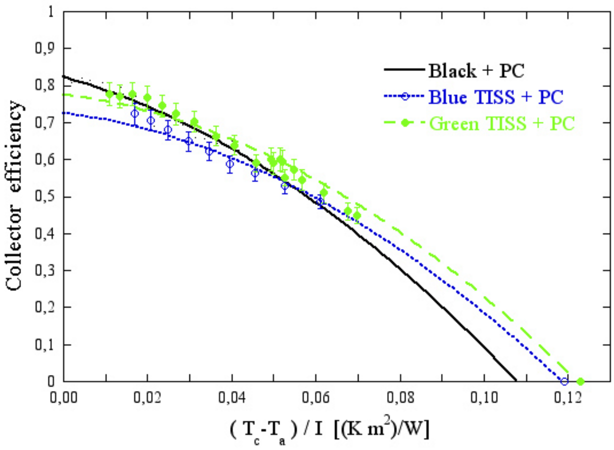

Fig. 4. Measured collector efficiency of the polymeric absorber painted with blue and green TISS paints and with 10 mm polycarbonate twin-wall sheet as collector cover.

The efficiencies of polymeric collectors (standard PC twin-wall sheet as cover) with uncoated (black) absorbers are compared with absorbers painted with blue and green TISS paints in Fig. 4. For small values of $(T_c-T_a)/I$, the efficiency of the collector with black absorbers is larger than for those covered TISS paints as expected from the absorptance spectrum (Fig. 2). However, the difference between the efficiency measurements with the blue and green TISS absorber cannot be explained from the absorptance. For the data of "Blue TISS + PC" only one set of measurements was available, while the data of "Green TISS + PC" are from measurements on several days.

When it comes to the selection black or coloured absorbers (and which colour) for façade integration, the aspect of aesthetics will be most important. According to studies among architects in Austria, 85 % would prefer coloured collector instead of black and accept the reduction in performance (Bergmann and Weiß, 2002). This study referred to a market dominated by metal absorbers with costly selective coatings relative to the polymeric absorber. The present TISS paint coatings are not a commercial product today. From the point of aesthetics, the TISS paints are estimated to be very competitive and have been demonstrated in other colours than the present green and blue (Colourface, -). However, based on the cost estimate of the TISS paint coatings (Orel, 2004), the square meter costs of the polymeric collector would almost double relative to the unpainted collector (sales of moderate volume).

4. CALCULATIONS, FAÇADE INTEGRATION

4.1 Roof versus façade

The REBUS project aims to design solar heating systems for Nordic conditions which can cover up to 50 % of the total heating demand. Key factors are among others to improve the thermal insulation of the houses and to increase the collector area. By integrating the solar collectors in the roof or façade, conventional building materials are replaced and the construction material costs can be reduced.

The heating demand in Nordic and middle European countries is a low-temperature heating demand with system temperatures in the range of 25-60°C, which does not require high efficient collectors at high temperatures. Hence a low-cost solar collector made of polymeric materials can meet these requirements. When high solar fractions should be reached, the costs per square meter collector area become a key issue due to the large collector area required.

Solar combisystems, which are designed for solar fractions of 50 % on a yearly basis, will more often reach stagnation conditions during summer time. The risk for overheating can be reduced by the integration of the collectors into the façade. This is demonstrated by simulations in the following section. In addition, the reflection of solar radiation due to snow on the ground is another positive aspect against the mismatch between the availability of solar radiation and heating demand.

4.2 Simulations

The simulation program SolDat (Haugen, 2000; Ingebretsen, 1992) was used to generate climate data and study the solar gain of a well-insulated single-family house with a solar combisystem and polymeric collectors.

Fig. 5 compares the solar irradiance per square meter on the roof (tilt angle 30°) and on the façade (90°) for a house at the location Oslo (latitude 59.9°). The irradiance on façade collector is better correlated with the space heating demand and will avoid high stagnation temperatures for the polymeric collector. Stagnation occurs when the solar collectors are not cooled by the heat carrier. In the case of the present polymer collector, the heat carrier is then drained to the heat storage and the absorbers are filled with air (drain-back).

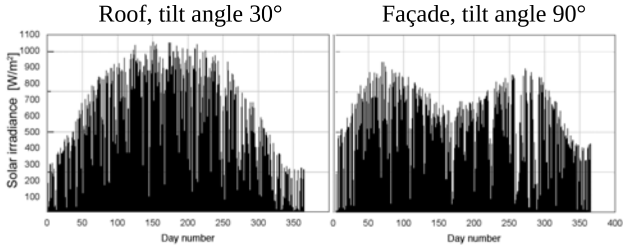

Fig. 5. Solar irradiance per square meter on a roof with 30° tilt angle and on the façade (90° tilt angle) calculated with the simulation program SolDat for the location Oslo (latitude 60°).

If stagnation cannot be avoided, the system design should be so that the collector's stagnation temperatures are not harmful to the material. From the irradiance and the ambient temperature (Fig. 6), the stagnation temperatures were calculated for a roof and a façade integrated collector (location Oslo). It is evident that façade collectors are exposed to a much lower thermal stress during stagnation than roof collectors.

Table 3. Stagnation temperatures of the polymer collector for roof and façade integration for Oslo climate calculated with the simulation program SolDat.

Month	**Max. ambient temperature [°C]**	**Collector stagnation temperature [°C]**	
		Roof (30°)	**Façade (90°)**
January	-1	45	65
February	3	75	90
March	7	95	95
April	15	113	103
May	20	120	100
June	28	130	115
July	27	130	105
August	24	125	107
September	20	115	101
October	13	95	102
November	8	65	85
December	4	41	50

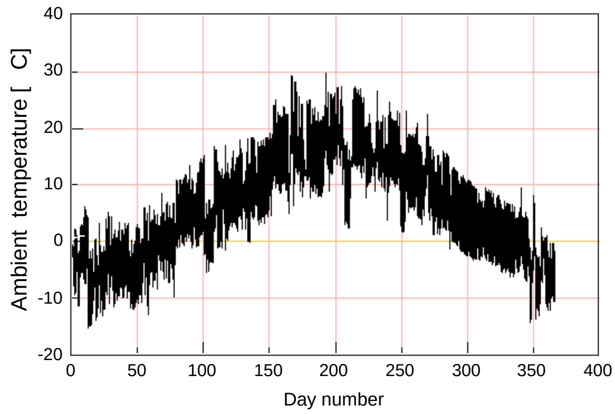

Fig. 6. Ambient temperature for Oslo climate (Norway, latitude 60°), calculated with the simulation program SolDat.

Even for Nordic climates as in Oslo, it is possible to reach solar fractions up to 50 % for solar combisystems in single-family houses, provided the houses are well-insulated with low-temperature heating (floor-/wall heating) and have a low annual heating demand in the range of 50 kWh per square meter heated living area.

Fig. 7 shows the total heating demand and the solar gain for a house with an annual space heating demand of 7800 kWh/a and a DHW demand of 5400 kWh/a (includes DHW supply to washing machine and dishwasher). The heat storage volume was 2 m^3 and the collectors were polymeric collectors with an area of 40 m^2, integrated in the south-facing façade. The solar fraction for the system with façade collectors was 59 %.

The solar fraction is approximately 12 % higher for façade collectors than for roof collectors, see Table 4. The solar gain per square meter collector area is with 185 kWh/a rather low. However, such systems are feasible with low-cost collectors as the present polymeric collector, which produce energy and substitute standard facade covers.

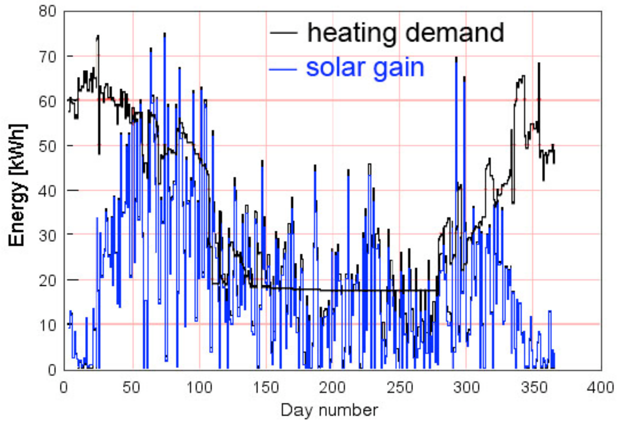

Fig. 7. Solar combisystem with façade collectors: Total heating demand and solar gain of a well-insulated single-family house for Oslo climate, calculated with the simulation program SolDat.

Table 4. Comparison of façade- and roof collectors: System data for simulations with SolDat and calculated performance of the solar combisystem with façade- and roof collectors for a well-insulated single-family house.

System data for simulations	
Heat storage volume	2 m^3
Façade collectors, tilt angle	90°
Collector area	40 m^2
Annual space heating demand	7441 kWh/a
Annual domestic hot water demand	5120 kWh/a

Performance for roof and façade integrated collectors			
		Façade (90°)	**Roof (30°)**
Solar fraction	[%]	59 %	52 %
Solar gain, total	[kWh/a]	7434	6537
Solar gain, space heating	[kWh/a]	4000	3070
Solar gain, DHW heating	[kWh/a]	3435	3466
Solar gain /m^2	[kWh/(m^2 a)]	185	163

The calculations give a conservative estimate in favour of façade integrated collectors, as façade shading during summer time (stagnation) and reflection due to snow during winter time (performance) have not been considered in the simulations with SolDat.

5. NORTHERN LATITUDES, EXAMPLES

What are the obstacles for solar thermal heating in Nordic countries? In Norway, the development was strongly influenced by the Norwegian energy market where abundant and low-cost hydroelectric power was accessible (approx. 0.06 EURO/kWh until 2002). Hence, approximately 80 % of the buildings in Norway were heated by direct electric heating. A major obstacle was also that water-based heating systems, which are necessary for solar heating systems, have rarely been installed in new houses since 1960.

In the following we present two examples of residences with façade collectors for solar thermal heating, which address another type of customer than the idealistic and energy concerned customer: High standard apartments and mass-produced single-family housing. Both examples reveal a new thinking around what has been the tradition in Norway concerning housing- and heating system design. New is that the addressed customer is not longer the group of enthusiasts with special interest in renewable energy.

5.1 Type-house "Karakter"

A large fraction of the private houses in Norway are so-called "type-houses" (typehus). In 2001 were 82 % of the new installed houses in Norway type-houses. Type-houses are pre-designed houses for living, mostly of wooden construction. They are standardized and made for mass production with the aim to simplify the building process and reduce costs. In contrast to a pre-fabricated house, the type-house is built step by step on-site.

Type-house customers choose from a pre-designed selection of houses with the possibility of certain individual adjustments. The type-house company or a contractor takes over the complete process from the application of the building permission to the house construction including technical and sanitary installations, kitchen, floor and wall covering.

Systemhus, a large Norwegian type-house producer introduces façade collectors for solar thermal heating in the concept of a new designed series of the type-house "Karakter" (Jo Aastorp, Arkitekstudio AS). Herewith, standardized solar thermal heating is offered to a new market and is accessible to customers who might have different motivations to choose the heating source than builders of individual houses.

The design of Karakter should be functionalistic, adjusted to modern living style and can be modified in order to fit to various grounds.

Fig. 8. Type-house KARAKTER, example of a standardized single-family house with façade collectors for mass production (Source: Systemhus)

One version of the Karakter type-house is shown in Fig. 8. The area of the solar collector façade is approximately 20 m^2, the heat storage 2 m^3 with gas as auxiliary heating. The solar fraction is expected to be in the range of 20-30 % dependent on the location. This is due to the relatively small collector area available and due to moderate insulation standard in mass-produced housing. Simulation studies have been carried out on the type house Karakter (Gao, 2005). The thermal insulation and the dimension of the solar heating system were varied and the energy performance of the building investigated.

The concept of Karakter has been awarded for the innovative design in 2003 (Boligprodusentenes Nyskapingspris 2003).

According to a study of the German market offered 24 % of the requested building companies of prefabricated houses the installation of solar collectors as an alternative in their advertising (Fiedler, 2003).

5.2 E-Living: High-standard apartments

Example two is a high-standard apartment complex, located at Holmenkollen in Oslo with a collector façade. Presently the building is under construction and the expected moving-in date is end of 2005. A model of the apartment complex is shown in Fig. 9. With the concept "E-Living" the building and contracting company Backe Project AS (Oslo) decided to design a complex of eight residences, which should be different from mass-produced housing and adjusted to modern life-style. "E-living" stands for "elegant, enjoyable, energy-efficient, environmental, economical, evolutionary and easy". The apartments have a living area between 131-161 m^2. Some of the high-standard elements are: A patio open to the interior through glazing (Fig. 10), floor heating, gas for cooking and fire place heating and choice of environmental friendly materials.

The solar heating system includes a collector façade of 97 m^2 on the southwest-facing façade and contributes to domestic hot water preparation and floor heating system. The buffer storage with 8 m^3 is the heating central for the eight apartments. The auxiliary heating source is propane gas. The solar heating system is dimensioned for a solar fraction of approximately 20 %.

It is interesting to see in which way a building and contracting company, which usually makes mass-produced housing, introduces and solar heating and to which customers.

Fig. 9. Model of a high-standard apartment complex with façade collectors in Oslo. Entrepreneur: Backe AS, Oslo; Architects: Arkitektkontoret Dahle/Dahle/Breitenstein AS, Oslo. Solar heating system: Solarnor AS. Source: (Backe, n.d.).

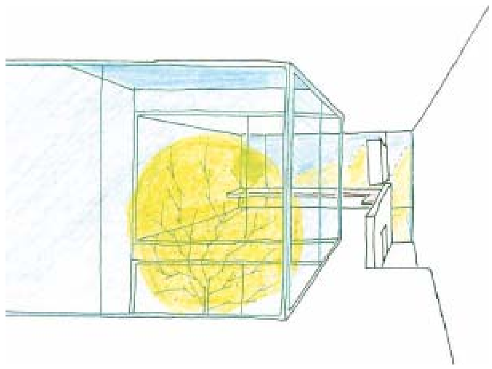

Fig. 10. The interior of each apartment includes a patio, which open to the interior through glazing. Source (Backe, n.d.).

6. SUMMARY

Façade collectors can be seen as multi-functional building modules, providing energy, new possibilities of façade design and surface protection for the building.

With the present polymeric collector, large facade areas can be covered at low costs. A simulation of the solar system performance show that large facade collector areas and well insulated houses with low heating demand are important factors for reaching high solar fractions in Nordic climates. The facade integration of solar collectors avoids the overproduction of heat during summertime. This aspect is of particular importance for the polymeric collectors.

The application of solar glass or polycarbonate twin-wall sheets as collector cover has no significant impact on the efficiency of the polymeric collector within the typical range of operation.

Two new examples of house concepts with facade-integrated collectors are presented which address new groups of customers in the Norwegian market: Solar heating for mass-produced single-family housing and high-standard apartments.

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