3 Global Status of Solar Thermal Technologies and Building Integration

The increase in the use of solar collectors for domestic hot water preparation since the early eighties has shown that SWH systems have developed to a mature and reliable technology. A broad variety of solar domestic-hot-water systems have been developed and adjusted to the needs and meteorological conditions around the world. Simple thermosiphon systems are mainly used in low latitudes without frost during the cold season. More advanced pumped systems are in use mainly in higher latitudes due to the lower outdoor air temperatures and frost in wintertime. Large collective installations with seasonal energy storage are not yet widely used.
From a building integrated perspective, there are a large number of examples to be found around the world of projects where special attention was given to the integration of solar heating products into buildings. Beside the technical and economical reasons there is clearly an increasing trend to consider the aesthetical reasons for building integration of solar hot water systems.

Solar water heating systems are currently widely applied in the residential sector for single-family houses and multifamily houses. Larger scale installations are mostly used in public or commercial buildings. Industrial applications, district heating and solar cooling have not yet been widely applied, although a large potential market certainly exists.

3.1 SWH Systems

In this section, we give a brief overview of the main system types and sizes, as a full introduction to the components and design of solar water heaters can be found in numerous good resources [7], [8], [9]. Solar water heaters are normally designed to cover 100% of the hot water demand in the summer and 40% - 80% of the total hot water demand over the whole year (for an example see Figure 19). Depending on the location, the climate and desired solar fraction, a typical solar domestic hot water system needs about 2 – 6 m² collector area and a 100 – 500 liter water tank for a one-family house.

The three main types of systems - natural circulation, forced circulation and drain-back - are discussed in the following sections. It should be noted that all three of these system types can be either direct systems – with domestic water in the collectors – or indirect systems – with one or more heat exchangers to separate the fluid in the solar collectors from the domestic water.

3.1.1 Gravity-driven Systems with Natural Convection for Domestic Hot Water

The so-called thermosiphon system consists of a solar collector situated below the hot water tank, with piping which allows natural circulation of the heat transfer fluid into the tank (Figure 5). It uses gravity differences between the cold water and heated water to circulate the heat transfer from the collector to the water tank.

The thermosiphon solar thermal systems are widely used, almost always as standardized products, at lower latitudes, the southern European countries (Figure 4), Israel and Australia. They are usually used for domestic hot water preparation and mounted on flat roofs. Advantages of the system are easy operation and installation as they operate without electricity for pumping and the controller, and also they have low investment and operation costs.

Figure 4: Thermosiphon systems in Greece

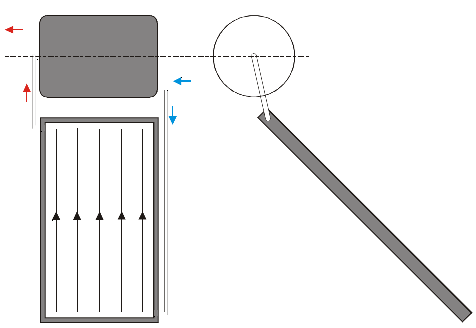

Figure 5: Principle of a thermosiphon system

3.1.2 Forced Circulation System

In forced-circulation systems, the collector can be above the store, and is often mounted on or in sloped roofs. The trend is to replace the roofing material so that the collector is embedded in the roof and not on top of the roof. More advanced pumped systems are used mainly in higher latitudes, with protection against the lower outdoor air temperatures and frost in wintertime.

In these systems, heat produced in the collector is transported by a heat transfer medium (water/anti-freeze mixture) that is circulated by a pump to the water tank (Figure 6). There, the heat is transferred through a heat exchanger to the domestic water and thus becomes useable. A key characteristic of the system is that the collector and the water tank can be located separately, which makes it easier to integrate the solar heating system with conventional heating systems, e.g. electricity or gas heater or combi-system. Specific measures for overheating protection are needed, such as a well-placed expansion vessel large enough to contain the collector fluid when the collector boils dry.

In the central and northern European climate, indirect double-circuit systems with forced circulation are mostly used (Figure 7).

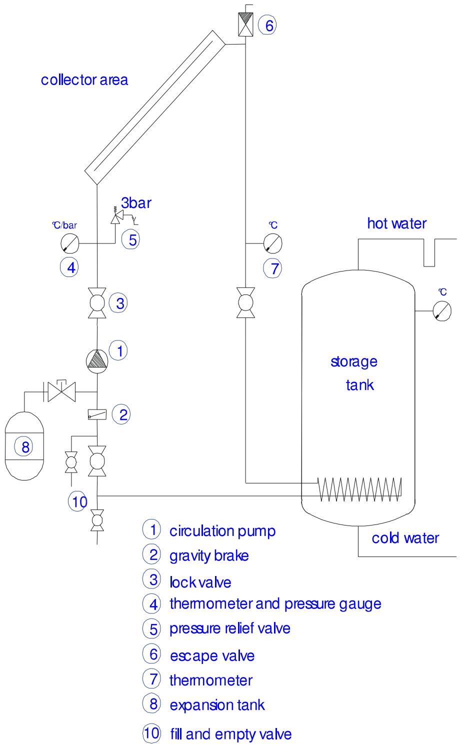

Figure 6: Typical domestic solar hot water system for a single family house in Austria

Figure 7: Hydraulic scheme of a hot water system with forced circulation

3.2 Drain-back System

Drainback systems are pumped systems, but there is a critical difference as the collector circuit is not completely filled with water, but also has air in it. When the pump switches off (during the night, in case of frost danger or in case of overheating danger) the water in the collector flows down and is replaced by air. As a result, ice cannot be formed and damage is, therefore, avoided. The water also drains back if the heat store is fully charged and overheating could occur. Then, the draining of the collector avoids boiling of water and high pressures inside the system.

Although the drain-back concept is simple, draining a solar collector requires special qualities in hydraulic design. The major feature is that every pipe (from the top of the solar collector loop to the point in the house where freezing will not occur) must slope downwards and that the collector must be designed to completely drain.

Figure 8 shows four examples of the drain-back concept where the drainback volume has been integrated into the heat store or into the heat exchangers in the store. Drain-back systems are in operation mostly in the Netherlands and have recently emerged in in Germany and Austria. In China, simple direct drain-back systems can also be found.

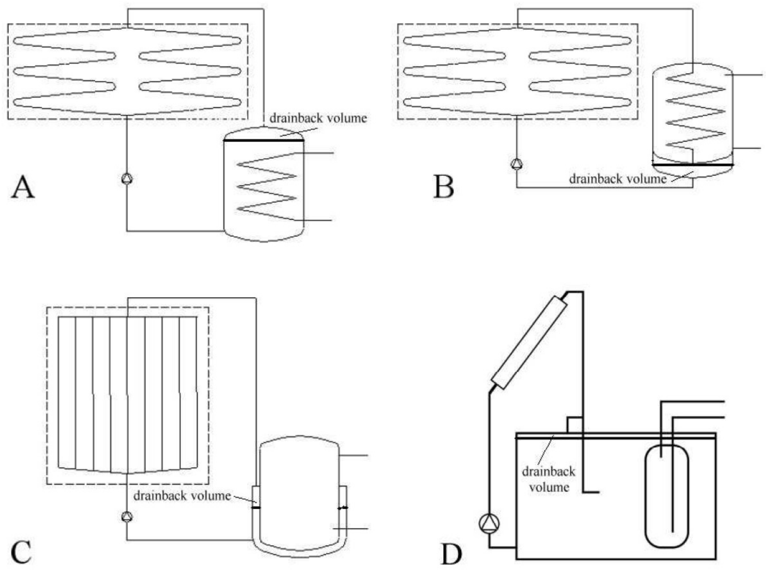

Figure 8: Different implementations of indirect drainback systems

3.3 Large Solar Water Heating Systems

Apart from the above-described smaller systems mostly used for single-family dwellings, the market for large systems has grown considerably in the last years. Large systems, generally considered to have a collector area above 20 m^2, are used for multi-family houses, hotels, elderly homes, care centers, sports centers, prisons and other buildings with a large demand for hot water. Furthermore large solar thermal systems are increasingly being used for housing estates connected to a district heating grid. Because of the large size, an increase in system performance and a decrease in investment per unit output can be realized. Three major system design categories can be distinguished:

3.3.1 Systems with Short-Term Storage

The typical storage volume referred to the installed collector aperture area is in the range of 50-75 l/m² for a system with short-term storage. With this design a short period of a few days with little sunshine can be bridged. In doing so, the solar fraction of the systems is mostly limited to a contribution to the hot water production, and therefore to a maximum of about 20% of the total heat demand (space heating, domestic hot water preparation and net losses) in temperate climates. In sunny, warmer climates the percentage may be higher because the heating demand is smaller. Several of these systems have been realized in Germany, the Netherlands and Austria.

3.3.2 Systems with Seasonal Storage

In several countries with long, dark winters, large central solar heating plants with 'seasonal storage' have been realized. With these large storage capacities, the solar heat produced in the summer months can be used for space heating in winter time thus leading to a substantially higher solar fraction of 50% to 70%. For solar heating systems with seasonal storage the storage volume referred to the installed collector aperture area is about 2.000 l/m² and this is often realized through using a large underground rock structure as the heat store. These systems have a long 'tradition' in Sweden and also in Germany. Notwithstanding their large size (up to 10,000 m² for one system), these systems generally have longer payback times than systems with short-term storage. Installations with seasonal energy storage have not been widely applied, but could be a promising market for the longer-term future.

3.3.3 Systems with Weekly Storage

With the third approach, mainly realized so far in Austria, a high solar fraction is obtained by reducing the space heating demand of the buildings as far as possible by optimizing the district heating net to the needs of the solar heating system. Typical storage volume referred to the installed collector aperture area is in the range of 200 to 400 l/m² for a system with medium-term storage.

Table 2 gives an overview of these three system types. For more information, see [8].

Table 2: Overview of large solar thermal system types.

	System with short-term heat storage	**System with weekly heat storage**	**System with long-term heat storage**
Solar heating system used for	DHW	DHW and space heating	DHW and space heating
Solar fraction as a % of the total heat demand	10 to 20% (50 to 70% of DHW)	30 to 40%	40 to 70%
Collector area per apartment	2 to 4 m²	4 to 10 m²	10 to 40 m²
Storage volume per m² of solar collector	50 to 70 l/m²	200 to 400 l/m²	2000 to 4000 l/m²

Figure 9: Example of a solar water heater for a multifamily house (Source: AKS DOMA)

3.4 Solar Combi-systems

A separate technology category is for solar heating systems with combined domestic hot water preparation and space heating, called ‘solar combi-systems’. These systems, which can be installed in single houses or in larger buildings, are essentially the same as solar water heaters when considering the collectors and the transport of the produced heat to the storage device. But solar combi-systems are more complex than solar domestic hot water systems, as there is more interaction with an extra subsystem – the space heating installation. And these interactions deeply affect the overall performance of the solar part of the system. The general complexity of solar combi-systems has led to a large number of widely differing system designs [9].

The collector size of a combi-system for a single house is about 7-20 m^2 and the storage tank has a volume in the range between 300 and 2000 liters. The amount of heat needed for space heating depends on the building size, thermal insulation, ventilation, passive solar use and internal heat loads. For best overall efficiency, collectors should be operated at the lowest temperatures. At higher temperatures, the system may lose too much heat.

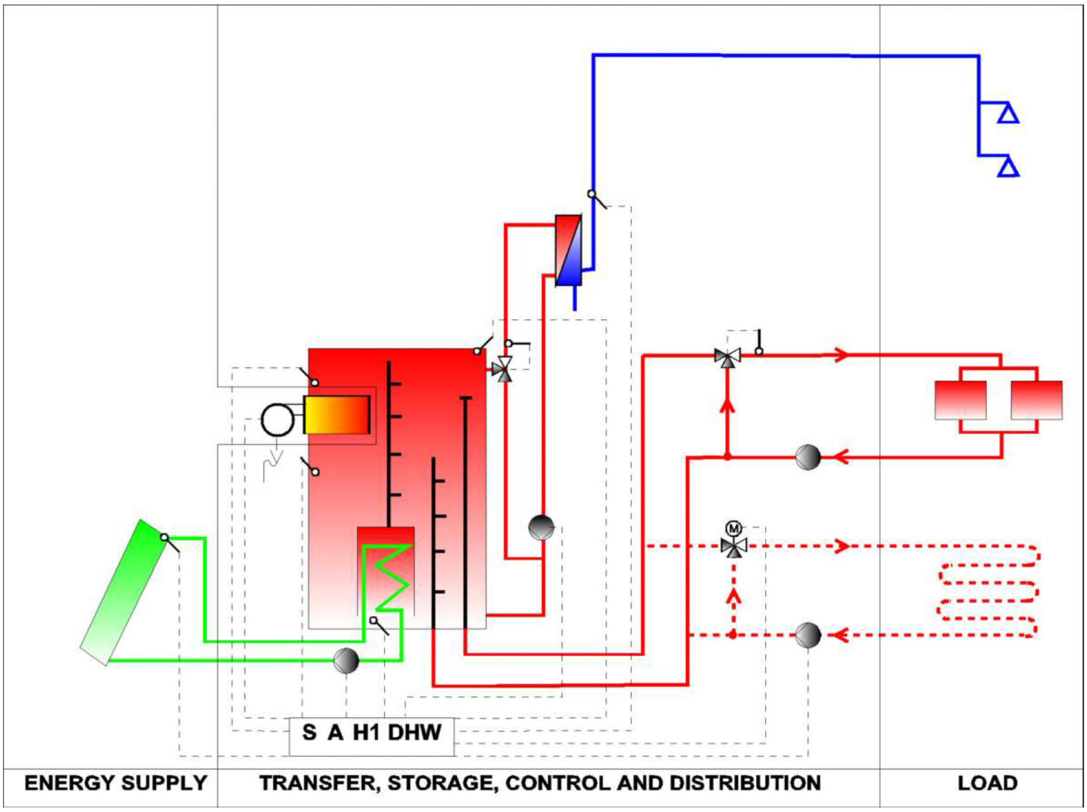

Figure 10: Hydraulic scheme of a solar combi-system [9]

In 2001 the total collector area installed for solar combi-systems in eight European countries (the region where these systems are most applied) equaled 340,000 m². Assuming that the average collector area for a combi-system is 15 m², this means that about 22,600 solar combi-systems were installed in 2001.

3.5 Global Practices in Building Integration

The way in which solar heating systems are mounted on or integrated in buildings differs strongly from country to country and in this section an overview is presented based on the case study review included in Volume 2.

3.5.1 Architectural Aspects

Building Integration concerns the physical integration of a solar heating system into a building, but it also covers the overall image of the solar heating system in the building. For the architect, the aesthetic aspect, rather than the physical integration, is the main reason for talking about building integration. The optimal situation is a physically and aesthetically well-integrated system. In fact, many examples of physical integration show a lack of aesthetic integration. Visual analysis of solar heating systems in buildings shows that the appearance of poorly designed building does not improve just by adding a well-designed solar heating system. On the other hand, the aesthetics of a well-designed building could be damaged by a a poorly designed solar heating system.

A number of aesthetical criteria for the architectural integration of solar heating systems are:

Natural integration

- The solar heating system seems to form a logical part of the building and adds the finishing touch to the building.

Architecturally pleasing

- The building should look attractive and the solar heating system should noticeably improve the design. This is a very subjective issue, but there is no doubt that people find some buildings more pleasing than others.

Good composition of colors and materials

- The color and texture of the solar heating system should be consistent with the other materials.

Fit the gridula, harmony, and composition

- The dimensions of the solar heating system should match the dimensions of the building. This will determine the dimensions of the modules and the building grid lines used. (gridula = modular system of lines and dimensions used to structure the building)

Matching the context of the building

- The solar heating system used should be consistent with the entire appearance of the building.

Well engineered (internally in the building and externally)

- Here the elegance of the details is meant rather than the waterproofing or reliability of the construction. Designers should pay a lot of attention to the details and ideally minimize the amount of material to be used in integrating the solar heating system with the buildings. These considerations will influence the ease of implementation of the solar heating system in the building and the subsequent ease of operation.

During the design process, these architectural criteria often need to be explained, particularly to non-architects and manufacturers developing solar heating systems for integration into roofs and façades, who often believe that their systems fit the building perfectly. In general however, architects are not yet convinced about the ´beauty´ of solar heating systems in buildings.

3.5.2 Technical Aspects

In this section we introduce a few of the technical aspects to consider for building integration with a more detailed outline included in Appendix 1.

Technical integration of SWH systems in a single-family house is relatively easy. Only a few square meters of the roof are needed for the DHW system. In several countries in Europe the collectors are routinely integrated into the roofs. Figures 11 to 14 give some examples of integration of solar collectors into residential buildings found in different countries.

Recently a new invention in building integration has been constructed in the Netherlands. The solar ridge (Figure 15) is a cylinder-shaped domestic solar hot water system integrated into the ridge of the roof. In this case a south-facing roof is no longer needed. This solution is also very suitable in some older (traditional) houses.

Figure 11: Small domestic hot water system

Figure 12: The fully integrated solar roof. This solution is suitable for smaller apartment buildings.

Figure 13: This north-facing roof was not suitable for integration so the architect used the south facade in a creative way.

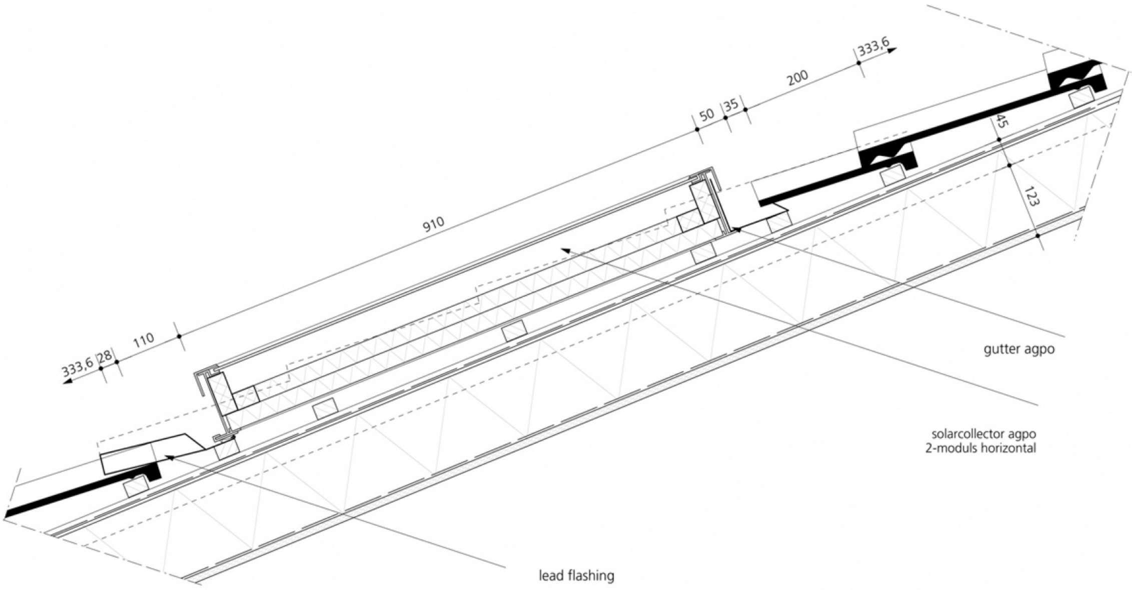

Figure 14: Solar collector integrated between the tiles on the roof.

Figure 15: The solar ridge (Ekonok)

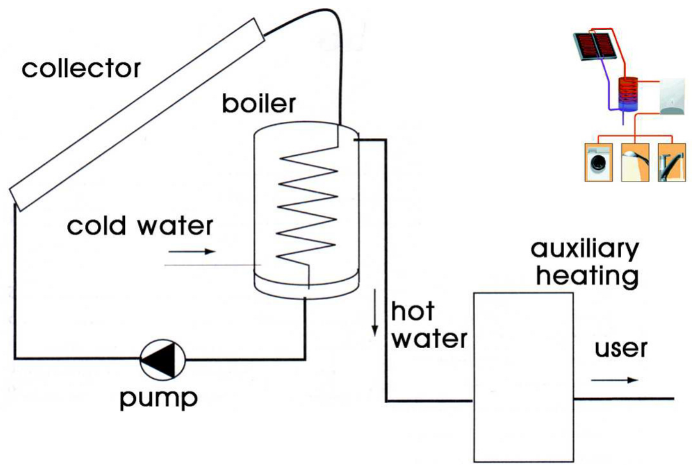

Figure 16: Domestic solar hot water system integrated in the space heating system.

In case of space heating, the roof must be large enough for the larger area of solar collectors – up to 20 to 50 m^2 for advanced systems with high solar fractions for low-energy houses. An extreme example is found in Almere, the Netherlands, shows a single family house with 70 m^2 of collector area and 40 m^3 of store tank. The system supplies about 95% of the heat demand of the building.

Figure 17: This house uses a huge 40 m^3 storage tank for a thermal solar heating system for space heating and domestic hot water use.

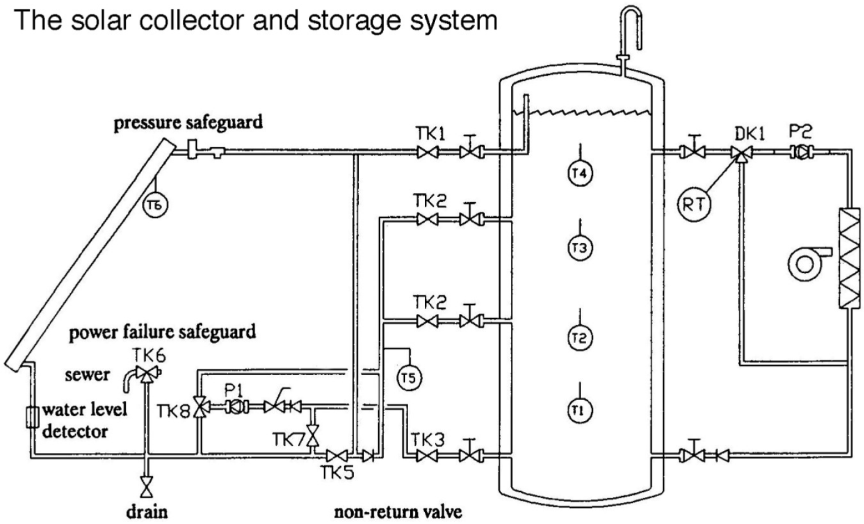

Figure 18: The scheme shows how the water tank is used to store water with different temperature levels.

In the case of an apartment building the integration approach needs to be different. For medium rise buildings, such as those shown in Figure 12 at Gneis-Moos, the solar output from the available roof space can be maximized through using a fully integrated solar roof. Figure 19 below the measured heat balance for the Gneis-Moos project in Austria. The design concept was to provide for "weekly" storage and the project had a collector area of 410 m^2, a storage volume of 100 m^3, a solar fraction of 34% and served 61 apartments. As can be seen from the heat balance, the system provided nearly all of the required heat load in the summer months.

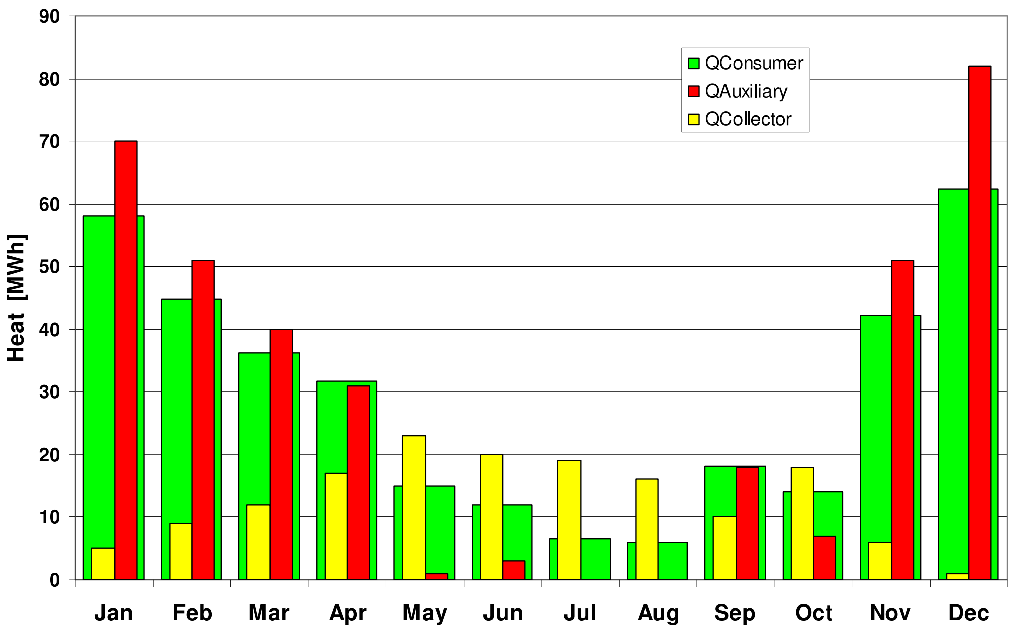

Figure 19: Heat balance 2001 for the project Gneis-Moos, Salzburg, Austria

For high buildings with more than about 10 to 15 floors, the amount of square meters needed for solar hot water systems will exceed the available surface of the roof. The principal options are then to provide solar hot water to the top floors only, or to use the façade of the building. In Northern European countries the use of solar heating systems in the facade is rather common and useful because of the lower sun angle in the space heating season. Depending on the latitude a different angle is needed. This gives the designer new ideas and possibilities for the integration of solar heating systems in the facade. For example, some systems are integrated as large awnings above the windows.

As an example of successful façade integration of solar collectors, the system shown in Figure 20 and Figure 21 for a student's apartment block is designed for 570 people each using on average 31 liters of hot water (at 60°) each day. Collectors provide heat for the water store tank of 7000 liters. Two smaller store tanks of 1500 liter contain the water for direct use. Auxiliary heating by means of the use of waste heat is also integrated in the total system.

Figure 20: Student apartment block in Germany, the facade is covered with evacuated solar tubes.

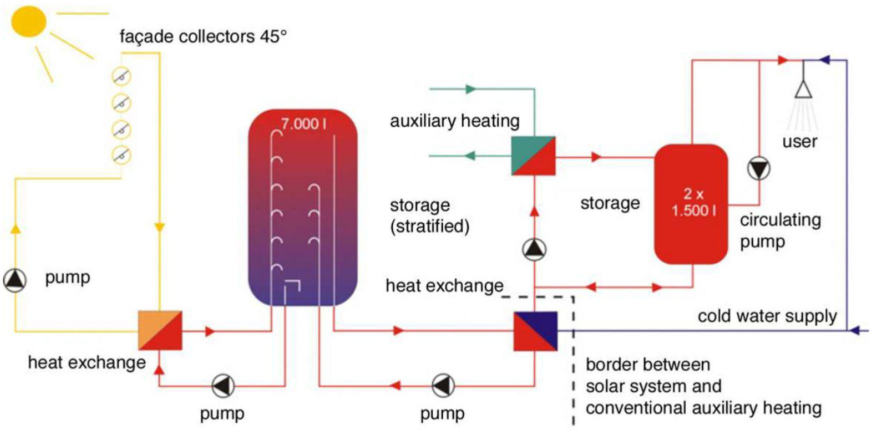

Figure 21: The system covers 35% of the domestic hot water for the 464 student apartments.

Another aspect of integration is the way the solar heating system is integrated into the other energy installations in the building. The SWH systems could be integrated with a central heating system of a single family house, with a central heating system for an apartment building or with a block- or district heating system. In north European houses which normally have a central heating system, SWH can be integrated into the central system. There are also multi-apartment buildings where central collector fields are coupled to individual store tanks in each apartment.

3.5.3 Building Integration Process Aspects

Solar heating applications are in most cases mounted on or in buildings. This means that for new buildings, solar heating installations are part of the construction process. The way the solar heaters are taken into account during the construction process differs from country to country and also depends on the scale, culture and type of financing of the building projects. In countries such as Denmark, the Netherlands and the United Kingdom, where public housing is common, serial production is strongly emphasized in construction projects. Professionals such as project developers, builders and architects implement construction projects using a standard structure of process steps. When solar heaters are included in the early (design) stages of that construction process, good possibilities arise for roof integration in single-family houses and for façade and roof integration in apartment buildings. Still too often, solar collectors are 'added' to the building in the latter stages. This can lead to less than optimal solutions in terms of aesthetics (for example: collectors mounted on top of the roof instead of in the roof), economics (collectors mounted on a finished roof instead of during the construction of the roof) and efficiency (sub-optimal placement of the store or piping).

In countries where the government has less influence in house construction, the building process is more often a private initiative carried out by professionals as project-developers. Also here it is advisable to take the solar heating installation into account throughout the process of design and construction.

When collectors are mounted on existing buildings, various situations arise. In buildings being thoroughly refurbished, opportunities for integration appear as in new construction projects. When solar installations are retrofitted on buildings as a separate project, there are less possibilities but still attention can be paid to connect the solar heater to the building in a correct and attractive way.

3.6 Practices in China

In the Chinese market, the cost of a solar heating system seems to be the main factor. However in new developments there is a growing interest for attractive looking residential housing. Solar heating systems that can be seen on most apartments buildings today are not well integrated at all because the market is mainly a consumer oriented 'retrofit' market and as such there is little scope or interest to integrate well the building integration aspects (see Figure 22).

Figure 22: Example installation showing lack of building integration of solar heating in China

There is a danger that solar heating systems, commonly perceived as being 'on-roof mounted' and lacking in aesthetic appeal, will be rejected by project developers because in general the aesthetical quality of their projects is becoming more and more important as a selling point. Solar heating systems therefore have to keep up with this development in order to keep their market position, thus underlining the importance of good integration.

We show three examples of residential housing in Kunming. The first project is about 10 years old. The solar heating systems are mounted on the flat roof and are facing south. The second project is a high quality product. These houses in a nice landscape setting have a modern western style and are very popular but unfortunately there are no solar heating systems. The third project is also in a modern western architectural style but here we see 'in the roof' integrated solar heating systems.

Figure 23: Common practice

Figure 24: New high level residential area, one of the potential markets for integrated solar collectors in China

Figure 25: Integrated solar heating systems

3.7 Outlook

Building integration is becoming more and more important as the solar water heater market is becoming more mature. Building integration will need to consider both technical and economic aspects but also the aesthetic. In China, new higher value houses have already begun to incorporate aesthetically pleasing designs with quite complex technical systems which are almost on par with those in European countries. However the key questions remain how to develop better integration for the medium and high rise buildings where typical 'on-roof' approaches will not provide the required output and performance and how to develop the medium and lower end of the market where cost is a more sensitive consideration than aesthetics or integration.