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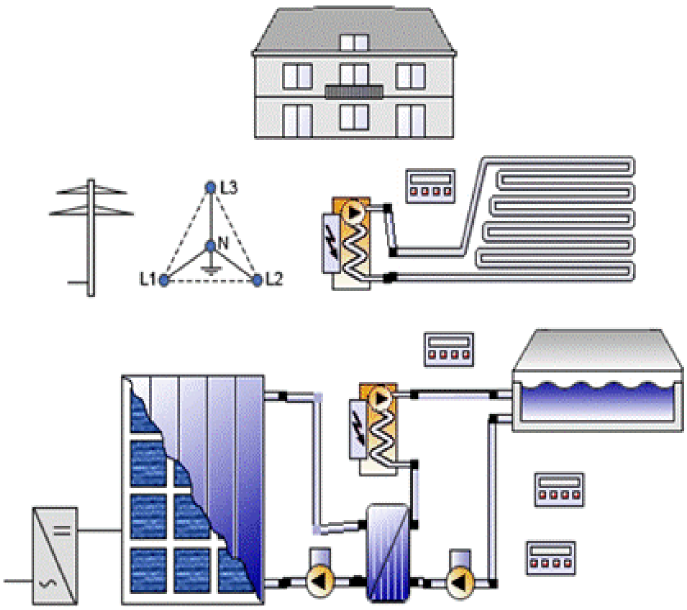

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Contents

1. Introduction and background.

Swimming pools used for leisure are installed in a number of residential and vacation houses in Denmark. Both indoor and outdoor swimming pool are present. Outdoor pools are typically used in the summer months. Indoor pools can be enjoyed all year round.

In colder climates like Denmark, the swimming pools typically are heated above ambient temperature for the user to enjoy the pool facilities. Typical comfort temperature of the swimming pool water is considered to be up to 28-31 °C for in door pools.

While maintaining the comfort temperature, heat losses from the pool to the ambient are occurring. The energy required to maintain the comfort temperature could be significant. The energy for heating the pool may come from gas or oil boilers, heat pumps or direct electricity. These energy sources are associated with CO_2 emission during operation, unless the electricity is from a renewable energy source. The relatively low temperature requirements for the pool can easily be reached with simple solar collectors, when solar radiation is available.

According to the International Energy Agency (IEA), 6% of the World's total installed capacity of solar thermal systems is for swimming pool heating, mainly outdoors [1]. This is a total capacity of 26 GWth (Gigawatt thermal power). Of all solar thermal system types, pool heating with simple unglazed collectors has the lowest levelized cost of heat of 1-2 Eurocent per kWh according to the IEA. This means short payback periods, typically less than 5 years.

1.1. Scope

The scope of this report is to evaluate the potential for using solar thermal collectors for heating swimming pools. In addition, the potential of utilizing PV panels and combined photovoltaics and thermal collectors is investigated. The focus is on indoor swimming pools in summerhouses in Denmark.

A simulation model of a case house with an existing indoor swimming pool in a poolroom is made, and solutions with different solar heating systems are simulated. Simulations are carried out with the software Polysun 9.1.

The costs of the different solutions and simple payback periods are estimated.

1.2. Swimming pool energy balance

1.2.1. Losses

Several researchers have studied the heat losses and gains to and from swimming pools. Douglass E. Root, Jr. describe the mechanisms for heat loss and heat gain of a swimming pool [2]. He states that, heat losses from a pool comprise primarily from evaporation from the surface, convection and infrared radiation. The endothermic process of evaporation of water cools the remaining water in the pool. The relative humidity of the ambient governs the evaporation losses, where a dry ambient lead to higher evaporation losses, and a humid ambient gives lower evaporation. The wind speed affects the convection loss to a high extend. Losses from conduction to the ground is usually very small and is often neglected in warmer climates. Some heat is lost via infrared irradiation exchange with the sky if the pool is outdoors. Sartori presents a critical review of the equations used for calculation of evaporation rate from water surfaces [3]. Czarnecki shows in a study back in 1963, that when a pool is not in use, a transparent cover is an effective way to reduce heat loss from evaporation [4]. Air pockets in the cover will reduce convection losses. However, it must be noted that water on top of cover (e.g. after rain or leakage) still has a cooling effect. This is due to the fact that as the water evaporates and cools the pool water below, if there is no insulating gap [5].

1.2.2. Gains

Heat gains to a pool may come from direct solar radiation or convection when the ambient temperature is higher than the pool temperature. Govaer and Zarmi present an analytical model of direct solar heating of swimming pools [6]. They consider open and closed pools and with the model, they can predict the heating demand. They model the conditions over the year. Transparent covers may let direct solar radiation in the pool while reducing the evaporative losses. Francey and Golding study the optical characteristics of pool covers related gains from direct solar radiation. They state that short wave radiation penetrates into the water depending on the wavelength of the radiation [7]. They also state that well-functioning pool covers act as selective transmitters. The covers admit the shorter wavelength radiation of the solar radiation and are reflective of the long wavelengths of the infrared radiation. The infrared radiation accounts for the radiation heat loss e.g. to the cold sky or surroundings.

1.2.3. Outdoor pools

Szeicz and McMonagle [8] investigate the heat balance of outdoor swimming pools in Toronto, Canada, and find that pool covers reduce the heat loss by evaporation during the day and the radiative heat loss during the night. Solar collectors with an area of 50% of the pool surface worked well for heating the pool. Also sheltering off wind had significant impact on the heat losses. Implementing these strategies for increasing the pool temperature resulted in an almost doubling the days of the swimming season. During an extended period of bad weather, however, these measures may not be sufficient to provide comfortable pool temperatures.

Rakopoulos and Vazeos [9] validate a model of the energy fluxes of an outdoor swimming pool in Athens, Greece. They find that the heat losses were dominated by evaporation from the surface of the pool and a cover over the pool at nighttime significantly reduced the heat losses. Heating of pool was not needed in the summer period. Unglazed solar collectors with an area of 62% of the pool surface kept the pool at the required temperature level of 24-27 °C during the winter months. The pool water was circulated through the collectors. Hahne and Kübler present the validation of a simulation model of the thermal performance for outdoor swimming pools in Germany [10]. They find that local wind velocities to a very large extend affected the thermal losses from the pools. Molineaux et al. present a thermal analysis of an outdoor swimming pool heated by unglazed solar collectors in Switzerland [11]. They determine a convection heat exchange coefficient, but they find that radiative heat losses are higher than evaporative heat losses. Ruiz and Martínez developed a TRNSYS model for a system with an open-air pool in Spain and validated it against measurements of the pool temperature and meteorological data [12]. They elucidate the potential for heating the pool with unglazed solar collectors. Katsaprakakis study replacing the existing heating system for an outdoor pool in Greece with various renewable energy solutions and find payback periods of less than 5 years [13]. Also Mousiaa and Dimoudi study the energy performance of outdoor pools in Greece and find that there is a huge potential for cost savings and reduction in emission of greenhouse gasses by implementing energy conserving methods [14]. Dongellini et al. study heating of outdoor pools in Italy using a MATLAB/Simulink model and find that unglazed collectors were the better choice. However, evacuated tubular collectors could be used, if there was a limited area for installing the collectors [15]. Haaf et al. also describe a validated model of solar heating systems of a large open air swimming pool including the energy balance of the pool [16]. Alkhamis and Sherif study the feasibility of a solar assisted outdoor swimming pool heating system [17]. The study of the system including domestic hot water preparation and storage tanks is made with the simulation software TRNSYS.

De Winter presents the experiences of operating a do-it-yourself solar heating system for swimming pools and concludes that the simple installation has a long life time and efficiently heats the pool [18],[19]. Lam and Chan present the life cycle energy cost analysis of heat pumps for heating of roof top swimming pools in tropical climates and find potential for substantial saving compared to conventional heating methods [20]. They do however not consider solar collectors.

1.2.4. Indoor pools

Brambley and Wells investigate energy usage and saving of indoor pools [21]. They present a theoretical model of the energy balance of the indoor pool including convective, evaporative, radiative and conductive heat transfer as well as heat losses in the piping system. They find that in the investigated case, the heat loss was dominated by the evaporative heat loss, which accounted for approximately 70% of the total heat loss. They also find that the ventilation rate of the indoor zone highly affected the heat loss. They recommend setting the ventilation rate to the minimum, which lives up to the requirements if possible. Singh et al. have made a simple transient analytical model for indoor swimming pool heating and validate it against experimental measurements [22]. In a technical note Tiwari and Sharma present an analytical expression for indoor swimming pool heating with solar collectors and heat exchanger [23]. In this model, the evaporation and convection losses are included. Chow et al. present a case study of a solar assisted heat pump system for indoor swimming pool and space heating in Hong Kong using a TRNSYS model [24]. They conclude that the proposed system would have a short payback period of less than 5 years.

Kincay et al. do a performance analysis of indoor Olympic sized swimming pools in Turkey focusing on heat losses and gains from solar collectors [25]. They find that for the indoor pool, the losses from evaporation is by far the largest. They suggest the optimal collectors areas for the pools in various locations based on economy. Tagliafic et al. do a study on solar assisted heat pumps for heating profiles which fit indoor pool heating demands in Italy [26]. The analyzed system was with a water-to-water heat pump coupled with unglazed collectors. Buonomano et al. present a case study of a solar heating system for an existing in- and outdoor swimming pool in Italy [27]. The system with a combined Photovoltaics and thermal collectors are simulated in TRNSYS.

1.2.5. Overview of heat loss mechanisms

Indoor and outdoor swimming pools are subject to very different environments, which leads to different heat losses and gains. Francey et al. lists in an article the mayor boundary characteristics which affect the heating of pools indoor or outdoor [28]. The list has been adopted with additional findings and presented in Table 1.

Table 1. Mechanisms of passive heat gains and losses of indoor and outdoor swimming pools.

Outdoor pool	Indoor pool
Direct solar gains = pool heating in sunny conditions	No or little direct solar gain
Humidity conditions of ambient air = large evaporation loss	Humidity controlled and larger = evaporation losses affected by indoor climate
Ambient air temperature = convective loss or gain	Indoor air temperature relatively close to pool temperature = low heat transfer by convection
Natural wind = large convective losses	Controlled ventilation rates with low air velocity = small convective heat losses
Low sky temperature = infrared radiation losses	Surfaces of surrounding building structures close to pool temperature = low infrared radiation losses.
Rain and top-up water = losses by colder water mixing	Top-up water = losses by colder water mixing

For outdoor pools, the heat balance of the pool is governed by the weather conditions such as solar radiation, air and sky temperature, humidity and wind speed. An effective way to reduce losses is to cover the pool when not in use to reduce heat losses from evaporation of the pool water. In addition, shielding off wind if the pool is in an exposed location will reduce convective heat losses. Circulating the pool water through unglazed collectors is a simple and efficient way to heat outdoor pools.

For heating indoor pools, the heat balance of the pool should be considered in conjunction with the room where the pool is located. At indoor swimming pools, the water is typically kept at 28-31 °C and the air temperature 2-3 K higher to reduce convective and evaporative heat losses from the pool and to provide comfort. When the air temperature is slightly higher than the water temperature, the evaporative heat loss counters the convective gain and there will be limited heat transfer between the pool and the room. In such case, the heating requirements of the room may be larger than for heating the pool due to a heat loss from the room to the ambient. Low room temperature, which leads to evaporation of the pool water, may also lead to moisture problems in the building. If the air temperature is too low, evaporation will increase, which leads to a higher need for dehumidification. Heat losses due to evaporation from an indoor pool is governed by the indoor relative humidity and thereby the ventilation rate or dehumidification. Controlling the indoor humidity of the room, so that moisture damage of the building is avoided, while keeping the relative humidity at a desired level (typically 55-60%), and thereby reducing evaporation, will lead to reduced energy for heating the pool. Also for indoor pools, using a pool cover when the pool is not in use to limit heat losses is recommended.

The heat losses from the pool to the ground is affected by the level of insulation of the pool walls and bottom and the ground temperature. The water volume affects the total heat capacity and thereby the time it takes to heat up the pool. If the pool is kept at a constant temperature year round, the requirement for this may not be relevant. Another thermal loss is from the topping up with new water to the pool after spillage and evaporation. The added water is normally about 10 °C. There may be heat losses in pipes between the pool and the plant room or gains from the pump that circulate the pool water through the filter. The distance between the pool and the plant room is typically small and the heat losses in the pipes are likely countered by the heat gain of the circulation pump for the filtering.

1.3. Solar heating solution for swimming pools

The optimal heating system for a pool depends on whether the pool is located indoors or outdoors and the period of the year where it is used. Also boundary conditions such as geographical location, local weather conditions including solar radiation affects the design.

A solar heating system consists of a solar collector where the solar radiation is absorbed as heat and transferred to a heat transfer fluid. A piping system circulates the heat transfer fluid to and from the collectors and the place of demand (pool, space heating or hot water tapping) potentially via a storage.

Solar collectors are optimally orientated towards south in the northern hemisphere and with a tilt 10-15° lover than the latitude of the location. This means 45° degree in Denmark. However, the margin for the optimal orientation is quite large and a non-optimal orientation can be compensated for by adding extra collector area. Objects such as trees may cast shadows on the collector, which will reduce performance.

1.3.1. The unglazed solar collector system

Unglazed collectors convert solar radiation into hot water with a high efficiency when they operate at a temperature close to the ambient temperature. With higher temperature differences between ambient and collector fluid, the heat losses from the collectors increase because they are uninsulated and unglazed. The heat loss from the unglazed collector is high when the ambient temperature in low and they may therefore not provide any useful power in the colder periods of the year. The performance of unglazed collectors is also highly affected by the wind speed they are exposed to as this affects the convection losses. Installing windshields around the collectors may enhance their performance.

A system with unglazed collectors can be simple where the pool water is circulated through the collectors. The collectors are typically of a plastic material, which can withstand the chemicals of the pool water. In some cases, the pump for circulating the pool water though the filter of the pool can also be used for circulating the pool water through the solar collectors.

For optimal performance, a control is needed in order to start the flow through the collectors when the temperature in the collector is higher than in the pool, and to stop it again when the collector temperature drops below the pool temperature. The control can also have a set point that stops the pool heating when a maximum temperature is reached.

Different system configurations are possible. If the water needs to be circulated through the filter when the collectors are not in use, an automated valve controlled by the control unit can be used to either direct the flow through or bypass the collectors. In some cases, it is enough to filter the water when it also runs through the collectors. In this case, the automated valve can be omitted.

As the pool water circulates in the collectors, they need to be emptied when there is a risk of freezing to avoid damage of the collectors and pipes. Therefore, installing the collectors so that drainage is easy is recommended. This is typically accounted for when the collectors are installed tilted, however, also the piping has to be considered. A few simple valves can be used for closing of the outside part of the solar collector loop in the winter.

If the heat produced in the solar collectors cannot be transferred away for the collectors e.g. in case of no demand or pump failure, the temperatures in the collectors increases to a point where the incoming radiation balances the heat losses. For an unglazed collector this is normally below the boiling temperature of water. Therefor no special arrangement is needed to solve stagnation in unglazed collectors.

A solar heating system with unglazed collectors can quite cost efficiently heat pools and extend the swimming season of outdoor pools. For Danish conditions, a rule of thumb for unglazed collectors for outdoor pools is that, a collector area of 50% of the pool surface area is recommended when the pool is covered when not in use and 67% of the pool surface area if the pool is not covered [29].

1.3.2. The glazed solar collector system.

Systems with glazed collectors such as flat plate collectors or evacuated tubular collectors typically perform better than the unglazed in cold conditions because the glazing reduces the convective heat losses from the collector. Flat plate collectors are also insulated on the backside. They are therefore less affected by wind and have higher performance when the temperature difference between the heat transfer fluid and the ambient is higher compared to the unglazed collectors. The glazed collectors may give a contribution in winter days with sunshine.

The solar collector loop outside the building needs to be protected from freezing to avoid damaging the pipes and collector. An antifreeze heat transfer fluid (glycol-water mixture) is therefore used in the solar collector loop. The piping system typically operate at a pressure above ambient. Thermal expansion of the heat transfer fluid needs to be accommodated for via an expansion tank. There are also systems, which operate with a drain back principle where expansion vessel and freeze protection of the heat transfer fluid can be avoided.

The heat absorbed in the heat transfer fluid is transferred to the pool water, a storage tank or the indoor heating system via a heat exchanger. If the heat is transferred to the pool water, the heat exchanger needs to be able to withstand the chemicals in the pool water. The requirement to a pool water heat exchanger is typically higher compared to a normal heat exchanger.

A separate pump for the solar collector loop is needed. A simple temperature difference thermostat controller can be used to start and stop the flow through the collectors. Typical controller start- and stop differences are 2-4 K and 0.5-1 K. Heat losses in pipes and energy for the pumps should be considered. When the requirement of the solar heating is relative low, high flow rates of 1-1.5 l/min/m^2 (liters per minute per square meter solar collector) are typically optimal.

In case of pump failure or no heat demand during sunny conditions, the heat transfer fluid in the collectors my start to boil. This stagnation can be accommodated for by the expansion vessel when the system is designed correctly.

A number of collectors can be connected in series or in parallel. A parallel connection will require more piping and will take longer to install. There may be concerns with obtaining an equal flow distribution through the parallel connected collectors. Adjustable valves can be used to obtain a uniform flow distribution. Serial connected solar collectors require less piping but there will be a higher pressure drop across the collectors which may require a pump with higher capacity. This is especially the case when high flow rates are needed. The collector performance is unaffected of the connection types when the overall flow rates are the same.

1.3.3. Solar air heating systems

Solar air heaters can be utilized for heating air in buildings and for dehumidifying the air. When the sun shines on the solar air collector, a small PV panel starts a ventilator, which sucks fresh air through the collector where the air is heated and then blown into the building. In some systems, an exhaust ventilator is needed to make sure the building is fully ventilated; in other systems, air is lost via leaks in the building. The ventilator can also be controlled by a controller, which operates based on temperature sensors. The thermostatic controller can be used to control a ventilator to a desired flow rate, which gives a specific inlet temperature. The solar air heater can also be used with an advanced controller, which controls both the temperature, ventilation rate and the humidity of the room. Figure 1. Shows a simple principle of the solar air collector.

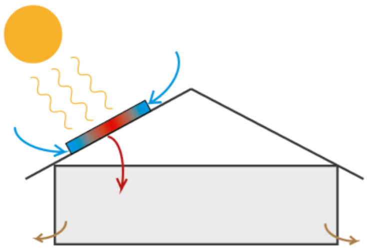


Figure 1. Principle of solar air collector.

1.3.4. PV systems

Solar cells (Photovoltaics – PV) convert solar radiation into electricity. PV system can be with or without storage. Batteries are used for storing electrical energy. The electricity can either be used directly on the site or sold to the electricity grid when production exceeds demand. Electricity sold to the grid is typically for a much lower price than the cost of buying electricity and depends on current feed-in tariffs.

The efficiency of solar cells decreases with increasing temperatures. Wind which removes excess heat from the PV panels therefore have a positive effect on their performance. Soiling or partial shading of the PV array has a very negative effect on the performance. Therefore, surrounding trees, other buildings, flag or electricity poles must be considered when planning a PV system to a higher extend than for a solar thermal system.

Inverters are needed in a PV system to convert the electricity produced in the panels to match the 220 V electricity of the grid. PV systems are often grid connected without battery storage. Battery storage can increase self-consumption of the produced electricity.

Technologies that combine photovoltaics and thermal collectors are emerging. The combined PVT panels produce both electricity and hot water.

2. Vacation houses with swimming pools in Denmark

Vacation houses with swimming pools have an average yearly electricity consumption of approximately 31,000 kWh according to the report “Varmepumpeanlæg til fritidshus eventuelt i kombination med solvarme” from 2006, [30]. A luxury vacation house has average yearly electricity consumption of approximately 10,000 kWh. This shows that the presence of a pool gives a significant increase in energy consumption. This increase may be directly linked to the pool facility such as heating of the pool and the poolroom, pumps and dehumidification. The report also states that the domestic hot water consumption is three times larger in houses with pool compared to similar sized houses without pools. This is most likely because people are showering before and after using the pool. The pool houses also tend to be larger and occupied by more people than other summerhouses.

The majority of this electricity consumption is for space heating, domestic hot water (DHW) preparation and pool heating and is covered by different electric heating elements. The majority of houses with pools have separate heating systems for the residential area and the pool area.

An electric heater controlled by the thermostat typically heats the pools. The poolrooms are typically heated by electric floor heating systems and possibly also by an electric heater connected to the dehumidifier. 10% have electric radiators in the poolrooms.

2.1. Energy usage

According to the report “Varmepumpeanlæg til fritidshus eventuelt i kombination med solvarme” from 2006 [30]:

- 16% (5000 kWh) of the electricity use is for electric appliances, which cannot be replaced by heating system.
- 3% (1080 kWh) of the electricity use is for the dehumidifier in the poolroom which runs up to 4-6 hours per day with a power of 1 kW when the house is in use.
- 23% (7150 kWh) of the electricity use is for heating the residential area and bathrooms.
- 16% (4930 kWh) is for domestic hot water preparation and the associated losses.
- 7% (2090 kWh) is for hot water to the spa and the associated losses.
- 23% (7070 kWh) is for heating the poolroom and is covered by electric floor heating or radiators.
- 12% (3770 kWh) is for heating of the pool and is covered by the electric heating integrated in the technical installation of the pool.
- A total of 80% (25,010 kWh) of the electricity consumption is for heating purposes which is currently covered by electric heating system. This heating demand can be covered by alternative heating systems with heat pumps combined with solar heating systems as the report suggests.
- A total of 42% (12,930 kWh) of the electricity consumption is associated with heating the pool including the spa facilities.

2.2. Case summerhouse

A selected NOVASOL test summerhouse with indoor pool located in Saltum, Denmark is considered as the case for the study [31]. It has a 17 m^2 swimming pool. The pool is located in a room on the south side of the building. The poolroom area is estimated to 42 m^2. The orientation is estimated to be 10° towards west and the slope of the roof 30°. See Figure 2 and Figure 3

Figure 2. Selected NOVASOL test summerhouse with indoor pool in Saltum, Denmark.

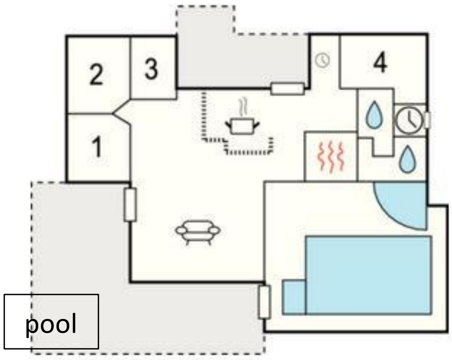


Figure 3. Floor plan of NOVASOL test summerhouse with indoor pool.

3. Calculations

Simulations of the base case of the existing heating system for the pool and poolroom as well as various solar heating systems for heating the pool and the room are carried out in the simulation software Polysun 9.1 [32]. Polysun has previously been used for investigations of thermal systems [33–35].

The energy savings by operating the proposed solar heating systems is estimated from the reduction of energy use of the existing electrical heating system.

Initially a model for the existing pool and poolroom is build up. As no specific construction details are available for the building and pool, the model of the existing pool and pool heating system is built up as a typical pool/poolroom heating system. The model is calibrated against the listed values for energy usage for the different parts of a vacation house in section 2.1. The U-values, which represents the heat loss through the façade of the building/poolroom, and the U-value of the pool walls, which represent the heat loss from the pool to the ground, is set so that the modelled energy consumption match the listed value in section 2.1. Layout of the poolroom including windows are estimated based on the pictures.

3.1. Model limitations

The poolroom is modelled as a building for itself and no heat exchange between the poolroom and the rest of the building is considered.

The software does not include the dynamic of heat transfer between the pool, the poolroom and the rest of the building. To evaluate the heating loads for both the pool and the poolroom they are therefore considered as separate systems. The room temperature set in the indoor pool component is not used in the balance of the building demand. The surface temperature of the room is considered the same as the air temperature of the room in the model. In reality this will not be the case when façade is to ambient and the outdoor temperature is lower than the room temperature. This affect the heat transfer by infrared radiation between the pool and the building structure. In the simulation of the pool, the air temperature is therefore set to be the same as the water temperature to avoid an unrealistic high infrared heat gain to the pool from the structures.

Heat transfer from the pool to the room may be large and depend on the actual pool and room temperature. According to the model, changing the room temperature a few degrees largely affects the heating requirements for the pool itself.

3.2. Base case

A model consisting of systems for heating the poolroom and the pool is made. The poolroom is heated by an electric floor heating system and the pool is heated by an electrical heating element. The model calculates the electrical energy demand for the pool and poolroom heating.

The house is assumed occupied from March 1 to November 30, 275 days of the year to model the typical use of a summerhouse in Denmark according the NOVASOL [31].

3.2.1. Swimming pool boundaries

The following assumptions are made in the model for the pool

- Pool is 4.8 m x 3.5 m and 1.3 m deep.
- Pool temperature is 29 °C.
- 1 kW electric heating element for pool heating[1].
- Surrounding walls/air temperature is set to 29 °C.
- U-values of the pool wall 0.55 W/m^{2}K.
- Occupied 4 hours per day from 12-16.
- Basement/ground temperature 10 °C.
- Humidity is set to 55%.
- Fresh water supply/exchange 0.9 % per day.
- The pool is covered when not in use with a cover that limits the heat losses by 70%.

3.2.2. Poolroom boundaries

- Poolroom temperature is 31 °C.
- U-value of the room is 0.34 W/m^{2}K.
- 3.5 kW electric heating element for floor heating.
- Wall to window ratio is estimated based on the pictures of the house to be 25% on south facing façade, 1% on north and east façade and 6% on west façade.

Figure 4 represents the model of the base case with electric floor heating for the building/poolroom and the electrical heating element for the indoor pool.

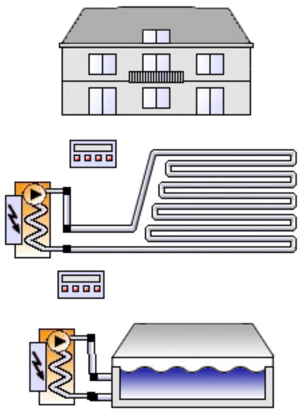


Figure 4. Base case scenario of an indoor pool in a poolroom with electric floor heating.

[1] 1kW is the smallest heating element that can cover the heating demand of the pool. In reality, the heating element in the pool may be larger. For the systems with solar thermal heating, the power of the electric heating element has minor effect. For the systems with PV, the power of the heating element will affect the fraction of electricity produced by the PV that is directly consumed. That is, if the power of the heating element is higher than the output of the PV then the heating demand is only partly covered by the PV production.

3.3. Pool heating systems

A number of different systems for heating the pool water and poolroom solar collectors are presented.

Solar collectors for heating the pool facilities are assumed to be placed on the roof above the poolroom. An estimation of partial shading from the trees on the east side of the building is made based on the pictures of the case summerhouse.

The existing electric heating of the pool is used as backup when the solar collectors cannot cover the demand. To prioritize the solar thermal system over the electric heating, the control set point for electric heating remains at 29 °C while the set point for solar heating is 30 °C. This makes sure that the electric heating element is only used when insufficient solar energy is available. This also implement a little storage of energy in the one-degree temperature difference between the two set points. The control stops the flow through the collectors when the set point is reached. This is to avoid overheating of the pool. In this case, the collectors goes into stagnation and the solar heat gain is lost to the ambient.

For all simulations, the solar collectors are assumed to have a tilt angle of 30° and facing south-south-west with an azimuth angle of -10°. This orientation represents the solar collectors being placed directly on the roof on the NOVASOL test summerhouse. The relative low inclination of 30° of the collectors will give a good performance of the collectors in the summer period. For better performance in the winter periods, lager inclination of 45° or higher should be used.

3.3.1. Unglazed collectors for pool

A simple pool heating system with unglazed solar collectors is simulated. The collectors are connected via pipes to the existing pool pump and the pool water is circulated through solar collectors. The system runs with a simple differential thermostat controller with temperature sensors in the collector and the pool water. It is assumed that the pump for circulating the pool water through the water filter is also used to circulate the water through the solar collectors. No expansion tank or heat exchanger is needed for this system. A three-way valve is used for the system.

The simulation is carried out with an efficiency expression of collectors from the company OKU Obermaier GmbH [36]. The collector efficiency is expressed as:

$$\eta = 0.89 \cdot (1 - 0.064 \cdot u) - (16.24 + 1.8 \cdot u) \cdot \Delta T / G$$

Where u is the wind speed in m/s, ΔT is the temperature difference between the average heat transfer fluid temperature and the ambient in K and G is the solar irradiance in W/m^2.

The wind speed at the collector surface is assumed to be 30 % of the wind of the Design Reference Year's wind velocity which is from a free standing sensor. This parameter highly affects the thermal performance of the unglazed collector.

The volume flow rate of the heat transfer fluid circulating through the collectors is assumed 1.2 l/min/m^2.

Figure 5 illustrates the system.

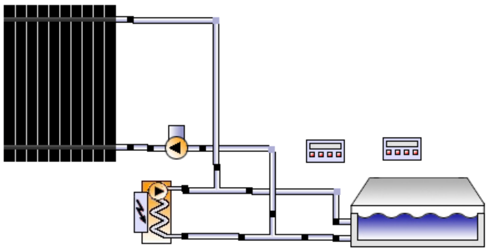


Figure 5. Unglazed solar collectors directly connected to the pool.

Variations with a collector area of 9 m^2 and 18 m^2 are made to show the effect of different system sizes. Variations with 10%, 30% and 50% wind speed fraction at the collectors are simulated to evaluate the effect of different wind speed fractions. Variations with the temperature set point for the solar pool heating of 29 °C, 29.5 °C, 30 °C and 31 °C are made to evaluate the control strategy of the solar heating system including the effect of a few degrees heat storage in the pool.

3.3.2. Glazed collectors for pool

Systems with evacuated tubular and flat plate collectors connected to the pool are simulated. The solar collector loop is connected to the pool pump loop via a heat exchanger. The heat exchanger needs to be of a quality that withstands the chemicals in the pool water. The solar collector loop needs to be filled with a freeze protected heat transfer fluid such as a water glycol mixture. An extra pump is needed for the solar collector loop, which also needs an expansion vessel. Possible stagnation protection is needed as the heat transfer fluid might boil during stagnation. The control can be a simple solar controller similar as for the unglazed system.

The system is simulated with Sonnenkraft VK25 evacuated tubular collectors with the efficiency [37]:

$$\eta = 0.605 - 0.85\ \Delta T/G - 0.01\ \Delta T^2/G$$

and with Sonnenkraft SK500N-ECO-AL flat plate collectors with the efficiency [37]:

$$\eta = 0.763 - 3.322\ \Delta T/G - 0.018\ \Delta T^2/G$$

Expressions on efficiency is based on the aperture area of the collector. The flow rate in the collector loop was set to 1.2 l/min/m^2 collector area.

Wind has minor influence on the performance of glazed collectors. The simulation is therefore carried out with 30% wind speed fraction at the collector array.

The systems are illustrated in Figure 6 A and B. The only difference in the type of collectors.

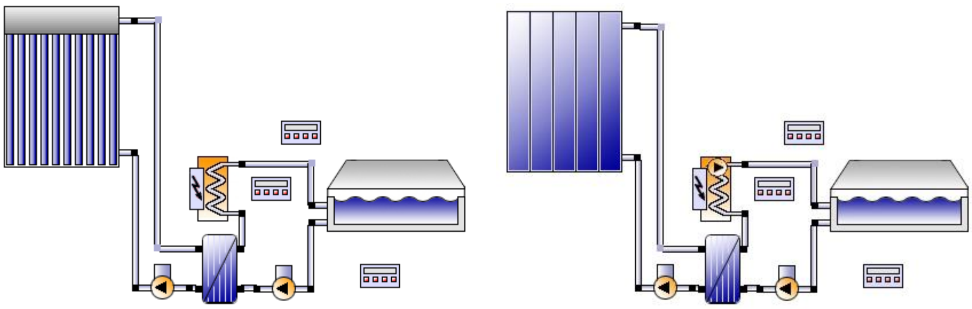


Figure 6 A and B. Solar heating system with evacuated tubular collectors and flat plate collectors connected to the pool via heat exchanger.

Variations with different collector areas are simulated. Variations with the temperature set point for the solar pool heating of 29 °C, 30 °C and 31 °C are made.

3.4. Room heating systems

3.4.1. Glazed collectors to room heating

A system with flat plate solar collectors connected to radiators is simulated. The system consists of the collectors, a pump, pipes, an expansion vessel, radiators and a controller. Stagnation protection is needed, as the system most likely will overheat in sunny periods in the summer.

The existing electrical floor heating system is used as back up when the solar heating system can not cover the demand. The set point for the electrical floor-heating unit remains at 31 °C, while the set point for the solar heating system is set to 32 °C. This is to favor the solar heating over the electrical heating.

The system is illustrated in Figure 7.

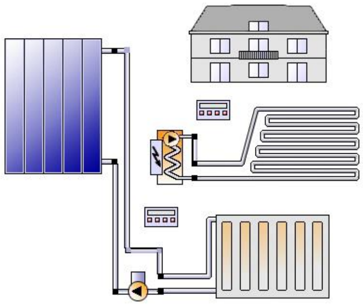


Figure 7. Evacuated tubes connected to radiator.

Variations with different collector areas are simulated. Variations with the temperature set point for the solar heating system for the room of 31 °C, 32 °C and 33 °C are made to evaluate the control strategy and the few degrees heat storage in the poolroom.

3.4.2. Glazed collectors to room heating with buffer storage tank

As heat is needed during nighttime when no solar radiation is available. The potential of integrating a buffer storage tank for the space heating system is investigated. The buffer tank can be charged when there is more solar energy available than what is directly used. The stored heat can then be used to heat the room when there is a heating demand but no solar radiation. The existing electrical floor heating system is used as back up when the solar heating system can not cover the demand. A storage tank with an inlet stratifier is considered. The system requires three pumps, a heat exchanger and a controller, which can operate both the solar collector loop and the space-heating loop. Different buffer storage tanks and collector areas are simulated. The principle of the system is illustrated in Figure 8.

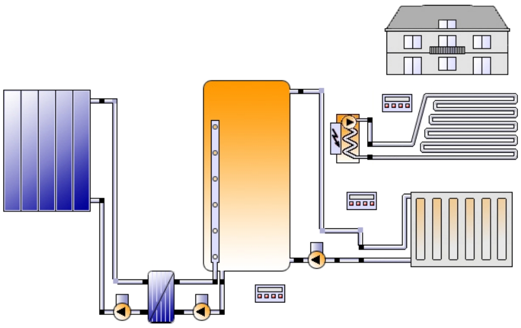


Figure 8. Flat plate collector connected to buffer storage tank with stratifier.

3.4.3. Solar air collector

The estimated performance of the SolarVenti SV30 is calculated. An expression of the collector efficiency is estimated from the test reports of the solar air collector [38], [39] to be:

$$\eta = 0.6 - 6\,\Delta T/G$$

The performance of the solar air collector was calculated based on weather data for the mid coastal region of Jylland including the irradiance and the ambient temperature [40], [41]. The performance is calculated for the collector operating with an inlet temperature of 33 °C. The system needs a variable speed ventilator and control for the air collector to operate as indicated.

It is assumed that the poolroom has a constant temperature of 31 °C in the season from March to November. The total heat loss from the poolroom over the season is calculated to 7070 kWh. The heat demand for maintaining the 31 °C is assumed equal to the heat loss. Hourly values for heat demands for the room and heat gains from the collector are calculated. When the gain over an hour is larger than the demand the excess energy is regarded as non-useful.

No storage in the building is considered. Depending of the control for the air collector, the room may be heated above the temperature of the electric heating setting of 31 °C. In this case, some heat will be stored in the building delaying the need for the electric heating to start. This is not considered but it is assumed that some heat will be stored in the building material and the useful heat from the collectors therefore is higher than the calculations show.

The useful gain from the collectors is calculated for solar air collector areas from 1 to 15 m^2.

The solar air heater will also dehumidify the poolroom. Currently up to 1080 kWh are used for the dehumidifier per year [30]. The effect of the dehumidifier is not calculated in detail but it is assumed that the solar air heater will cover 50% of the demand for dehumidification of the poolroom.

3.5. PV systems

The feasibility of installing a PV system for supplying the electricity to the existing electrical heating elements is investigated. It may be beneficial to utilize the electrical heating elements already in place in the existing building and provide the electricity from PV panels.

Currently feed in tariffs of electricity produced by private PV systems are 0.6 kr/kWh for the first 10 years. After this, the tariff will be 0.4 kr/kWh. Special funds targeted households allow for feed in tariff of 0.74 kr/kWh for the first 10 years [42].

Only the electricity used for the heating elements are considered in this study. Electricity use for other purposes are not considered.

3.5.1. PV without storage

Systems with Sonnenkraft PV modules of the type 280 WP MONO are simulated. System sizes of 5/10/20 kWp consisting of 18/36/72 panels with an array area of 30/60/120 m^2 are investigated. A wind fraction of 30% on the array is considered. The panels are considered mounted with a tilt of 30° and an azimuth of -10°.

The produced electricity is either directly used by the electric heating elements when the time of production overlaps with the heating demand. Otherwise, the produced electricity is sold to the electricity grid. Electricity for the electrical heating system comes from the grid when there is a heating demand and the PV is not producing electricity. The system is illustrated in Figure 9.

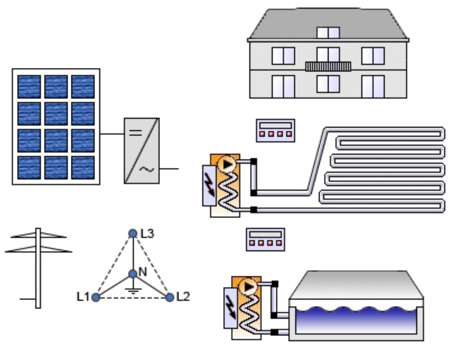


Figure 9. Grid connected PV system

3.5.2. PV system with battery storage

Systems with different PV array sizes and battery storage capacities are simulated. The batteries are Fronius Energy Package 6/12 from Fronuis International GmbH with nominal capacities of 4.8 kWh and 9.6 kWh. The PV are 5/10/20 kWp arrays of Sonnenkraft´s 280 WP MONO.

The battery is charged when the electricity production exceeds the demand of the heating elements. When there is a heating demand and the PV panels do not produce electricity, the battery is discharged. The system is illustrated in Figure 10.

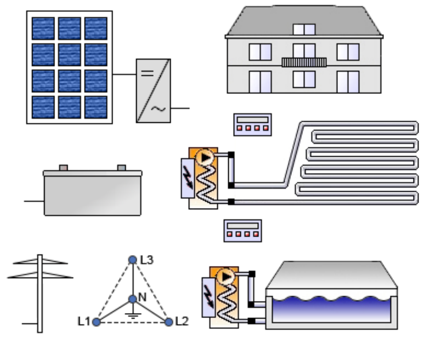


Figure 10. Grid connected PV system with battery storage.

3.6. Combined Photovoltaics – Thermal collectors

Solutions for combined photovoltaic and solar thermal collector panels are emerging. The company Racell manufacture hybrid PVT panels, which can be retrofitted to existing building or be used as a façade building element. The solar cells in Racells modules are with an efficiency of up to 19%.

The efficiency of the electricity production of solar cells decreases with increasing temperature of the panel. The panels are uninsulated to keep the temperature of the solar cells low. The thermal side of the PVT panel can potentially remove heat from the panels and thereby increase the electric output of the PV compared to PV without the thermal element. To fully utilize the thermal side of the PVT modules, the temperature increase should be high enough to cover a heating demand.

In this scenario, the thermal part of the PVT modules are connected to the swimming pool, which has a relatively low temperature requirement. Therefore, the heating of the pool and the cooling of the PV may fit well together. No official efficiency test has been carried out with the Racell PVT panels. Therefore, the efficiency expressions are estimated. The useful generated electricity of the PVT also depends on the efficiency of the inverter installed in the system. In the simulation, inverters with an efficiency of approximately 90% are used.

It is assumed that the pool water cannot be directly circulated through the PVT collector. The outside part of the collector loop is anti-freeze protected and connected to the pool water loop via a pool water heat exchanger. Like for the PV system the generated electricity is either directly used by the electric heating element of the pool or poolroom heating or delivered to the grid. The system needs two pumps and a simple controller for the thermal part of the system. Systems with 10, 20 and 30 m^2 PVT collectors are simulated.

The system is illustrated in Figure 11.

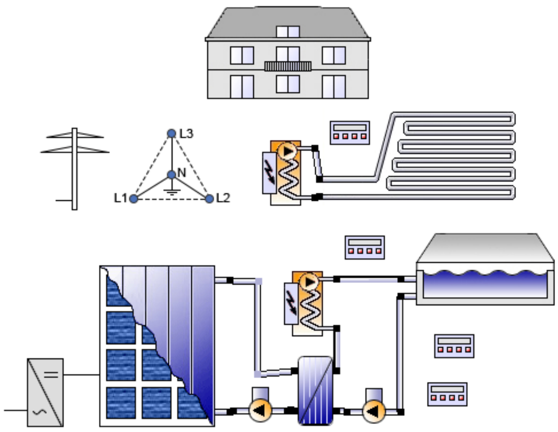


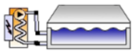
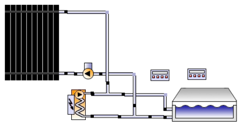
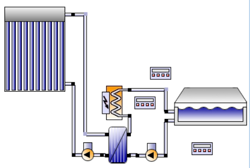
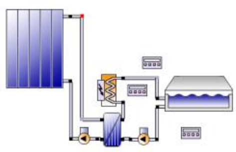
Figure 11. PVT collectors connected to the pool.

4. Simulation results

Table 2 to Table 6 summarizes the yearly performance of the investigated systems. For each scenario the electricity consumption for the electric heating systems and the solar yields for one year are listed. The electricity use and the solar yield may sum up to be higher than the base case demand because the temperature of the pool and pool room will be slightly higher in the case with solar heating due to the control strategy. The energy savings are calculated as the difference between the energy consumption of the base case (3,600 kWh/year) and the electric energy demand in the cases with the respective solar heating systems installed. The cost savings are based on an electricity price of 2.3 kr/kWh.

Table 2 summarizes the scenarios for heating the swimming pool with solar collectors.

Table 2. Overview of performance and saving of solar thermal systems for pool heating.

Scenario	**System**		**Boundary**	**Pool heating**		**Yearly savings**	
	Coll. area (no. of collectors)	Control temp. setting	Wind speed	Electric energy	Solar energy	Energy	Cost
	m^2	°C	-	kWh	kWh	kWh	DKK
 Electric pool heating	NA	29	NA	3,600	0	0	0
 Unglazed collectors for pool, electric backup.	9.5 (9 coll.)	29	30%	3,157	480	443	1,019
		29.5	30%	2,260	1,462	1,340	3,082
		30	30%	2,142	1,660	1,458	3,353
		31	30%	2,083	1,789	1,517	3,489
	19 (18 coll.)	29	30%	3,079	560	521	1,198
		29.5	30%	1,921	1,848	1,679	3,862
		30	0%	1,347	2,673	2,253	5,182
		30	10%	1,459	2,536	2,141	4,924
		30	30%	1,692	2,252	1,908	4,388
		30	50%	1,955	1,937	1,645	3,784
		31	30%	1,543	2,698	2,057	4,731
		32	30%	1,499	2,951	2,101	4,832
 Evacuated tubular collectors for pool, electric backup.	5 (2 coll.)	29	30%	2,870	729	730	1,679
		30		1,263	2,523	2,337	5,375
		31		1,250	2,558	2,350	5,405
	10 (4 coll.)	30		561	3,581	3,039	6,990
	15 (6 coll.)	30		355	3,928	3,245	7,464
	20 (8 coll.)	30		262	4,092	3,338	7,677
 Flat plate collectors for pool, electric backup.	2.6 (1 coll.)	30 °C	30%	2,259	1,351	1,341	3,084
	5.1 (2 coll.)	29 °C		2,797	802	803	1,847
		30 °C		1,250	2,585	2,350	5,405
		31 °C		1,222	2,676	2,378	5,469
	7.7 (3 coll.)	30 °C		849	3,192	2,751	6,327
	10.3 (4 coll.)	30 °C		630	3,516	2,970	6,831
	15.4 (6 coll.)	30 °C		420	3,840	3,180	7,314
	20.5 (8 coll.)	30 °C		326	4,003	3,274	7,530

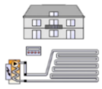
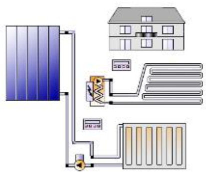
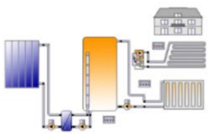
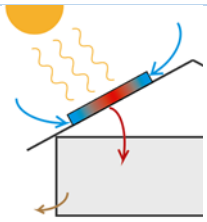
It can be seen that the unglazed collectors connected to the pool a can cover 40-53% of the energy demand for heating the pool depending on the collector area. The glazed collectors can cover up to 90% of the heating demand for the pool if a large system is installed. The high fraction is because thermal energy is stored in the thermal mass of the pool water over a few days when it has been heated 1-2 K above the electric heating set point. In addition, the good performance of the glazed collectors in the spring and autumn results in larger coverage by the glazed collectors compared to the unglazed collectors.

Variations of the wind fraction showed that the wind speed had a strong impact on the performance on the system with unglazed collectors.

Table 3 shows the results for the simulation of the collectors connected to radiators for space heating of the poolroom with and without the buffer storage tank and the calculations for the heating performance of the air solar collector.

A wind speed fraction at the collector surface of 30% is assumed for all calculations. The energy savings from dehumidification by the solar air collectors are not included.

Table 3. Overview of performance and saving of solar thermal systems for space heating of poolroom. *not including dehumidification.

Scenario	System			Room heating		Yearly savings	
	Coll. area (no. of collectors)	Tank volume	Control temp. setting	Electric energy	Solar energy	Energy	Cost
	m^2	liters	°C	kWh	kWh	kWh	DKK
 Electric floor heating	NA	NA	31	7,200	0	0	0
 Flat plate collectors for room heating, electric backup.	5 (2 coll.)	NA	31	7,075	139	125	288
			32	5,490	1,835	1,710	3,933
			33	5,347	2,049	1,853	4,262
	10 (4 coll.)		32	4,756	2,641	2,444	5,621
	15 (6 coll.)		32	4,357	3,084	2,843	6,539
	20 (8 coll.)		32	4,117	3,351	3,083	7,091
 Flat plate collectors for	10	250	32	4,383	3,048	2,817	6,479
	10	500		4,185	3,270	3,015	6,935
	10	750		4,079	3,391	3,121	7,178
	10 (4 coll.)	1000		4,005	3,480	3,195	7,349
	20	500		3,296	4,272	3,904	8,979
	20	750		3,141	4,451	4,059	9,336
	20 (8 coll.)	1000		3,048	4,561	4,152	9,550
 Solar air collector for room heating, electric backup.	1 (1 coll.)	NA	33	6,670	409	400*	920*
	2 (1 coll.)			6,331	819	739*	1,700*
	3 (1 coll.)			6,088	1227	982*	2,259*
	4 (2 coll.)			5,916	1636	1,154*	2,654*
	5 (2 coll.)			5,795	2045	1,275*	2,933*
	6 (2 coll.)			5,702	2454	1,368*	3,146*
	9 (3 coll.)			5,515	3681	1,555*	3,577*
	12 (4 coll.)			5,407	4908	1,663*	3,825*
	15 (5 coll.)			5,337	6135	1,733*	3,986*

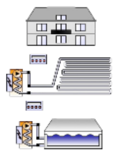
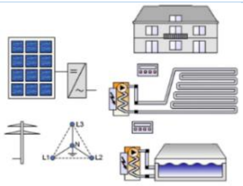
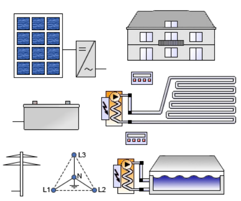
It can be seen, that the systems with flat plate collectors connected to radiators for heating the poolroom without the buffer storage tank covers 23-42% of the heating demand. If a buffer tank is installed up to 57% of the heating demand can be covered.

Air solar collectors can cover up to 24% of the heating demand. Additional savings of 540 kWh or 1242 DKK/year can be expected for a reduction in the need for the already in place dehumidifier to operate.

Little thermal energy is stored in the building materials (thermal mass) and when there is a high heat loss from the building, the control strategy of heating the building to 1-2 K above the electric heating set point only benefits short term.

Table 4 shows the electricity production and the interaction with the electricity grid and the estimated yearly savings for the PV systems with and without battery storage. The yearly savings are calculated as the difference of standard cost of running the pool and poolroom heating (10,800 kWh at 2.3 DKK/kWh, 24,840 DKK/year) and cost of the electricity purchased from the grid minus the income of electricity sold to the grid at the feed in tariff of 0.74 DKK/kWh for the first 10 years and a feed-in tariff of 0.4 DKK/kWh afterwards. The wind speed fraction was 30 %.

Table 4. Overview of performance and saving of installing PV system.

Scenario	**System**		**Electricity yearly**				**Yearly savings**
	PV peak power (area)	Batt. Cap.	Elec. prod.	Self/direct consumption	To grid	From grid	0.74/0.4 tariff
	kWp (m^2)	kWh	kWh	kWh	kWh	kWh	DKK
 Electric heating, No PV	NA	NA	0	0	0	10,800	0
 PV system grid connected, electric heating.	5 (30)	NA	4,655	1,532	3,122	9,379	5,571/4,513
	10 (60)		9,070	1,891	7,189	9,019	9,416/6,972
	20 (120)		18,141	2,389	15,752	8,521	16,898/11,543
 PV system grid connected with battery, electric heating.	5 (30)	4.8	4,655	2,383/1,533	1,973	8,528	6,686/6,015
	5 (30)	9.6	4,655	2,857/1,533	1,332	8,053	7,304/6,851
	10 (60)	4.8	9,070	2,897/1,891	5,818	8,012	10,718/8,740
	10 (60)	9.6	9,070	3,560/1,891	4,924	7,350	11,579/9,905
	20 (120)	9.6	18,141	4,259/2,389	13,224	6,651	19,328/14,832

It can be seen that even with large PV systems the fraction of self-consumption is relatively small. A majority of the produced electricity is fed to the grid. The feed in tariffs therefore highly affects the economy of the systems. For these systems, no thermal storage is considered. A smart control of the system where the pool is heated to a higher temperature, and thereby storing some heat, when solar energy is available may enable more self-consumption of the PV generated electricity. Further, the direct use of electricity for other household appliances may improve the economy of the PV system.

Table 5 and Table 6 summarized the electric and the thermal yield of the simulated PVT system. The total saving for PVT is the sum of the electric part and the thermal part. The wind speed fraction was 30 % at the collector and the temperature control setting for the thermal part of PVT for the pool heating was 30 °C.

Table 5. PVT system electrical part

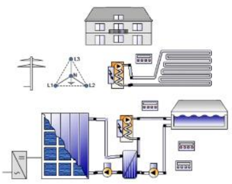
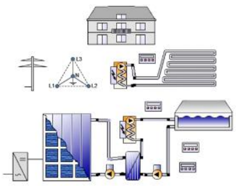
Scenario	**System**	**Electricity yearly**				**Yearly savings**
	PVT area (Peak power)	Electricity production	Self/direct consumption	To grid	From grid	0.74/0.4 tariff
	m^2 (kWp)	kWh	kWh	kWh	kWh	DKK
Electric heating for pool and pool room, No PVT	0	NA	NA	NA	10,800	0
 PVT grid connected, electric backup.	10 (1.7)	1,406	395	1,011	9,591	4,411/3,662
	20 (3.4)	2,798	595	2,203	9,005	5,759/5,010
	30 (4.9)	4,530	772	3,759	8,664	7,694/6,416

Table 6. PVT thermal part.

Scenario	**System**	**Pool heating yearly**		**Yearly savings**	
	PVT area	Electric	Solar collectors	Energy	Cost
	m^2	kWh	kWh	kWh	DKK
Electric heating of pool, No PVT	0	3,600	0	0	0
 PVT grid connected, electric backup.	10	2,660	991	940	2,162
	20	2,276	1,471	1,324	3,045
	30	2,110	1,687	1,490	3,427

In the investigated scenarios, the heating demand for the pool is covered by up to 41 % by the thermal part of the PVT panels. This is slightly lower than the for the unglazed collector system. The lower thermal efficiency is due to some to the incoming solar irradiance is converted into electricity and not thermal energy.

5. Cost

The cost calculations are made with an electricity cost of 2.3 kr/kWh. No interests or future electricity price increase are considered. Prices for the systems are determined including 25% VAT. Tax reductions for energy renovation (håndværkerfradrag) are not considered. Tax circumstances related the owner selling of electricity to the grid or renting out the summerhouse as well as potential subsidies for installing the solar energy systems, are not included in this study. Maintenance costs are not considered but are assumed to be low. The simple payback time is calculated as investment cost divided by yearly cost savings. The economical surplus/profit after 20 years is calculated. The life times of the systems are considered to be 30 years or longer.

The economics of the most promising simulation scenarios are calculated. Scenarios with set points for the solar heating for the pool/room of 30/32 °C are used.

The main components of the systems and their costs are listed along with estimated installation costs. VVFS.dk estimates an installation cost for solar thermal systems of 50-67% of the cost of the system. The installation cost depends on the ease of access to the roof, complexity of the system, potential connection to existing system in the house and the experience of the craftsman installing the system.

5.1. Unglazed solar collectors

A quote of a complete system with 9 m^2 unglazed collectors for pool heating was obtained from OKU Obermaier Gmbh, Germany with a price of 1607 EUR incl. VAT. The cost of an 18 m^2 system was estimated based on the quote. Installation of the system was estimated to be 50% of the system cost. Delivery cost was estimated and included in the installation cost. The economy of the unglazed collector system for pool heating is presented in Table 7. Yearly saving has been transferred from Table 2.

Table 7. Economy of unglazed collector systems.

Collector	System cost	Installation cost	Total cost	Yearly saving	Payback time	20 year saving
OKU	DKK	DKK	DKK	DKK/year	Years	DKK
9 m^2	12,053	7,526	18,079	3,353	5.4	48,989
18 m^2	22,043	12,521	33,064	4,388	7.5	54,704

The smaller system has a shorter payback time of 5.4 year but the larger system has potential for larger savings over the lifetime of the system.

5.2. Evacuated tubular collectors to pool

Cost of components for the glazed evacuated tubular collectors system are listed in Table 8. The costs are based on pricelists from Sonnenkraft, "Varmt vand fra solen" and "solbadet".

Table 8. Components for tube to pool system.[1] www.sonnenkraft.dk, [2] www.vvfs.dk, [3] www.solbadet.dk

Component	Product	Price incl. tax
Evacuated tube collector[1]	VK25	8,625 DKK/coll. (2.5 m^2)
Mounting brackets[1]	Sonnenkraft 2/4/6/8 panels	1,538/2,812/4,125/5,250 DKK
Circulation pump[2]	Grundfos UPS 25-40	775 DKK
Controller[2]	Technische Alternative ANS 21	999 DKK
Pool heat exchanger[3]	Aquatemp 44/69 kW	3,895/4,995 DKK
Expansion vessel[2]	Zilflex 35/50/80 liters	399/450/800 DKK
Solar collector fluid[2]	Tyfocor LS 20/30/40 liters	370 DKK/10 liter
Pips incl. insulation[2]	Flex pipes/Aeroflex 20/30/40 meters	61 DKK/meter

Installation of the system is assumed to be 60/55/50/45 % of the cost of the components depending of the system size. The system, installation including delivery and total cost of the system are listed in Table 9 along with the saving and payback time. Yearly savings are transferred from Table 2.

Table 9. Evacuated tubular collector to pool system economy.

Collector	System cost	Installation cost	Total cost	Yearly savings	Payback time	20 year saving
VK25	DKK	DKK	DKK	DKK/year	Years	DKK
5 m^2	26,450	16,336	42,971	5,375	8.1	63,611
10 m^2	46,491	25,911	72,712	6,990	10.5	66,208
15 m^2	66,384	33,430	100,226	7,429	13.5	48,354
20 m^2	85,739	38,760	124,972	7,645	16.3	27,932

The 5 m^2 system has a shorter payback time but the 10 m^2 system has potential for larger savings over the life time of the system. The 20 m^2 system seems to be overaized.

5.3. Flat plate collectors to pool

The components and their costs for the flat plate collector systems are listed in Table 10

Table 10. Components for flat plate collector to pool systems.[1] www.sonnenkraft.dk, [2] www.vvfs.dk, [3] www.solbadet.dk

Component	Product	Price incl. tax
Flat plate collector[1]	SK500N-ECO-AL	4,750 DKK/coll. (2.5 m^2)
Mounting brackets[1]	Sonnenkraft 1/2/3/4/6/8 panels	737/962/1,412/2,137/3,062/3,375 DKK
Circulation pump[2]	Grundfos UPS 25-40	775 DKK
Controller[2]	Technische Alternative ANS 21	999 DKK
Pool heat exchanger[3]	Aquatemp 44/69 kW	3,895/4,995 DKK
Expansion vessel[2]	Zilflex 35/50/ liters	399/450 DKK
Solar collector fluid[2]	Tyfocor L 20/30/40 liters	295 DKK/20 liters
Pips incl. insulation[2]	Flex pipes/Aeroflex 20/30/40 meters	61 DKK/meter

Installation of the system in assumed to be 60/55/50/45 % of the cost of the components depending of the system size. The system, installation, delivery and total cost of the system are listed in Table 11 along with the saving and payback time. Yearly savings are transferred from Table 2.

Table 11. Flat plate collector to pool system economy.

Collector	System cost	Installation cost	Total cost	Yearly saving	Payback time	20 year saving
SK500N-ECO-AL	DKK	DKK	DKK	DKK/year	Years	DKK
2.5 m^2	13,081	8,498	21,579	3,084	7.0	40,101
5 m^2	18,056	11,483	29,539	5,405	5.5	78,561
7.5 m^2	23,256	13,441	36,696	6,327	5.8	89,844
10 m^2	30,182	17,250	47,431	6,831	6.9	89,189
15 m^2	41,828	21,564	63,391	7,314	8.7	82,889
20 m^2	51,640	23,888	75,528	7,530	10.0	75,072

The 5 m^2 system has a shorter payback time of 5.5 year but the larger systems have potential for larger savings over the life time of the system.

5.4 Flat plate to radiator

The main components for the solar space heating system is listed in Table 12.

Table 12. Components for flat plate collector to space heating.[1] www.sonnenkraft.dk, [2] www.vvfs.dk, [3] www.solbadet.dk,

Component	Product	Price incl. tax
Flat plate collector panel[1]	SK500N-ECO-AL	4,750 DKK/coll. (2.5 m^2)
Mounting brackets[1]	Sonnenkraft 2/4/6/8 panels	962/2137/3,062/3,375 DKK
Circulation pump[2]	Grundfos UPS 25-40	775 DKK
Controller[2]	Technische Alternative ANS 21	999 DKK
Radiator	1700 W (1-4 pcs)	1,700 DKK/pcs
Expansion vessel[2]	Zilflex 35/50/ liters	399/450 DKK
Solar collector fluid[2]	Tyfocor L 20/30/40 liters	295 DKK/20 liters
Pipes incl. insulation[2]	Flex pipes/Aeroflex 20/30/40 meters	61 DKK/meter

Installation of the system is assumed to be 60/55/50/45 % of the cost of the components depending of the system size. The system, installation, delivery and total cost of the system are listed in Table 13 along with the saving and payback time. Yearly savings are transferred from Table 3.

Table 13. SK500 Flat plate collector to space heating system economy.

Collector	System cost	Installation cost	Total cost	Yearly saving	Payback time	20 year saving
SK500N-ECO-AL	DKK	DKK	DKK	DKK/year	Years	DKK
5 m^2	16,461	10,526	26,987	3,933	6.9	51,673
10 m^2	29,182	16,700	45,881	5,621	8.2	66,539
15 m^2	42,213	21,756	63,969	6,539	9.8	66,811
20 m^2	54,020	24,959	78,979	7,091	11.1	62,841

The smaller system has a shorter payback time but the larger systems has potential for larger savings over the lifetime of the system.

5.5 Flat plate to radiator with storage

The system with buffer tank needs a more advanced controller and three pumps and an extra heat exchanger. The cost of the inlet strafifier is from Eyecular Technologies. Table 14 lists the component additionally needed to include a storage in the solar space heating system.

Table 14. Components for buffertank.[1] www.vvfs.dk, [2]http://eyecular.com/

Component	Product	Price incl. tax
Storage tank[1]	VVFS' buffertank FLEX 250/500/750/1000 l	5,575/6,075/7,225/7,875 DKK
Inlet stratifier[2]	Eyecular	500 DKK
Controller[1]	Technische Alternative UVR63	1,925 DKK
Heat exchanger[1]	VVFS	1,985 DKK

Installation of the system in assumed to be 60/50 % of the cost of the components depending of the system size. The system, installation, delivery and total cost of the system are listed in Table 15 along with the saving and payback time. Yearly savings are transferred from Table 3.

Table 15. Flat pate and buffer tank system economy.

Collector + storage tank	System cost	Installation cost	Total cost	Yearly saving	Payback time	20 year saving
SK500 + FLEX	DKK	DKK	DKK	DKK/year	Years	DKK
10 m^2+ 250 l	39,257	23,554	62,810	6,479	9.7	66,770
10 m^2 + 500 l	39,757	23,854	63,610	6,935	9.2	75,090
10 m^2 + 750 l	40,907	24,544	65,450	7,178	9.1	78,110
10 m^2 + 1000 l	41,557	24,934	66,490	7,349	9.0	80,490
20 m^2 + 500 l	64,595	32,298	96,893	8,979	10.8	82,688
20 m^2 +750 l	65,745	32,873	98,618	9,336	10.6	88,103
20 m^2 + 1000 l	66,395	33,198	99,593	9,550	10.4	91,408

The smaller systems have shorter payback times but the larger system has potential for larger savings over the life time of the system.

5.6 Air solar collectors

The components needed for installing solar air collector from SolarVenti is listed in Table 16

Table 16. components for solar air heaters.

Component	Product	Price incl. tax
Solar Air collector	SV30K (3 m^2)	14,200 DKK
Roof mounting kit	SolarVenti	1,865 DKK
Exhaust ventilator	SolarVenti	1,850 DKK
Advanced controller	SolarVenti	2,000 DKK

Estimated installation cost of the air collectors are from SolarVenti. The system, installation and total cost of the system are listed in Table 17 along with the saving and payback time. Yearly savings are transferred from Table 3. Also the saving for dehumidification is included.

Table 17. Economy of solar air heaters.

Collector	System cost	Installation cost	Total cost	Yearly saving (heat)	Yearly saving (dehumid.)	Payback time	20 year saving
SV30K	DKK	DKK	DKK	DKK/year	DKK/year	Years	DKK
1 stk	17,915	4,500	22,415	2,259	1,242	6.4	47,605
2 stk	35,830	8,000	43,830	3,146	1,242	10.0	43,930
3 stk	53,745	11,000	64,745	3,825	1,242	12.8	36,595

A small system with one SV30K air collectors shows to have most favorable economy. This is due to the large fraction of saving coming from the dehumidification which is independent on the collector area.

5.7. Photovoltaics systems

Cost of PV systems are from Sonnenkraft´s pricelist. The 5 kWp system is a package price. Cost of mounting brackets are added. The costs of the larger systems are based on the prices of additional components.

Table 18. Components for PV system. [1] www.sonnenkraft.dk

Component	Product	Price incl. tax
5 kWp 280 WP mono package[1]	Incl. inverter, DC-box, cables etc.	43,868 DKK
Mounting brackets[1]	For each 5 kWp	6,000 DKK
PV panel[1]	280 WP-MONO	1,800 DKK per panel
Inverter[1]	For 10/20 kWp	15,000/18,000 DKK
Fronius Solar Battery incl. smart meter[1]	Capacity 4.8/9.6 kWh	52,125/83,625 DKK

The cost of installation of the PV systems are approximated based on information from SOLEL.dk. Payback time is calculated with the 0.74 DKK/kWh feed in tariff for the first 10 years and 0.4 DKK/kWh for the remaining. Cost saving are transferred from Table 4.

Table 19. Economy of PV systems.

PV + Battery	System cost	Instal. cost	Total cost	Running cost 0.74/0.4 tariff		Yearly saving 0.74/0.4 tariff		Payback time	20 year saving
280WPmono + Fronius	DKK	DKK	DKK	DKK/year		DKK/year		Years	DKK
Base	0	0	0	24,840	24,840	0	0	NA	0
5 kWp	49,868	15,000	64,868	19,269	20,327	5,571	4,513	12.0	35,975
10 kWp	95,260	18,000	110,260	15,424	17,868	9,416	6,972	12.7	50,620
20 kWp	178,910	23,000	193,910	7,942	13,298	16,898	11,543	12.9	82,496
5 kWp + 5 kWh	107,993	15,000	122,993	18,154	18,825	6,686	6,015	19.3	4,011
5 kWp + 10 kWh	139,493	15,000	154,493	17,536	17,989	7,304	6,851	21.9	- 12,946
10 kWp + 5 kWh	159,385	18,000	174,385	14,122	16,100	10,718	8,740	18.0	17,188
10 kWp + 10 kWh	190,885	18,000	205,885	13,261	14,935	11,579	9,905	19.4	5,948
20 kWp + 10 kWh	286,535	15,000	301,535	5,512	10,008	19,328	14,832	17.8	32,072

The investigations showed that the PV systems have longer payback periods than the thermal systems. Battery storage did not improve the economy of the systems.

The electrical appliances in the house was assumed to use 5000 kWh/year. An estimated 25% of this electricity demand can be directly from the PV. This equates to an additional cost saving of 2000 DKK per year for the 5 kWp system reducing the payback time by 6-7 months.

5.8. PVT system

The cost of the PVT panels is from Racell.

Table 20. Components for PVT system. [1] www.racell.dk, [2] www.vvfs.dk, [3] www.sonnenkraft.dk

Component	Product	Price incl. tax
PVT collector panel[1]	Racell	2,200 kr/ m^2
Inverter[3]	For 2/3.5/5 kWp	10,000/13,000/15,000 DKK
Circulation pump[2]	Grundfos UPS 25-40	775 DKK
Controller[2]	Technische Alternative ANS 21	999 DKK
Pool heat exchanger[3]	Aquatemp 44 kW	3,895 DKK
Expansion vessel[2]	Zilflex 35 liters	399 DKK
Solar collector fluid[2]	Tyfocor L 20 liters	295 DKK/20 liters
Pips incl. insulation[2]	Flex pipes/Aeroflex 20 meters	61 DKK/meter

Racell states that their panel are easy and fast to install. This is considered in the installation cost which is estimated. The economy of the PVT system is listed in Table 21, cost saving are transferred form Table 5 and Table 6.

Table 21. Economy of PVT system.

Module size	System cost	Install. cost	Total cost	Yearly saving 0.74/0.4 tariff		Payback time	20 year saving
PVT	DKK	DKK	DKK	DKK/year		years	DKK
10 m^2	40,419	18,000	58,419	6,573	5,824	8.9	65,549
20 m^2	64,644	23,000	87,644	8,804	8,055	10.0	80,944
30 m^2	89,254	28,000	117,254	11,121	9,843	10.5	92,395

The payback time for the PVT system is 9 years or longer. The larger system has the potential for larger savings over the lifetime of the system compared to the other systems.

6. Discussions and alternative technologies

Generally, the seasonal usage of the vacation house favor the use of solar heating systems as the house is mainly in use in the spring, summer and fall where the solar radiation can cover a significant part of the heating demand.

Combining some of the presented solution may be possible and beneficial. Installing individual or combined systems for both the pool and poolroom heating is possible.

Implementing smart control strategies, which predict heating demands, based on weather forecasts, future electricity prices and incorporates thermal energy storage in the building, pool or buffer storage may further improve the systems and reduce electricity use.

Apart from the savings for the pool and poolroom heating, there is also a potential for large electricity savings by installing solar heating system for the domestic hot water (DHW) consumption. A majority of the hot water demands can potentially be covered by a simple solar domestic hot water system, especially when considering the seasonal usage. These systems require a water storage in which heat for a few days can be stored. Solar water storage tanks are typically larger than normal water storage tanks and need an auxiliary heating source. The DHW solar heating system can normally be retrofitted to the existing water heating system of the building if it consists of a central water storage.

Solar heating system can also be combi system, which provide both DHW and space heating. This will require a water carrying heating system with radiators or floor heating for the building.

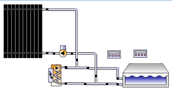
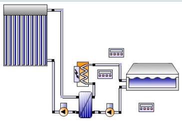
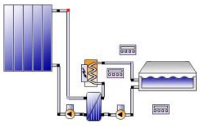
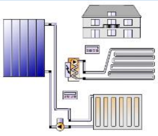
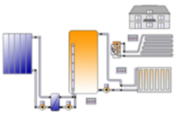
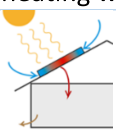
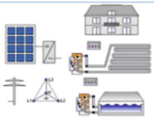
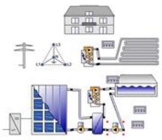
In the period where the house is not in use and it needs to be kept frost and moisture free. The Solar air collectors can heat and dehumidify the residential part of the house at low running cost.

Solarventi made a combi solar liquid/air collectors which could be used for heating both air and water e.g. the SolarVenti30 [43] . Some system may potentially benefit from this type of collector.

7. Conclusions and summary

The economy of selected sizes of the presented system are listed in Table 22 with rounded numbers. It can be seen that all the system provide substantial savings when considering a 20 year period. The thermal systems seems have shorter payback periods compared to the PV systems. Especially the simple unglazed collector and solar air collector system have short payback periods. When considering the investments cost and the 20 years saving the thermal system have a better saving to investment ratio but he PV/PVT systems gives a larger total saving after 20 years.

Table 22. Summary of economy of the presented system.

System	**Investment**	**Running cost savings**	**Payback**	**20 year saving**
	DKK	DKK/year	Years	DKK
 19 m^2 unglazed to pool	33,000	4,400	7,5	55,000
 10 m^2 tubes to pool	73,000	7,000	10.5	66,000
 10 m^2 flat plate to pool	47,000	6,800	6.9	89,000
 10 m^2 flat plate to space heating	46,000	5,600	8.2	67,000
 10 m^2 flat plate to space heating w 1000 l storage	66,000	7,300	9.0	80,000
 3 m^2 solar air collector	22,000	3,500	6.4	48,000
 20 kWp 120 m^2 PV system	194,000	17,000/12,000	12.9	82,000
 30 m^2 PVT system	117,000	11,000/10,000	10.5	92,000

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Products and components

The following manufactures and suppliers has been considered in this study;

Unglazed collectors:

OKU GmbH (http://www.okuonline.com/en/products.html)

Flat plate and evacuated tubular collectors:

Sonnenkraft A/S (www.sonnenkraft.dk)

Solar Air heater/dehumidifier:

SolarVenti A/S (http://www.solarventi.dk/)

Various components: controllers, buffer tank, pumps, pipes, heat exchangers etc.

Varmt vand fra solen (http://www.varmtvandfrasolen.dk/)

Inlet strafitier: http://eyecular.com/

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