Unglazed Solar Thermal Systems for building integration, coupled with District Heating Systems. Conceptual Definition, Cost & Performance Assessment

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Abstract

With limited access to fossil fuels, there is a need to reduce the consumption of these. In order to achieve that, renewable and innovative solutions are increasingly common in domestic energy supply. For this reason, solar thermal systems are increasingly used in buildings. Equally, District Heating systems are systems are identified as a key technology to de-carbonize heat supply in Europe.
To ensure a wide market adoption of solar thermal systems, technologies should be compatible with the architectural design of the building. Thus, it is highly recommendable a discreet technology that enables designers to implement it without constraints, for example without aesthetical issues that limit the integration of solar thermal systems to roofs out of the sight of observers at street level.
From all the thermal solar energy systems that actually exist, the unglazed collectors are the best choice for this application. Despite the fact that these collectors are quite simple, they are a suitable technology to reach low-to medium temperature levels required by modern heating systems such as Low Temperature District Heating (LTDH)
The aim of this study is to analyse the performance of an unglazed system integrated in an existing building. In this case study, the energy performance of the installation is analysed, coupled with District Heating. Moreover, the economic comparison between some different ways of installation is shown.

1 Introduction

The potential of solar power and technological devices taking profit of it is well known. The solar radiation is divided into two types: the direct radiation and the diffuse radiation, both of them useful for the exploitation of this energy source. In gross numbers, the amount of solar energy reaching Earth's surface in one hour is the same that the energy used in the whole world in a complete year. It is true that not all the energy reaching the surface is useful and the exergy of this energy is quite low. However, the potential is still the biggest one to find in the planet.
Nowadays, the energetic transition from fossil fuels to renewable energy sources is one of the most important issues that people are facing, and in this context, solar energy is still in the phase of development. A clear example of this transition is the minimum solar contribution required by national building codes in developed countries such as the Spanish CTE [1]. In most common cases, solar thermal (ST) systems are only sized in order to cover just a part of the whole demand for thermal energy. The heat demand changes all over the year. The demand for SH (Space Heating) is interrupted in summertime in most places, but DHW (Domestic Hot Water) is required all year round. For this

reason, heat captured by ST in wintertime is not sufficient for covering heat loads in buildings, while in summertime solar heat production clearly exceeds the demand of the building.
District-Heating (DH) systems are one of the most efficient ways in order to cover heating demand in urban areas. Traditionally, DH systems have been designed to operate in centralised way, where there is a large gas boiler or a large CHP (Combined Heat & Power) responsible for producing heating energy. Nowadays, there is a trend to incorporate distributed energy sources, commonly with lower exergy in comparison with traditional high temperature power plants. This includes the exploitation of industrial waste heat or other renewable energy sources, such as Solar Thermal Systems. All this results in a reduction of consumption of fossil fuels and contribute to a de-carbonised environment.
With lower operational temperatures and distributed energy sources, there is a substantial reduction of the temperature of the calorific fluid (in most cases, water). It has been demonstrated that heat losses in DH system are proportional to the temperature gradient between supply temperature and environment temperature. This is why, when the supply temperature drops, the performance of the whole system improves.
Finally, with the steady incorporation of nZEB (nearly Zero Energy Buildings) in cities, in the near future the reduction of heat consumption and the utilization of renewable energies far above present ST installations. This will substantially modify the hierarchy in the production-consumption role. With a massive integration of renewable sources such as ST, traditional ST sizing criteria will be modified. As a result, ST systems are expected to generate excess heat that could be useful in a DH network.
For achieving this massive integration of ST, the façade is the best option because of the large available surface. However, there are still some barriers for the incorporation of ST in façades. The most relevant barrier is the economical one. Nevertheless, with the reduction of working temperatures, the opportunities to overtake this limitations increases considerably.
In this paper, the potentialities, constraints and performance levels of the integration of Solar Thermal Systems coupled with LTDH (Low Temperature District heating) are studied, comprising their thermal and economic performance.

2 Unglazed Solar Thermal systems for building integration

The incorporation of solar thermal systems to meet local heating loads needs to study a large amount of possibilities for finding the best solutions. These solutions have been already investigated and demonstrated over the last decades.
The most common way to incorporate ST systems is the utilization of collectors, with a pressurized circuit where the calorific fluid gains energy from the solar irradiation, and increases its temperature. Among all the solar thermal collectors available in the market, the most common ones are evacuated tubes collector, glazed flat plate collector and unglazed solar collectors [2]. In this article, PV and PVT (hybrid Photovoltaic-Thermal) are not considered. In *Figure 1*, performance levels of each technology are shown as a function of environmental conditions.

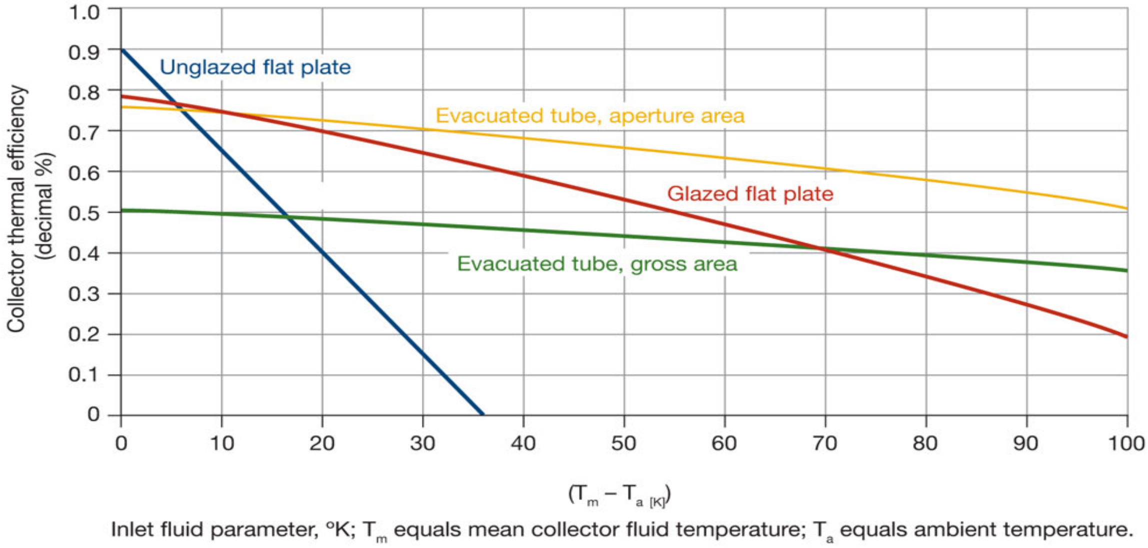

Figure 1: Collector efficiency vs (T_m-T_a) [3]

The efficiency is defined by [3]:

$$Q_u = A_c[S - U_l(T_{pm} - T_a)] \quad (1)$$

$$\eta_u = \frac{\int Q_u dt}{A_c G_T} \quad (2)$$

In the previous equations, Q_u is the total thermal energy loss, A_c refers to the collector surface, U_l is the heat loss coefficient and T_{pm} and T_a are the absorber temperature and ambient temperature respectively. Finally G_T is the total irradiance.

Looking into the performance of the different collectors, it is clearly seen that with low temperature difference, the unglazed collectors show the best performance. The possibility to incorporate these systems in buildings has been studied in diverse investigations such as [4]. Anyhow there are only a few companies who propose to implement collectors in façade, and the technology is still underexploited.

In general, all the collectors are composed by a cover, an absorber, a heat transfer network and rear-side insulation. This composition makes it complex to integrate ST systems in visible parts of buildings. Anyhow smart, but marginal integration solutions for vacuum tubes have been achieved in balconies or transparent areas [5].

Unglazed solar collectors are the simplest collectors from all the collectors above. The way for its integration in façades is explained in [4]. Moreover, the unglazed collector is the only one which can be integrated in façade without modifying the architecture of the building. Specifically, the unglazed solar collector enables varied form (shape, size…) and material (colour, texture…).

In broad terms, it has to be considered that façades are the prominent image of the building. In the selection of ST technologies and their integration of Solar Thermal Façades (STF) the involvement of all the stakeholders in the design is critical, engineers and architects are obliged to work together. The existence of a wide-range of architectural facades obliged to have also a wide range of STF products, what it causes difficulties of design.

3 ST integration into DH systems

In the last decades more and more district heating systems are integrating ST systems. Basically, there are two main ways to realize the integration: centralized and distributed ST systems. The first one is based on a large amount of collectors far away from the consumption point. The distributed one tries to move energy sources closer to consumption points.
Distributed ST systems however, can be connected in different ways and each way performs in a different way. Depending on which are the requirements of the case, it will be connected in one or other way. Basically, [7] describes the types of connections.

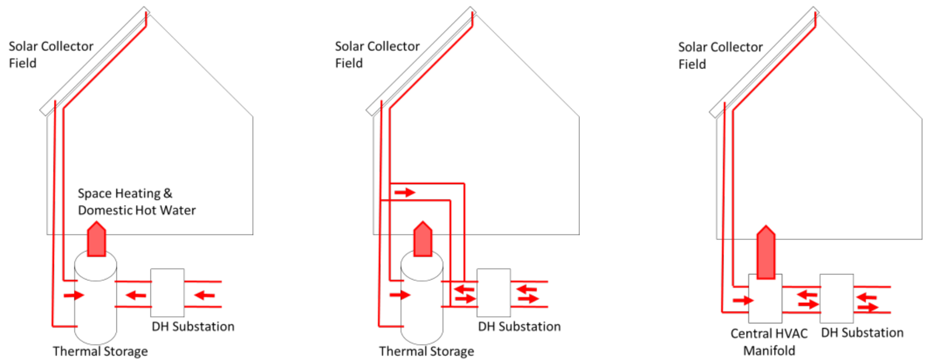

Figure 2: ST integration into DH networks [6]

4 Generation costs analysis

The aim of this part of the article is not only to compare generation costs between different technologies, but also know the possibilities of this technology to success in an economical aspect. For this comparison, natural gas boiler (condensing), joule or electric heating, ground source heat pump, air source heat pump, unglazed solar thermal collector with district heating and without district heating will be considered. For this calculation, it has been taken into account all the devices needed for the installation of each technology. It is true that in each country, the price of primary energies (natural gas and electricity) is different, but it will be taken an average value for considering the maximum amount of countries. The cost of Natural gas and Electricity is showed in Table 1. Costs of investments in different heat production technologies are showed in Table 2. These cost have been estimated based on cost databases in the construction sector in Spain [8]

Table 1: Generation prices for different installations

Technology	Generation cost (€/kW)
Natural gas boiler	91
Joule heater	5
Air-source heat pump	358
Ground source heat pump	1293
Unglazed collector without DH	442
Unglazed collector with DH	82

Table 2: Prices for primary sources

Primary energy	**Price (€/kWh)**
Natural gas	0.14
Electricity	0.056

In the tables above, it is considered that DH heat supply will be generated in CHP plants. It is clearly seen that installing ST collectors in an isolated installation, with auxiliary heat inputs to cover all the heat load of buildings requires a substantially higher investment than incorporating the collector system with a DH supply system. Moreover, the price become more competitive than natural gas boilers that actually are the main technology used in developed countries.

5 ST systems performance

Solar thermal collector in general and unglazed collectors in particular, they show better efficiency data when the difference between collector temperature (average) and environmental temperature is low. In order to limit the average temperature of the solar field, it is common to make collector arrangements in such a way that the inlet-outlet temperature difference is limited to 10 ºC. Serial connection of collectors is commonly limited to 4-6 unit arrangements, which are replicated in parallel.

In the cases where DH is performed, if the heat output is delivered in the return pipe of the DH, greater performances are achieved due to the lower service temperature than insulated ST systems. The efficiency equation that all the manufacturers use is the following:

$$\eta_i = \eta_0 - U_1 \frac{\Delta T}{G_T} - U_2 \frac{\Delta T^2}{G_T} \quad (3)$$

Considering an insulated system where the service temperature is achieved by solar thermal collectors, the efficiency of ST is increased when the service temperature is lower. A particular case study is performed with performance data provided in [9]. In the case of an isolated system, the service temperature must be achieved by the collectors when there is sufficient irradiance and in the case of considering the system coupled with DH, there is no need to configure ST to raise fluid temperature to the overall flow temperature in the DH network. There is a minimum temperature difference (normally 3-5 ºC) that the system must achieve in so that it is worth turning on the pumps to boost the fluid.

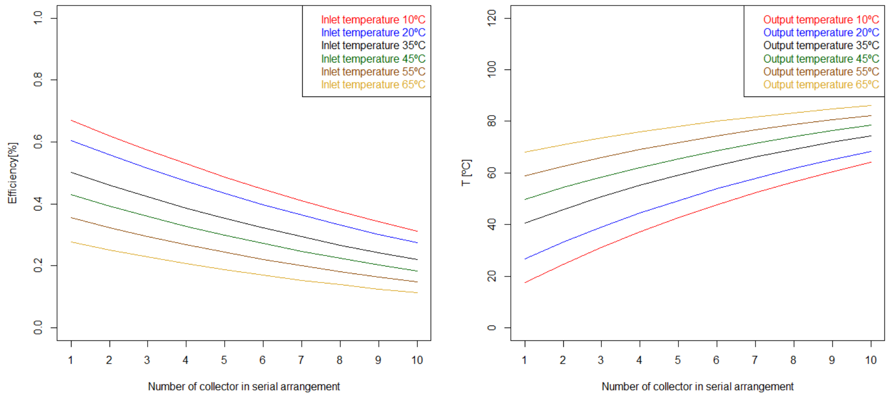

Figure 3: Collector performance for different situations

Depending on the service temperature required, the number of collectors arranged in series increased, so that the surface needed proportionally increases. Taking into account that the delta temperature is limited, the number of collector is also limited.
Nowadays, LTDH (Low Temperature District Heating) is considered as an alternative to ordinary DH, and the working temperatures of this system are much lower for reducing heat losses in supply temperatures. In this cases, the best solution to install ST integrated, is installing the ST system to the return pipe of LTDH system.

6 Economic evaluation

For this economic evaluation, a particular case of a DH network in Barcelona [10] will be taken, where there are two main district heating networks: *Districlima and Ecoenergies*. The main purpose is to study the viability of connecting ST systems to the heat network. In [10] is described the main ways of connecting the solar collectors to the DH in two situations: residential and non-residential buildings. For the case that conceives us, only the residential case will be studied. The most energetically efficient system is connecting the ST to the return pipe of the DH, figure 4. Energy calculations of ST systems presented in this source are used and an economic study over the investment and operational revenues of the system are performed. In this particular case, the total surface of absorption is 77 m^2, composed by 35 plate collectors. The data necessary for this economic evaluation is presented in the next table.

Table 3: Economic considerations for calculations

Energy cost selling to DH network [c€/kWh]	3.9
Energy cost buying to DH network[c€/kWh]	5.12
Initial inversion [k€]	9.439
Solar collector production yearly [MWh/year]	43.925

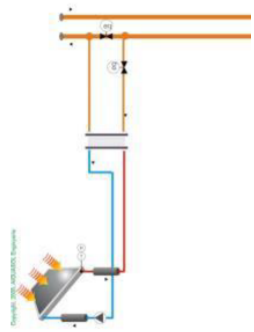

Figure 4: Connection scheme [10]

Depending on the configuration of the DH substation and heat production/purchase strategy in the DH system, the energy production in the solar collectors could be used directly for the self-consumption or sold to the network. The economic analysis shows that the best option to have an adequate ROI (Return of Investment) is making a mix from the two options.

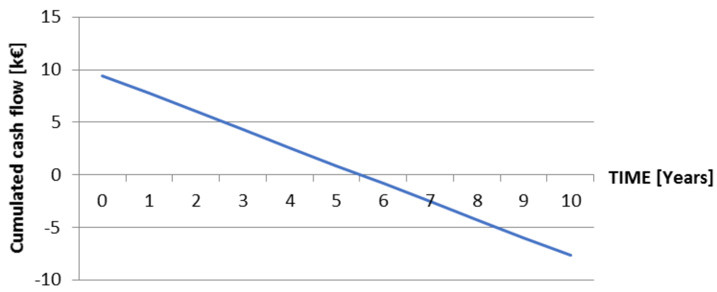

Figure 5: Capital evolution when selling heat to DH

The economic study has been done considering not having any public aid, and the system is still profitable with a reasonable margin.

7 Discussion

In this work the possibility to install solar thermal collectors in the façade of ordinary buildings is presented- The capacity of ST system to satisfy heat demand for both DHW (Domestic Hot Water) and SH (Space Heating) is studied.

The integration of unglazed solar thermal collectors is proposed. These types of solar collectors are promoted in order to limit its architectural impact, with the additional benefit of reduced costs, when compared with other ST technologies. The architectural integration of the collector needs to be addressed in detail within the architectural project of the building, because the possibilities of façade are infinite and the design of the collectors must be in accordance with the façade.

Sizing of ST systems to meet specific heating loads is complex. The full heat load in winter is impossible to satisfy with the only contribution of ST, so it has to be accompanied by alternative energy sources, such as heat pumps or connection to district heating networks.

The recent DH networks try to reduce the supply temperatures in order to reduce heat losses. In this case, low exergy sources are able to contribute in the heat load. In this context, ST technologies can play a role in heat production within DHs, and the selected Unglazed ST collectors can be used to deliver any surplus energy to the DH network. As a result, the share of fossil-fuel fired CHP in DH can be reduced and the incorporation of renewable sources is possible.
As for the economical results, the unglazed collector presents a great opportunity due to the low investment necessary for its implementation. The fact that it is not necessary to connect any heat pumps or auxiliary equipment to meet heat loads in the building results in substantially reduced investment costs. The payback time in both cases is around five years, which is a very reasonable time for this kind of projects.
In this context, the unglazed ST collectors introduce a great solution to fill the technological gap that actually exists.

Acknowledgements

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