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Technical & Economical assessment of the interconnection between façade integrated solar thermal system and low temperature district-heating.

Mikel Lumbreras
1st author's affiliation
Tecnalia, Sustainable Construction Division
Geldo 700, 48160 Derio, Spain
+34 667 101 474
mikel.lumbreras@tecnalia.com

Roberto garay
2nd author's affiliation
Tecnalia, Sustainable Construction Division
Geldo 700, 48160 Derio, Spain
+34 667 178 958
roberto.garay@tecnalia.com

ABSTRACT

This paper explores the techno-economic viability of coupling unglazed solar thermal façade system with a low temperature district heating network. this concept allows a more efficient control strategy for heat is allowed, where direct solar heat and heat from district heating are alternated in order to maximize the efficiency of the whole system. ST heat is directly used in the building when there is underproduction and when ST overproduces, this system allows to take profit from the network for the delivery of the excess heat. The use of unglazed collectors for low-intrusive architectural interaction in façades is discussed. Each system separately have proven efficiency, however, the most novel part of the study is finding a method which permits de combination of both technologies, proposing technical solutions and economic studies.

Unglazed system reach thermal efficiency up to more than 30% in reference of the total radiation in the south façade, which are similar to other high efficiency solar systems. As for the economic results, it has been made an economic assessment at mid-time sight and positive economic meters have been achieved. Moreover, economic results from simulations prove the viability for unglazed solar district heating when integrated massively in facades.

Keywords

Solar systems, Thermal energy, Building integration, Energy systems

1. INTRODUCTION

In developed countries, there is a clear need, and political impulse, to achieve an energetic transition from fossil fuels to renewable sources. Within renewable energy sources, the potential of solar power and associated technologies is well known. In particular, solar thermal systems are a proven renewable heating technology. Although the exergy of this energy source is quite low, the potential of solar energy is still one of the greatest on the planet (Ehsanul, Kumar, Kumar, Adelodun, & Kim, 2018).

DH systems are one of the most efficient ways to cover heat loads in urban areas. Traditionally, DH systems have been based on large boilers or CHP (combined heat & power) systems. Nowadays, it is increasingly common to find DH networks that incorporate distributed energy sources (Monsalvete Álvarez de Uribarri, Eicker, & Robinson, 2017), commonly with lower exergy in comparison with traditional high temperature power plants.

With the steady incorporation of nZEB (nearly Zero Energy Buildings) in cities, relevant reductions in heat loads can be foreseen in the near future. The utilisation of renewable energies in these same buildings will reach a point where the directionality in the production-consumption role will be altered. The increase in ST installation with the reduction of heat loads in buildings modifies traditional ST sizing criteria. As a result, excess heat may be available from these ST systems. In this paper, the connection to district heating (DH) is explored in order to allow this excess production to be used in adjacent buildings.

Potentialities, constraints, and performance levels of façade-integrated solar thermal systems coupled with low temperature district heating (LTDH) are studied, comprising their thermal and economic performance. The techno-economic viability of unglazed façade-integrated solar thermal systems when combined with low temperature district heating systems.

1.1 Ultra Low Temperature District-Heating

The ULTDH or the 4th Generation district heating, unlike traditional heat networks, works with pressurized hot water (and not steam) and they are based on high share of fluctuating renewable sources for heating and cooling. At the same time, the supply and return temperatures are dropped as far as consumption temperature.

Reduced supply temperatures ensure a reduction in distribution heat losses from generation point up to consumption point. Moreover, the temperature range of ULTDH allows the injection of low grade energy sources, such as, ST systems and waste heat sources, increasing the renewable factor in heat production. The low-grade energy sources, on account of their low exergy should be injected near consumption points. The direct connection of these sources into the DH is named as decentralized or distributed heat sources.

To date, most ST installations have consisted of centralised and large ST plants outside cities. This paper explores the possibility to integrate distributed ST systems in buildings, by means of their integration in building façades. Moving the energy sources closer to the consumption points reduces transmission losses associated with the aforementioned centralised plant. DH connection of ST systems can be performed in different ways, with different

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functionalities. (Sanchez Zabala and Garay Martinez, 2017) describe several types of connections.

1.2 Unglazed thermal collectors

Regarding the distributed and building integrated application for the ST systems, the most adequate collectors are the non-concentrating collectors, where the solar irradiation is directly used. In general, these types of systems are composed of solar thermal collectors, where a heat transfer fluid is circulated in a pressurised circuit. Solar heat is absorbed and transferred to the fluid, resulting in an increment of the temperature. Depending on external conditions and collectors` characteristics, the performance of each collector is different. Their performance definition is described in detail in (Duffie and Beckman, 1980).

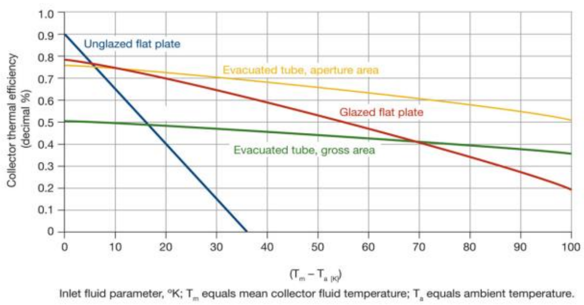

Figure 1. Thermal performance of collectors vs (Tm-Ta). G_T = 800W/m^2. Source: Stickney, B. & Soifer, B, (2009).

In Figure 1 is shown the potentiality of unglazed collectors. When the temperature gradient between the mean collector temperature and the ambient temperature is lower than a limit, the highest performance is shown by the unglazed. This is why, there is interest on these types of collectors in decentralized installations. The possibility to incorporate unglazed systems in buildings has been studied in diverse investigations such as (A. Giovanardi, 2016) but only a few companies propose integration into the façade, and the technology is still under-exploited.

In broad terms, it must be considered that façades are the prominent image of the building. In the selection of ST technologies and their integration with solar thermal façades (STF), this aspect needs to be taken into account. The existence of a wide range of architectural façades requires delivery of a wide range of STF products, to ensure freedom of design intent. In (Garay Martinez, Arregi Goikolea, Bonnamy, and Lopez, 2017), an experimental study is performed on unglazed ST collectors and their potential to deliver heat to HVAC systems in buildings. In this work, it is identified that façades are the biggest area on to which collectors can be installed, and that unglazed collectors are one of the most sensible alternatives to achieve ST production and architectural integration.

2. METHODOLOGY & APPROACHES

In this paper, simulations are performed in order to assess the technical and economic viability of unglazed ST systems connected to DH networks in order to deliver decarbonised heat within reasonable economic metrics.

For this purpose, simulation studies are performed for a multi-storey building in the region of Bordeaux (France). According to the Koppen-Geiger climate definition, described by (Kottek, M., Grieser, J., Beck, C., Rudolph, B., & Rubel, F., 2006), Bordeaux´s climate is classified as a C_{fb} climate, which covers most climates in Western Europe, from the north of Spain to central EU latitudes such as UK, The Netherlands, etc... For this reason, Bordeaux is considered to be a representative location for West-EU climates.

2.1 Heat load modelling

Once the installation location is determined, the heat load must be calculated according to a constructive model.

According to (Giovanardi, A., 2012) , in the EU around 70% of residential building stock in built before 1980. For this reason, this study will be based on a residential functionality 5-storey building. As for the general geometrical features, the selected case study is a 50x25 m (largest facades oriented perpendicular to the N-S line), with a south façade area of 1250 m^2 and a window to wall ratio of 40%. This model has been made with (Trnsys 16.1) and in Table 1 is shown the thermal characteristics of the building.

Table 1. Building model characteristics

Constructive characteristic	Value
Approximate year of construction	1980
U_{wall} [W/m^2]	1.994
$U_{foundation}$ [W/m^2]	0.280
U_{roof} [W/m^2]	0.04795
$U_{framing}$ [W/m^2]	1.942
Infiltration + natural ventilation rate [1/h]	0.4 + 1
U_{window} [W/m^2]	5.730

On the hand, with climatological database and modelling of the building, boundary conditions for calculating demand for the SH is filled. The next step is to simulate by the specific load for the case study by (Trnsys 16).

On the other hand, DHW heat load has been calculated assuming some considerations. The total floor area of 5000m^2 is divided in 80m^2 apartments inhabited by families comprising 3 people. A correct assumption for a typical consumption in the EU is 22 litres per person and day and a water temperature of 60ºC.

2.2 Simulation for BISTS

For the modelling of the ST façade, a self-developed model in the software R has been used for thermal calculations. This software tool allows big databases to be worked with as vectors, thereby reducing calculation times. Within this model, specific collector Energie Solaire Kollektor AS (2012) [9] data has been used in order to calculate efficiency and other parameters used in the model.

As for the working temperatures, the inlet temperature has been fixed in order to be the same as the DH return line temperature (± 30 ºC) and the outlet temperature from the collector field has been set according to each of the simulation cases, which are further defined later in the text. Moreover, heat losses have been estimated to be 10%.

A ST collector system is studied in a high-rise building. This collector field comprises 240m^2 of south-oriented unglazed ST. The field is arranged in 20 parallel circuits, comprising 6 collectors in a serial arrangement, with each collector covering and area of 2m^2. Data relating to the specific collector used for

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this installation can be found in Energie Solaire Kollektor AS (2012).

In general, collectors achieve better efficiency when the temperature difference between the collector (average) and environment is low. In order to limit the average is the solar field, a sensitivity analysis is carried out to ensure that the inlet-outlet temperature difference is limited to 10 ºC. That temperature difference is defined by difference between the average temperature in the collector battery and the ambient temperature. This results in the aforementioned configuration.

This paper explores a direct ST and DH connection to central HVAC manifolds in building, allowing bi-directional heat transfer to the DH. In this concept, local storage is avoided.

3. RESULTS

3.1 Energetic performance

Solar production is simulated for the climate of Bordeaux for various operational conditions. These conditions consider various inlet temperatures, among which low temperatures are incorporated and used in line with LTDH. Temperatures in the range of 50-60ºC are representative of flow temperatures, while temperatures of 20-30ºC are representative of DH return lines. In Fig. 6, the total heat production of a solar unglazed facade (Energie Solaire Kollektor AS, 2012) is shown when it is connected to a DH network with temperatures abovementioned. The highest production levels resulted of return connection, due to the high performance of unglazed collectors with low operational temperatures. So, in terms of absolute production is the most feasible scheme. It is also metionable that solar collectors achieve better efficiencies when connected to DH than when are used for self consumption for the increase in operative hours.

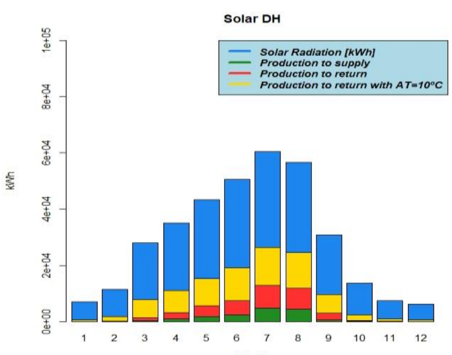

Figure 2. Solar radiation and production for different connection schemes

3.2 Economic Analysis

The economic assessment is based on general economic metrics. For their calculation, it has been calculated the investment necessary for the installation and exploitation of each technology, to then calculate the yearly revenues and operational costs. This will include the consumption of primary energy sources and the heat purchase and delivery. As it is a theoretical study, the maintenance costs have been avoided for being much lower in comparison with other cash flows.

Specifically, the metrics used for this economic assessment are the followings. Return of Investment (ROI), which is the time to recover the investment. Cash-Flow, the net amount of cash moving into and out from each technology and Net Present Value (NPV), which is the difference between present value of cash inflows and the present value of cash outflows over a period of time. In next equations are shown each mathematical definition.

3.2.1 Investment budget

In this chapter is resumed the initial investment necessary to implement the system in a real case. In Table 3 is shown the summary of the budget, divided into most important elements of installation.

Table 2. Project approximate initial investment

Concept	Unitary cost (€/unit)	Quantity	Total €
Solar Collector RK // ALPIN RKM 2001 2m^2	305	120	36630 €
Support assembly for façades // SFV-AR	120	120	14400 €
Valves and other installation materials	---	---	4041 €
Workforce costs	---	---	7251€
Total	---	---	**62023 €**

Representative HVAC systems for multi-storey buildings have been used and their cost normalised per kW. Data has been taken from (Precio centro Guadalajara, 2018) and from (Tarifa de precios solar térmica Salvador Escoda, 2018).

3.2.2 Operational Costs

For making an economic analysys in the estimated period of 20 years, it is necessary to calculate the operational costs of the system, which in this case are the same as the fuel costs. The costs for primary energy are shown in Table 3.

Table 3. Energy source pricing. Source: [7]

Primary energy	Price (€/kWh)
Natural gas	0.05
ST	0
DH heat (UNE-EN ISO 13790:2011)	0.0685
Heat purchase (estimated 70% of DH heat cost) (UNE-EN ISO 13790:2011)	0.04795

3.2.3 Economic assessment

The most used technology for heating in residential areas are the individual (or small group) gas boilers. Thus, the economic assessment of DH connected ST system are calculated and presented against the traditional gas boilers as reference. In Figure 3 is shown the results for different DH heat prices and the effect that varying this price has on the economic performance of the whole system.

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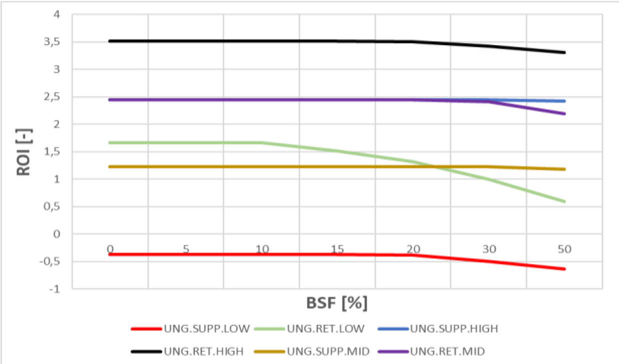

Figure 3. ROI vs Building Solar Fraction for district scale

4. DISCUSSION

In this work the thermal and economic viability of incorporating unglazed thermal collectors into the façade of most common buildings has been studied when it is coupled with LTDH.

Through the thermal collectors, unglazed collectors are the most cost-effective and in low-temperature ranges, they present the highest performance levels. However, ST system still need a large relative initial investment. In spite of this, the connection of ST to the DH avoids the need for large heat production to be installed for back up and also the need for local heat storage, reducing operational costs. In relative terms, operational costs are negative when the ST are connected to the DH because in time of solar overproduction, the heat is sold to DH operators.

As for the energetic results, different connection schemes have been studied. Connecting solar thermal system to the DH directly increases the performance of ST in comparison with isolated for self consumption system due to the capacity of the DH to perform as a sink. From all the connection schemes studied, the connection to the return line of DH shows the most positive results as the solar production is the highest.

Finally, economic results have proven the capacity of these systems to compete in economic terms against other traditional technologies for heating demands. The main conlusion from the economic results is the capacity for DH to act as a perfect heat sink. In Figure 2, for a district scale, have shown that with almost 20% of the buildings (BSF) including the technology, the performance of the whole system is still the same.

DH will inevitably evolve to low temperature systems and energy sources for heating purposes may also adapt. In this context, distrivuted solar thermal os positioned as a promising solution, however there are no many studies where the combination of DH and solar technologies are performed. Moreover, the novel concepts of BISTS & 3FS are added into the study, allowing the better efficiency of the resources.

5. CONCLUSION

This activity will be carried out within the EU h2020 project RELaTED (2017). Within this project, among other activities, an unglazed ST system will be adapted for DH operation, and tested under a controlled test environment in the north of Spain. This same system will be integrated in up to 4 DH networks across Europe.

6. ACKNOWLEDGMENTS

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