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Building integrated solar thermal design: assessment of performances of a low cost solar wall in a typical Italian building

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Abstract

Present work deals with the topic of building integration of solar thermal collector (BIST) as a refurbishment measure. Such equipment, more than its main function as heating generator, plays a specific role as a building component (envelope finishes, thermal insulation layer, roof cover etc). Consequently, from a heat transfer point of view, an integrated component affects twice the global building balance: supporting the thermal plant (i.e. providing heat for final uses) and modifying the wall heat-transfer pattern (i.e. reducing thermal losses). In turn, the collector performance itself is influenced by the wall structure (back losses reduction). Present work proposes a method for evaluating the yearly performance of a low cost BIST by means of a Trnsys model on a reference building. This model arises from previous studies based on experimental validation of a FEM model that was implemented in order to describe the collector-wall system efficiency.

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Keywords: Solar energy, air solar collector, BIST; building energy retrofit, façade refurbishment.

1. Introduction

1.1. State of the art

Nowadays energy and environmental issues represent globally and locally one of the main emergencies for all the governments since the building sector uses a significant amount of energy. From that point of view, the use of renewable energy technologies can provide important contribution towards the zero or nearly zero energy buildings target [1]. The importance of reducing energy demand while integrating local renewable energy sources has been then strongly recognized. In fact, buildings are responsible of around 40% of the total final energy consumption in Europe, representing an important energy saving potential. For this reason, the Energy Performance of Buildings

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Directive (Recast) recommends that by 2020 all new buildings would be "nearly zero-energy buildings". Actually, new dwellings built in 2009 consumed from 30% to 60% less than dwellings built in 1990. Nonetheless, it should be noted that in most EU countries the dwelling stock increases by less than 1% per year [2], so the impact of the new energy-efficient buildings is limited and policies to regulate the energy performance of new buildings are not sufficient. The scientific community agrees about the need of operating on the already existing building stock [2].

Nomenclature

A	collector area [m^2]	a_1	1st term coefficient of collector efficiency-curve
C	collector thermal capacity [$kJ\ kg^{-1}$]	a_2	2nd term coefficient of collector efficiency-curve
I_{sun}	solar irradiation [$W\ m^{-2}$]	b_0	IAM coefficient
IAM	incident angle modifier	c_p	specific heat [$J\ (kgK)^{-1}$]
F'	collector efficiency factor	h	heat transfer coefficient by ISO 6946:2007
F_R	collector heat removal factor	h_c	convective heat transfer coefficient [$W\ (m^2K)^{-1}$]
Q_{glass}	heat transfer through the glass [kWh/m^2y]	h_r	radiative heat transfer coefficient [$W\ (m^2K)^{-1}$]
Q_{vent}	sensible energy by ventilation load [kWh/m^2y]	m	inflow mass rate [$kg\ s^{-1}$]
$Q_{s\text{-}wall}$	energy transfer through the south façade [kWh/m^2y]	s	layer thickness [m]
Q_{sens}	building sensible energy need [kWh/m^2y]	α	radiative absorptivity
R	thermal resistance [Km^2W^{-1}]	ε	radiative emissivity
T	temperature [K]	η	collector efficiency
U	U-value [$W\ (m^2K)^{-1}$]	κ	thermal conductivity [$W\ (mK)^{-1}$]
U_L	overall heat loss coefficient [$W\ (m^2K)^{-1}$]	λ	wavelength
U_{back}	back loss coefficient [$W\ (m^2K)^{-1}$]	ρ	density [$Kg\ m^{-3}$]
U_{top}	top loss coefficient [$W\ (m^2K)^{-1}$]	τ_{tot}	glass global trasmissivity
V	building ventilation rate [m^3/h]	$(\tau\alpha)_n$	$\tau\alpha$-product at normal incidence

At the same time, researchers agree to promote plant components as closed as possible to the building itself [3]. Solar thermal component integration has consequently became an important goal. Actually, according to recent surveys (Garde and Donne, http://task41.iea-shc.org/ and Enob, http://www.enob.info/en/net-zero-energy-buildings/map/), it is evident how the solar thermal option is more exploited when NZEB target is directly addressed and flat plate collectors integration in façade is preferred wherever possible. Solar collector should be hence conceived as multifunctional envelope systems in which functional aspects, constructive issues and formal (aesthetical) targets have to meet in a unique component, as stated in IEA SHC task 41 proceedings by Munari et al. [4]. This task was of special interest and led to some design criteria and guidelines for integration [5], [6] and [7]. It is worth noticing that up today researches in BIST topic have been often focused on technological and aesthetical issues ([8], [9], [10] and [11]). At this regard, Lamnatou et al. [1] gave a general overview on solar technologies for buildings. The authors make differences between building integrated component (BIST) and building added component (BA) outlining how the first ones allow reducing the transmission losses through the building envelope while improving the overall efficiency of the system. On the other hand, higher initial costs and higher constructive complexity represent the main obstacles to the BIST diffusion. Solar thermal collectors, Trombe wall, solar chimney, solar façade PV and PVT researches are critically reviewed and grouped according to the studied topics. Recently, Buker and Riffat have proposed a general overview on building integrated solar technology distinguishing PV/T collector from solar collector and giving an overview of integration potential and on results by task 41 [12]. Moreover, Ghafoor and Fracastoro [13] remark how in EU countries, solar thermal collector are traditionally confined to domestic hot water production. These two authors then proposed a Multi-Purpose Solar Thermal Systems (MPSTS) whose optimal sizing is based on the maximization of Net Present Value. A detailed study of a BIST thermal performance have been addressed in Albanese et al. [14] and in Robinson *et al.*[15]. The authors focused on a heat pipes system to transfer heat through an insulated wall from an absorber outside the building to a storage tank inside the building. Other research focused on FEM model calculation of integrated component overall performance [16].

In conclusion, the way how solar collector efficiency curves changes when the component is integrated into the building, is addressed by Leone [17] and by Maurer et al. [18]. The latter proses a simplified method for calculating the efficiency curve of BIST component arranging the solar collector standard formula. The former refers instead to previous results on a low cost solar air collector tested at the University of Palermo - DEIM [19]. Leone's work was aimed to characterise these two prototypes by means of a finite element method model (FEM) while integrating them in an ordinary not insulated wall structure. Starting from the results of these researches, this paper presents an assessment of the possible performances of one of these prototypes when utilised as a retrofit insulation in some typical Italian buildings typologies.

1.2. The low cost solar wall.

Main idea of the low cost solar air collector is the use of common "sandwich" corrugated panel composed by an insulation core enclosed between two brown-painted aluminum layers. Accessories for fixing the panels to roof or façade structures are specifically designed by the factory and different modules could be coupled together covering the whole façade/roof surface. All these aspects make this kind of panel attractive in the market for building finishes. At the same time, metal insulated profiles could be fixed at the panel perimeter by screws and in order to enclosure the collector-module by fixing the glass cover, Fig. 1.

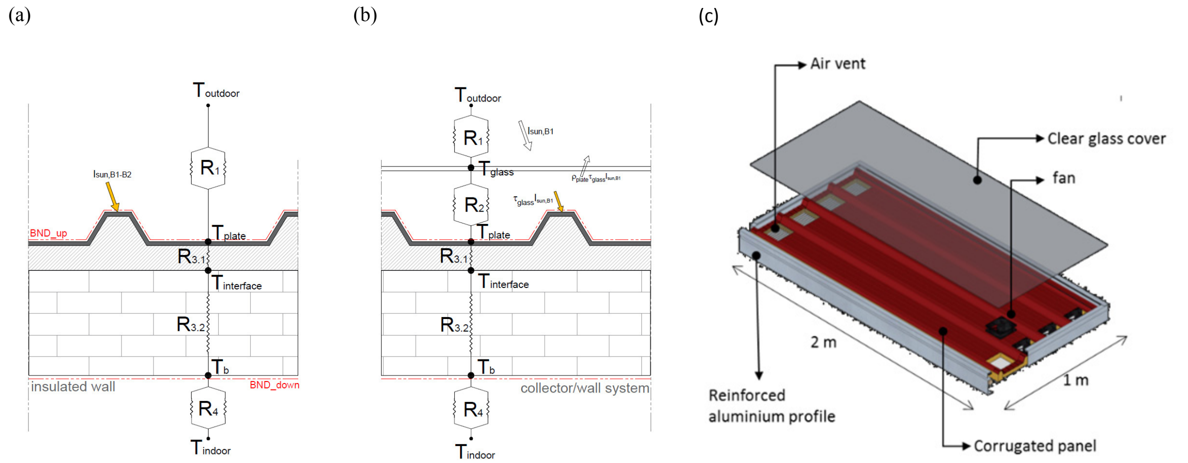

Fig. 1. (a) Electrical analogy for the integrated wall/collector system; (b) electrical analogy for the merely insulated wall; (c) technological detail: solar collector assembly scheme,

According to Munari Probst *et al.* [4], the proposed system presents an advanced level of potential integration that "is reached when a complete active envelope system is offered by providing also all the needed complementary façade interface elements" following the approach "from the envelope component to the active component". Vertical strings, i.e. between windows series can be easily created. In this way, a conductive thermal flux between collector and wall structure takes place and the whole system can be considered as STC-wall. Leone [17] has assessed the efficiency of the integrated system in the form of Bliss efficiency function by following the electrical analogies in Fig. 1 and in a way similar to the main standard rule for stand-alone component UNI 8937/1987 and to EN 12975-2:2006, Fig. 2. The x-coefficient ($a_1=F_RU_L$) and the intercept term ($a_2=F_R\,(\tau\alpha)$) in the efficiency curves are the main input for present work. At the same time, other important parameter such as the plate emissivity in the visible and IR bands and the convective coefficient at the channel walls were assessed in Leone's work [17] and are also the base for present work.

2. Method

Present work aims to assess building energy balance in a typical Italian building while integrating a solar air collector system in the south façade as an energy refurbishment measure. How the STC-wall affects the building energy balance during heating and cooling seasons when it is considered as a BIST?

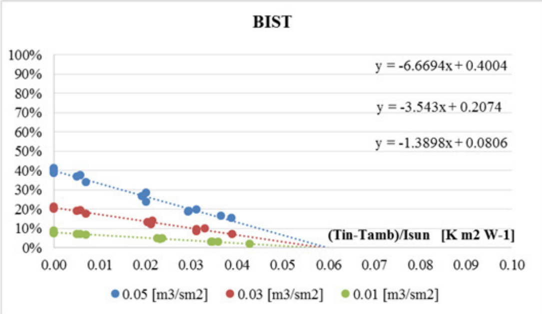

Fig. 2 Bist efficiency curves at different inflow rate

Actually, the BIST has a strong influence on wall heat transfer for many reasons. The overall U-value changes and becomes a dynamic parameter, due to variable convective losses related to airflow changes and to the heat removal capacity of the BIST (function of solar radiation and air temperatures). Seasonally advantages depend strongly on climate conditions and need to be carefully evaluated. Moreover, we can assume to account for the heat removed by the air flowing through the collector as a positive contribution to the building heating balance since this air flow rate can be used for the building ventilation requirements (i.e. reducing the ventilation load). At the same time, a passive contribution to the balance is related to the fact that the collector itself influences heat transfer through the STC-wall. Consequently, simulation model focuses on the following figures, measured in kWh $m^{-2}y^{-1}$:

- Q_{vent}, sensible energy demand by ventilation load;
- $Q_{s\text{-}wall}$, heat transfer through the south façade (STC-wall).

A Trnsys model has been then set up in order to calculate thermal output and heat exchanges from/to STC-wall and to consider them as heat load and gains at building level. Main idea is to exploit Type 46 for the building balance and Type 539 for the collector balance connected each other by a system of equations. Specifically, in the building balance the outdoor boundary condition for the south façade is the one of Dirichlet Boundary Condition assuming that the surface temperature depends on the fluid temperature given by type 539. The latter is evaluated considering the fact the solar collector is an integrated component and it is used as input for the ventilation load. Specifically, Q_{vent} by Type 46 is:

$$Q_{vent}=V\,\rho\,cp\,(T_{vent}-T_{zone}) \quad (1)$$

where T_{vent} is the inlet air and T_{zone} the indoor temperature that was fixed according to the heating and cooling operation. So that, main assumption is that the inflow air temperature in heating period is equal to the outlet temperature from the collector strings (T_{out}) when $I_{sun}>0$. Meanwhile, $T_{vent}=T_{outdoor}$ during the cooling period and when $I_{sun}<0$. At the same time, $Q_{s\text{-}wall}$ is evaluated between the indoor environment conditions stated by UNI EN ISO 6946 and the wall/collector interface temperature (T_i). Specifically T_i values can be calculated by assessing the heat transfer through the wall by:

$$T_i=T_p-Q_{back}(R_1+R_2) \quad (2)$$

where T_p is the plate temperature while R_1 and R_2 are respectively the insulation and wall-layers thermal resistances, as schematically displayed in Fig. 3 (system A). Specifically, the back heat flux is evaluated by solving:

$$Q_{back}=(\tau_{tot}I_{sun})\alpha - h_{c,1}(T_p-T_f) - h_{r.1}(T_p-T_g) - h(T_b-T_{zone}) - [(T_p-T_b) / (R_1+R_2)] \quad (3)$$

where $\tau_{tot}= \tau_r\ \tau_a$ is the transmittance coefficient of glass calculated in function of the incident angle (transmission related to reflection losses, τ_r) and of the absorption coefficient (transmission related to absorption losses, τ_a).

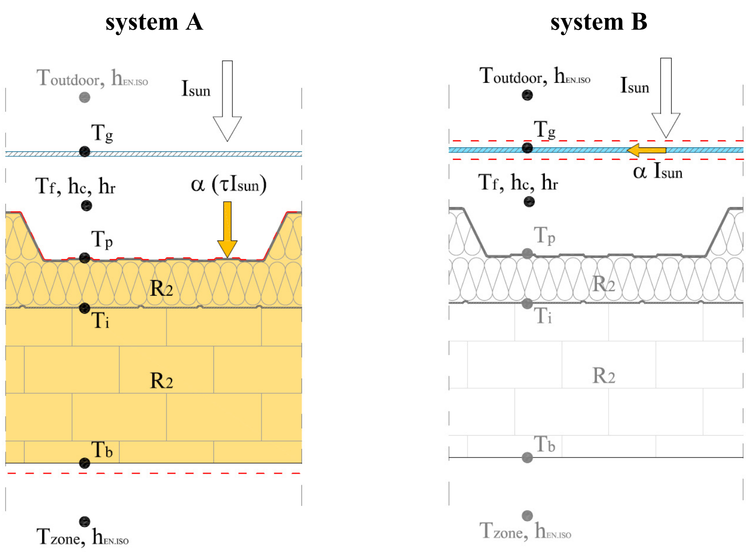

Fig. 3 STC-wall analysed system

Specifically $h_{c.1}$ and $h_{r.1}$ are respectively the convective coefficient in the collector channel and the radiative coefficient between plate and glass; finally, T_p, T_f, T_g, T_b and T_{zone} are respectively plate, fluid, glass, back surface and indoor temperatures. Among the previous values some unknowns have to be noticed: the glass temperatures, the $h_{r.1}$ and $h_{c.1}$ coefficients. For this reason, some assumptions have been done and the scheme "system B" in Fig. 3 introduced. Then for solving eq. (8) the plate temperature is approximated to the sol-air temperature ($T_{sol\text{-}air}$):

$$T_p \cong T_{sol,air}=T_f+\left[(\tau_{tot}I_{sun}\alpha)/\left(h_{c.top}+h_{r.top}\right)\right] \quad (4)$$

At the same time, the unknown h_r and T_g values are calculated by solving system B:

$$T_g=T_f- Q_{glass}/h_f = T_f-T' \quad (5)$$

$$Q_{glass}=U_{glass}(T_f-T_{outdoor}) \quad (6)$$

$$h_r=\sigma\ \left[\left(T_p^2+T_g^2\right)\left(T_p+T_g\right)\right]/\left(\varepsilon_{p,B2}^{-1}+\varepsilon_{g,B2}^{-1}-1\right) \quad (7)$$

where U_{glass} is the glass transmittance, $\varepsilon_{p,B2}$ and $\varepsilon_{g,B2}$ are respectively the plate and glass emissivities for $\lambda>2{,}500$ µn (considering that the analysed radiative phenomena happens in the IR band). At the same time, making the assumption $T_{sol.air} \rightarrow T_p$, it follows that replacing the incoming solar radiation in (3) with expression in (4) while expressing T_g in function of T_f (5) and simplifying all the expression (3), the back heat flux is:

$$Q_{back}=-T'/h_r^{-1}- \left(T_p-T_{zone}\right)/(R_1+R_2) \quad (8)$$

Once the systems A and B are solved, it is possible to substitute Q_{back} from (3) in (2) in order to find out the searched T_i. It is worth noticing that both Q_{vent} and $Q_{south\text{-}wall}$ calculation depend on fluid temperature which is an input of type 539. Indeed, this type properly describes a stand-alone component and it is suitable for finding out T_{out} as well as the useful energy from the collector introducing the climatic conditions and the main collector characteristics: efficiency curve coefficients, incident angle modifier coefficient (b0) and collector thermal capacity. This type runs solving:

$$C\,(dT/dt)= F'[I-U_L\,(T-T_{amb})] - m\,c_p(T-T_{in}) \qquad (9)$$

$$I=(\tau\alpha)_n\,IAM\,A\,I_{sun} \qquad (10)$$

where T_{amb} is the surrounding temperature. It is worth noticing that, contrariwise for the stand-alone component bounding all around with the outdoor environment at T_{amb} (as evaluated by type 539), top and back losses for the integrated component depend respectively to the outdoor temperature ($T_{amb}=T_{outdoor}$) and to the indoor temperature (T_{indoor}). For that reason and taking into account that the first ones are generally predominant, an ambient weighted temperature ($T_{amb,w}$) has been calculated according to:

$$T_{amb,w} = (T_{outdoor}U_{top} + T_{zone}U_{back})/(U_{top} + U_{back}) \qquad (11)$$

$$U_{top} = h_{indoor}{}^{-1} + \frac{s_{glass}}{k_{glass}} + h_{channel}{}^{-1} \qquad (12)$$

$$U_{back} = h_{indoor}{}^{-1} + \sum \frac{s_{ST}}{k_{ST}} + h_{channel}{}^{-1} \qquad (13)$$

where specifically $h_{outdoor}$ and h_{indoor} are coefficients given by EN ISO 6946 and accounts for radiative and convective heat exchange towards indoor and outdoor ambient. U_{back} accounts on the channel, collector&wall layers and indoor resistances, s_{glass} and k_{glass} are respectively the glass thicknesses and conductive coefficients and finally s_{ST} and k_{ST} are the thicknesses and the conductive coefficients of each layer from the absorber plate to the indoor surface. Finally, the collector thermal capacity is defined by EN 12975-2:2006. In order to account on how each element participates at the thermal inertia of the whole component, weighting factors (p) in the standard rule are introduced criterion raging from 1 for the absorber and for the liquid heat carrier, to 0.5 for insulation. Once again, this standard addresses liquid solar thermal collector, so that weighting factor are prescribed only for the absorber, the heat transfer liquid, the insulation and the glass cover. Following the EN 12975-2:2006 approach, we introduced other weighting factors for adapting the C calculation for stand-alone component to the specific BIST study case. Specifically, p=1 is applied to solid element with high-density (brick and plaster), p=0.5 to the air flow in the collector channel and to the air gap between the brick layer, Table 1.

Table 1 STC-wall and prototype thermal characteristics and capacities comparison

		p [-]	ρ [kg m^{-3}]	cp [kJ (K kg)$^{-1}$]	s [m]	ε_{B1}	ε_{B2}	κ [W/(Km)]	C [kJ/K]
collector	glass cover	0.01	2200	750	0.008	0	0,84	1,40	2
	air channel	0.5	1	1009	0.080			-	0.1
	absorber plate	1	7850	475	0.005	0.7	0.8	44,5	8
	insulation	0.5	30	1800	0.060			0,025	6
wall layer	plaster	1	1800	837	0.020			0.9	86
	brick	1	775	837	0.120			0.4	222
	air gap	0.5	1	1009	0.060			0.030	0.2
	brick	1	775	837	0.080			0.4	149
	plaster	1	1800	837	0.020			0.9	86
STC-WALL THERMAL CAPACITY									559
STAND-ALONE COLLECTOR THERMAL CAPACITY									16

B1:band 1; B2:band 2; UNI 12524/2001 "Building materials and products-Hygrothermal properties-Tabulated design values" for thermodynamically properties; "Optics" software by LBNL for glass radiative properties, Leone studies for ε absorber radiative properties

Before running the Trnsys model, a validation procedure has been undertaken comparing Trnsys node temperature results with the values calculated by the FEM model [17]. Consequently, Trnsys model ran firstly at the same ambient conditions as the detailed FEM module in order to verify the reliability of results for the proposed method. Since the FEM model works on steady-state conditions, an appropriate time step has been chosen in order to stabilize results. Glass temperature (T_g), plate temperature (T_p) and interface temperature (T_i) from FEM model and from the Trnsys model are compared. A good reliability for Trnsys model is detected being the relative error in a range between +5% and -5% (Fig. 4 (b)), meanwhile absolute error is in a range between +2°C and -2°C.

3. Calculation

A reference building is considered for the present study goals. Authors adopted the characteristics defined by Caputo et al. (2011) [21] in a previous research focused on the characterization of Milan building stock for energy refurbishment issues. Among the different building typologies introduced in this study, present work deals with the one that presents the easiest way for integrating the solar collector array and is, at the same time, the most spread in the Italian context [21], Fig. 4 (a).

(a) (b)

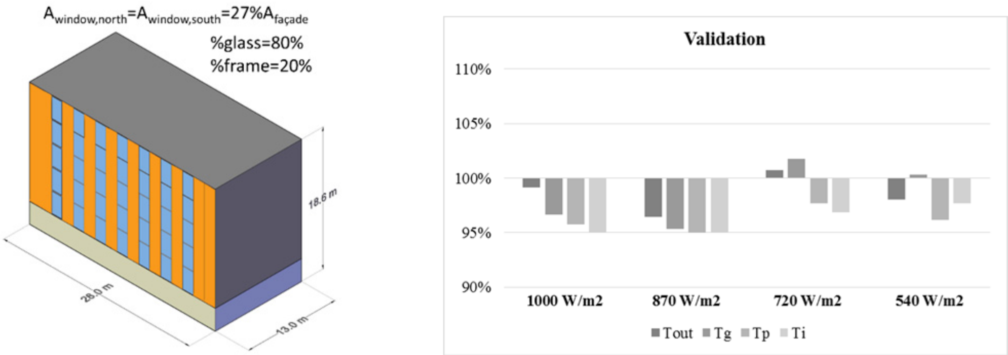

Fig. 4 (a) Reference building geometrical features; (b) Trnsys model validation

Such representative example is a 5-storey residential building with aligned windows. It has been assumed that up to 10 solar thermal arrays could be installed in the South façades. Each solar array is composed by 5 collectors supposed to be connected in series. Moreover, dealing with the integration at thermal plant level, it is supposed that the STC-wall is able to provide a pre-heating of air required for minimum air change per hour during heating season ($n = 0.33\ h^{-1}$). Heated air during cooling season is supposed to be discharged through a by-pass damper. Moreover, two scenarios have been assessed: in the first one, the building is considered as it is (reference building); in the second one, the refurbished building where the STC-wall is integrated in the south-façade is studied (STC-building). Both scenarios have been assessed for different Italian cities corresponding to opposite different climatic conditions: Milan (2404 heating degree-days) and Palermo (751 HDD). Indoor temperature is fixed at 20°C during heating season and at 26°C during cooling season. The time extension of heating season is defined by law in Italy: for Milan, it ranges from 15th October–15th April and for Palermo from 1st December to 31st March (UNI 10349:1994 and UNI 10339:1995). Law in Italy does not define the cooling season. In present work, it is simply considered as the complementary period of the year with respect to the heating season. It may be observed that according to the above definition of H/C seasons, hours with no heating or no cooling demand could happen. These cases are properly predicted in a dynamic simulation. In order to focus the analysis on the BIST performances, a one-zone building model has been adopted. The lowest floor of the analyzed thermal zone bounds with buffer-basement zone in free floating temperature condition. Actually, this work aims to verify how the BIST installation can affect the building balance as active/passive component. For that reason, the calculation of the building energy balance has been simplified in order to reduce the number of variables. Internal gains have been assumed according to average standard rules that prescribe a load of 9 Wm^{-2} for kitchen and living room and 3 Wm^{-2} for bedroom and other spaces. These mean values have been assumed to be constant all over the year and have been used in all analyzed cases. Ventilation rate varies from 0.33 m^3/h in heating period to 0.5 h^{-1} in cooling period. Façade heat transfer characteristics (specifically listened in Table 1) as well as roof and ground thermal properties are inferable from Caputo et al. [21]. In particular:

- roof: U= 0.96 $[W(m^2K)^{-1}]$, ρ= 950 $[kg\ m^{-3}]$, c_p= 960 $[J\ (kg\ K)^{-1}]$, s= 0.33 m
- floor: U= 1.66 $[W(m^2K)^{-1}]$, ρ= 1200 $[kg\ m^{-3}]$, c_p= 740 $[J\ (kg\ K)^{-1}]$, s= 0.29 m

Moreover radiative absorber plate properties and convective coefficient for south-façade channel boundary belongs to Leone, [17]. Assumptions have been also made for modeling the typical heating and cooling plant [21]. Overall plant efficiencies were assumed in order to assess primary energy demand for heating and cooling purposes (η=0.97, EER= 2.0). Finally, weather files have been taken from the Energy plus database.

4. Calculation and Results

Trnsys model have ran for typical years in Milan and Palermo, for the reference building itself and for the one with BIST south-façade (BIST-building). Considering the heating mode, the BIST technology would then influence the overall energy balance both as ventilation/active component and as passive solution. If we consider the whole year, the coldest the climate (Milan) the highest the energy advantages: 13% energy-consumption reduction in Milan and 9% in Palermo (Fig. 5).

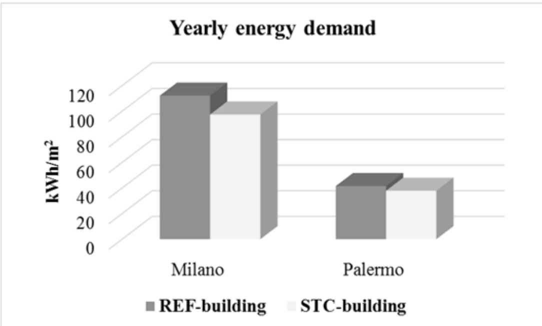

Fig. 5 Yearly energy demand for the REF-building and the STC-building in Milan and Palermo.

At the same time, in Fig. 6 the seasonal sensible energy need are plotted and Q_{vent} and $Q_{s\text{-}wall}$ influence on the balance outlined for the heating balance. It is worth noticing that due to the low efficiency of collector and to the chosen building/STC-building system, the highest influence is available in Q_{south} values. Actually, comparing the Reference building to the STC-building, the heat transfer through the south wall in winter falls down from -10 kWh/m^2 to zero in Milan while in Palermo changes from -2 kWh/m^2 to 1 kWh/m^2, becoming a gain for the balance. Nonetheless, some differences could be noticed also in Q_{vent} analysis, and a reduction about 5% and 15% can be obseved respectively in Milan and in Palermo. Such different behavior in the two cities is mainly associated to the different climatic conditions.

Moreover, an overall analysis for the cooling balance is required and shown in Fig. 6 (b). Generally, during the cooling season and according to the simulation hypotheses, BIST installation generates only heat gains from the south wall. Indeed, during cooling period, this increases the energy demand for cooling and, obviously, the higher the latitude the higher the impact. Therefore, it will be important to verify how much the additional energy transfer due to the BIST technology is counterbalanced by the energy saving generated in heating mode. Looking at cooling energy demand for the study cases, it is worth noticing that there is no significant difference. The STC-building energy demand increase about 3% and 1%, respectively in Milan and in Palermo, Fig. 6 (b).

Finally, examining the results at hourly level (Fig. 7) the difference between the reference building and the STC building are checked by: $Q(t)= -(|Q_{ref}|-|Q_{STC}|)$. This has been done either for the ventilation load and for the total heat transfer through the south façade.

(a) (b)

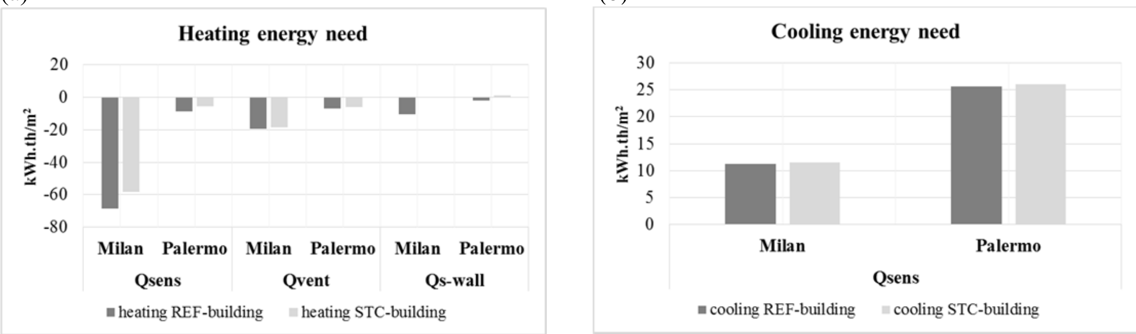

Fig. 6 (a) Q_{vent} and Q_{south} contribute to the heating balance. (b) Cooling energy demand.

A different order of magnitude between the two phenomena is recorded and STC-wall "passive effect" prevails in both cities, confirming good seasonal results. Focusing the analysis on the contribution to pre-heating air, Q_{vent} reduction is actually comparable in Milan and in Palermo all year long, taking into consideration the heating/cooling setup (Fig. 7 (a)) meanwhile the $Q_{s.wall}$ decreases more in Milan than in Palermo overall in heating season and results are anyway comparable in cooling mode.

(a) (b)

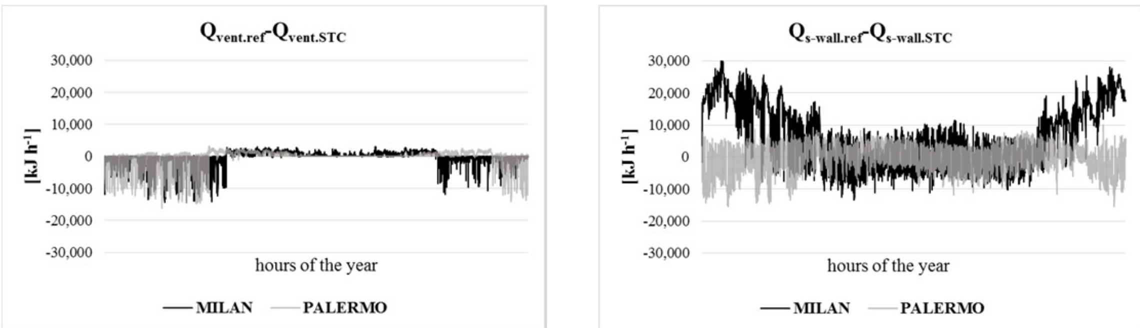

Fig. 7 (a) Differences between ventilation load in REF-building and STC-building;
(b) Differences between south wall heat transfer in REF-building and STC-building

5. Conclusion

The analysis of integrated solar building active and passive systems with regard to their contribution to heating and cooling demand is well known and present in the technical literature. Works mainly refer to passive solutions such as skin façade, solar chimney, Trombe wall; ect… . Present work proposes an analysis of an integrated solar thermal component on the global building energy balance. The effects of a south-façade integrated solar air collectors have been analyzed for a typical Italian building for shape and thermal characteristics. Transient simulations were then performed for two different sites in Italy characterized by opposite climatic conditions (Milan and Palermo). It is worth emphasizing that the overall performance of the system is affected also by the transient response of building to hourly shift of climatic conditions. Present work shows that the BIST positively affects the yearly energy balance in climate where heating demand is prevalent: reduction of heating demand are always higher than the rise of cooling demand. Positive effects on heating demand are ensured by the fact the energy transfer through the solar façade generally is more than doubled. At the same time, the mismatching between maximum heat production by the active air driven STC-wall and the increase in cooling demand has to be carefully observed and give useful hints for further future developments. Actually, it is reasonable to suppose that higher efficient solar technologies could enhance better results than the ones assessed in this study. At the same time, other heating/cooling plant schemes could be considered together with possible integration with air-to-water heat exchangers for DHW production or with air-driven solar cooling systems. This would certainly permits to better exploit the produced energy all year long.

Moreover, present work proposed a method for the assessment of overall building heat balance by means of available Trnsys types for solar collector whose output are utilized for the calculation of heat transfer through the STC-wall. Anyway, this method is based on the fact that main parameters of the integrated component as well as benchmark values useful for validating the Trnsys model were available from a previous detailed study [17].

Another focus point is related to the choice of a suitable ambient temperature for collector losses calculation. Specifically, present work deals to the use a weighted indoor/outdoor temperature. At the same time, the required collector thermal capacity input has been evaluated by adapting the standard calculation proposed for stand-alone component to the integrated one, including all wall layers. Given the fact that architectural integration is an important issue in the spreading of solar thermal technologies there is a need for further investigations, either experimental and by modelling in the field of BIST systems. Certainly, the experimental investigations are important to test a system behavior; however, modelling tools can be used to predict a system performance.

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