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MINISTERO DELLO SVILUPPO ECONOMICO

Ricerca di Sistema elettrico

Raccolta delle principali attività di diffusione

G. Puglisi

Report RdS/PAR2018/110

RACCOLTA DELLE PRINCIPALI ATTIVITÀ DI DIFFUSIONE

G. Puglisi (ENEA)

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Report Ricerca di Sistema Elettrico

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Piano Annuale di Realizzazione 2018
Area: Efficienza energetica e risparmio di energia negli usi finali elettrici e interazione con altri vettori energetici
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Obiettivo: F. Comunicazione e diffusione dei risultati
Responsabile del Progetto: Giovanni Puglisi, ENEA Giovanni Puglisi

Indice

1 Introduzione

Il rapporto descrive le attività messe in atto per la comunicazione e diffusione dei risultati prodotti dal progetto D1 “tecnologie per costruire gli edifici del futuro” relativo all’Accordo di Programma MiSE-ENEA, piano annuale di realizzazione 2017.

Tali attività sono state suddivise, per ciascuna linea in cui è diviso il progetto, in:

- pubblicazioni su riviste specializzate o su atti di convegni,
- presentazioni a convegni.

Nei paragrafi successivi si riportano rispettivamente l’elenco delle pubblicazioni, gli articoli integrali e le pe presentazioni ai convegni.

2 ELENCO PUBBLICAZIONI

Di seguito si riporta l’elenco delle pubblicazioni effettuate nel periodo 1 ottobre 2018 – 31 dicembre 2018 e successivamente gli articoli integrali:

- L. Piterà, M. Dell’Isola, G. Ficco, L. Canale, I. Bertini, B. Di Pietra, G. Puglisi, Contabilizzazione del calore: Luci ed ombre, Aicarr Journal, n°53, dicembre 2018
- G. Puglisi, G. Vox, E. Schettini, G. Morosinotto and C.A. Campiotti, Climate control inside a greenhouse by means of a solar cooling system, Acta Hortic. 1227. ISHS 2018. DOI 10.17660/ActaHortic.2018.1227.7.
- E. Schettini, C.A. Campiotti, I. Blanco and G. Vox, Control, Energy-Saving and Crop Production in Greenhouse and Plant Factory, Acta Hortic. 1227. ISHS 2018. DOI 10.17660/ActaHortic.2018.1227.9.

Contabilizzazione, i nodi ancora da sciogliere

Sebbene la revisione 2018 della norma UNI 10200 migliori e corregga alcune criticità, permangono diversi punti controversi che dovrebbero essere affrontati e risolti

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LA REVISIONE DELLA NORMA UNI 10200 (UNI, 2018), presentata in questo stesso fascicolo (Piterà, 2018), in parte chiarisce e risolve alcuni punti controversi creatisi con l'introduzione degli obblighi di installazione dei sistemi di contabilizzazione previsti dal D.Lgs. 102/2014 e s.m.i. Purtroppo, accanto ad alcuni miglioramenti che la norma introduce, permangono ancora alcuni nodi non completamente sciolti.

Trasparenza dei consumi e consapevolezza degli utenti

È ampiamente dimostrato che negli edifici il comportamento degli occupanti ha un rilevante impatto sui consumi energetici connessi al riscaldamento e al raffrescamento e che l'uso inconsapevole dell'utente può determinare rilevanti sovraconsumi. La consapevolezza dei consumi può essere raggiunta attraverso la disponibilità dei dati di consumo in tempo reale, garantita dalla possibilità di leggere i propri consumi sui dispositivi di misura, e da un'efficace e frequente fatturazione o bollettazione dei consumi effettivi. Il metodo ritenuto in letteratura più efficace è senz'altro il primo, specie se i dispositivi di misura forniscono direttamente agli utenti finali i dati di consumo, ad esempio attraverso "in home display". Tecnicamente i ripartitori potrebbero fornire tali informazioni agli utenti finali attraverso la lettura delle unità di riparto, ma nella pratica molti ripartitori non vengono "programmati", sebbene la nuova revisione della norma ne raccomandi, non ne vincoli, la programmazione, il che comporta che anche in futuro all'utente finale potranno essere visibili solo le unità di conteggio.

Ripartizione dei consumi e coefficienti di compensazione dell'inefficienza

La norma UNI 10200 prevede l'attribuzione a ciascun utente di una quota di consumo volontario, rilevata dagli appositi dispositivi di contabilizzazione del calore, e di una quota di consumo involontario, ottenuta in base ai rispettivi millesimi di fabbisogno di energia o di potenza termica se sprovvisto di termoregolazione.

La ripartizione dei costi energetici dovrebbe avere come obiettivo principale la riduzione dei consumi, sia attraverso il risparmio energetico dovuto a un comportamento virtuoso e consapevole dei singoli condomini sia mediante interventi di riqualificazione energetica. La ripartizione dei costi basata sugli effettivi consumi individuali conduce l'utente a una riflessione sul proprio profilo d'uso degli impianti termici e comporta generalmente una modifica degli stili di consumo (Canale et al., 2018) grazie alla possibilità di soddisfare le specifiche esigenze di comfort e nel contempo di ridurre i costi di riscaldamento e raffrescamento, ad esempio modificando gli orari di accensione, escludendo alcuni ambienti, controllando la temperatura interna e la ventilazione degli ambienti in funzione delle necessità. È verosimile supporre che questa propensione al risparmio sia tanto più elevata quanto maggiore sia la quota variabile, così come correttamente previsto dalla UNI 10200.

Purtroppo, per quanto riguarda l'inefficienza delle parti comuni dell'intero edificio, non sempre è possibile ridurre i consumi, in quanto la coibentazione delle superfici disperdenti dipende dalla volontà dell'intero condominio e la gestione delle parti comuni determina una situazione singolare: spetta all'intera assemblea decidere eventuali migliorie, quali la coibentazione, mentre le conseguenze della mancata coibentazione vanno a incidere prevalentemente sui consumi delle unità immobiliari delimitate dalle strutture oggetto di intervento. Ciò da una parte genera un disallineamento fra i titolari del potere di intervento, che hanno anche l'onere della spesa, e i potenziali beneficiari degli interventi, la cui approvazione è ostacolata in assemblea, dall'altra comporta che le unità più sfavorite dal punto di vista energetico, quali attici, mansarde e piani terra presentino generalmente quote di consumo volontario e involontario più elevate, motivo per cui in assemblea condominiale i proprietari delle unità immobiliari termicamente favorite potrebbero avere minore interesse a promuovere interventi di efficienza energetica.

Per superare tale problema AiCARR, in accordo con ENEA, ha proposto il metodo degli extraconsumi per la compensazione delle inefficienze, che è stato però stralciato dalla norma nella sua ultima revisione anche per i vincoli imposti dall'attuale legislazione e la ferma opposizione di alcuni costruttori di sistemi di ripartizione. Il metodo prevede di stimare le conseguenze economiche delle inefficienze energetiche delle parti comuni dovute al carente isolamento termico, i cosiddetti extraconsumi, e di attribuirle "temporaneamente" all'intero condominio. La peculiarità del metodo proposto consiste nel fatto che:

- la redistribuzione degli extra-consumi viene concepita come ripartizione derivante da un inefficiente isolamento e non come correzione permanente dei consumi;
- si responsabilizza l'intero condominio sulle inefficienze delle parti comuni e conseguentemente si motiva economicamente tutta l'assemblea alla riqualificazione energetica;
- una volta effettuato l'intervento di riqualificazione, gli extraconsumi

Tipo di impianto	Dispositivo di Contabilizzazione	Norma tecnica
Aeraulici	misuratori di portata ad inserzione, ad esempio griglie di Wilson, con coppia di sonde entalpiche, ad esempio di temperatura e umidità relativa dell'aria, su mandata e ripresa	ISO 3966: 2008 UNI EN 12599:2012
Idronici	misura diretta con CET	UNI EN 1434:2016
	misura indiretta con totalizzatori dei tempi di inserzione (utilizzabile solo su fan coil a velocità costante)	UNI 11388:2015 UNI 9019:2013
Misti aria-acqua	tecnica mista (misuratori CET e misuratori di portata a inserzione)	UNI EN 1434:2016 ISO 3966: 2008
Espansione diretta	contatori volumetrici, combinati con misura di pressione	-

Tabella 1- Possibili soluzioni tecniche attualmente disponibili per la misura del freddo negli impianti di raffrescamento

si annullano e ogni utente paga solo quanto compete al proprio appartamento (Dell'Isola et al., 2018).

Ciò non accade utilizzando una quota fissa per i consumi involontari, come per alcuni Paesi europei che arrivano fino al 50%, che deresponsabilizza significativamente l'utente finale, riducendo il potenziale risparmio, e non induce a investire sull'efficientamento energetico (Castellazzi, 2017).

Affidabilità e fede pubblica nella ripartizione

In merito all'affidabilità dei sistemi di contabilizzazione del calore dalla tutela della fede pubblica esiste una notevole dissimmetria tra sistemi diretti e indiretti. I contatori di energia termica, infatti, rispondono a regole puntuali della metrologia legale in termini di certificazione metrologica di prodotto CE M, fabbricazione e verifica prima (EU, 2014). L'Organismo Notificato (accreditato IEC/ISO 17065) è responsabile dell'approvazione del modello ed esercita una funzione di controllo sul Fabbricante che generalmente effettua anche la verifica prima in laboratorio. In linea teorica, i sotto-contatori dovrebbero essere anche soggetti agli obblighi dei controlli successivi stabiliti dal D.M. 93/2017, cioè alla verifica periodica da Laboratorio accreditato (ISO 17025) o da Organismo di Ispezione/Certificazione accreditato (ISO 17020 o 17065), nonché ai controlli casuali e su richiesta sotto la responsabilità degli Uffici Metrici delle CCIAA. I sistemi di contabilizzazione indiretti, invece, non sono regolati dalla Metrologia Legale: la certificazione di prodotto CE è fatta rispetto a norme tecniche armonizzate europee per i ripartitori (UNI, 2013a) e nazionali per i totalizzatori (UNI, 2013b; UNI, 2015a) e pertanto non sono soggetti a verifiche periodiche obbligatorie, ai sensi del D.M. 93/2017.

In ogni caso, la nuova UNI 10200 prevede che il responsabile dell'impianto debba attivare procedure di verifica della funzionalità del sistema di contabilizzazione basate sull'analisi statistica delle variazioni stagionali del rapporto tra unità di riparto e consumi volontari mediante diagramma di Cusum, ma non definisce un livello di errore massimo ammissibile, limitandosi a verificare unicamente la deriva nel tempo del sistema di ripartizione, malgrado la proposta AiCARR di indicare tre fasce di errore massimo ammissibile a garanzia degli utenti finali, ad esempio <5%; <15%; >15%. Tutto ciò nonostante sia stato dimostrato quanto la ripartizione possa diventare critica in termini di affidabilità in alcune condizioni di installazione, come nel caso di corpi scaldanti molto diversi per taglia e tipologia, e di funzionamento, a causa ad esempio di portate e temperature diverse (Ficco et al., 2016; Arpino et al., 2016).

Contabilizzazione dell'energia termica nella climatizzazione estiva

L'obbligo di contabilizzazione delle spese di climatizzazione estiva trova solo in parte riscontro nella UNI 10200:2018 in merito alle modalità di ripartizione, ma risulta ancora indeterminato in merito alle modalità di misura, a causa dei seguenti fattori:

- diverse tipologie di impianti di climatizzazione esistenti;
- limitata applicabilità tecnica dei sistemi indiretti di contabilizzazione;
- non applicabilità della Direttiva MID ai contatori di energia termica diretti utilizzati per la misura del freddo.

Alle diverse tipologie di impianto è possibile applicare differenti tipologie di strumenti di misura e sistemi di contabilizzazione, solo in parte normati. In particolare, in Tabella 1 sono riportate le possibili soluzioni tecniche attualmente disponibili per la misura del freddo negli impianti di raffrescamento, tema sul quale AiCARR ed ENEA hanno recentemente attivato un gruppo di lavoro per lo studio prenormativo.

Fattibilità tecnico-economica

Come noto, l'obbligo di installazione dei sistemi di contabilizzazione individuale del calore negli edifici riforniti da una fonte di riscaldamento centralizzata è subordinato all'esito di una valutazione di fattibilità tecnico-economica da parte di un Progettista o di un Tecnico abilitato (Celenza et al., 2016).

Dal punto di vista della fattibilità tecnica, la UNI 10200:2018 fornisce indicazioni relativamente alla compatibilità fra il tipo di impianto e il tipo di contabilizzazione, diretta e indiretta. In particolare, nelle configurazioni di impianto verticale o a colonne montanti e a distribuzione orizzontale a collettore o ad anello, sono fornite indicazioni relativamente al sistema di contabilizzazione ottimale rispetto al terminale di emissione utilizzato.

In merito alla fattibilità economica dei suddetti sistemi la norma fornisce unicamente indicazioni generiche. Il D.Lgs. 102/2014 e s.m.i. all'art.9 comma 5 punti b) e c) richiama esplicitamente la norma UNI EN 15459 come metodologia applicabile per

BOX 1

ACCURATEZZA DELLA RIPARTIZIONE

I sistemi di contabilizzazione indiretti sono tecnicamente utilizzabili nella quasi totalità degli edifici esistenti, ma presentano incertezze tipiche del singolo dispositivo pari a circa 8% e che, in condizioni critiche, possono anche superare il 30% (Celenza et al., 2015). Se invece si considera l'intero sistema di contabilizzazione installato nell'edificio, in alcuni casi gli errori dei singoli dispositivi possono trovare parziale compensazione e generare quindi un valore complessivo di incertezza che in talune condizioni, ad esempio in presenza di dispositivi tutti uguali, radiatori installati di uguale potenza e identiche condizioni di installazione sulle verticali e stesse condizioni di uso da parte degli utenti, si può ridurre anche fino a 2-3% (Dell'Isola et al., 2017). Di contro, in presenza di variazione delle condizioni di installazione e uso del sistema, questo valore può crescere in maniera anche significativa, come mostrato in Figura 1.

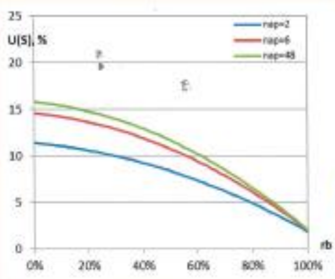
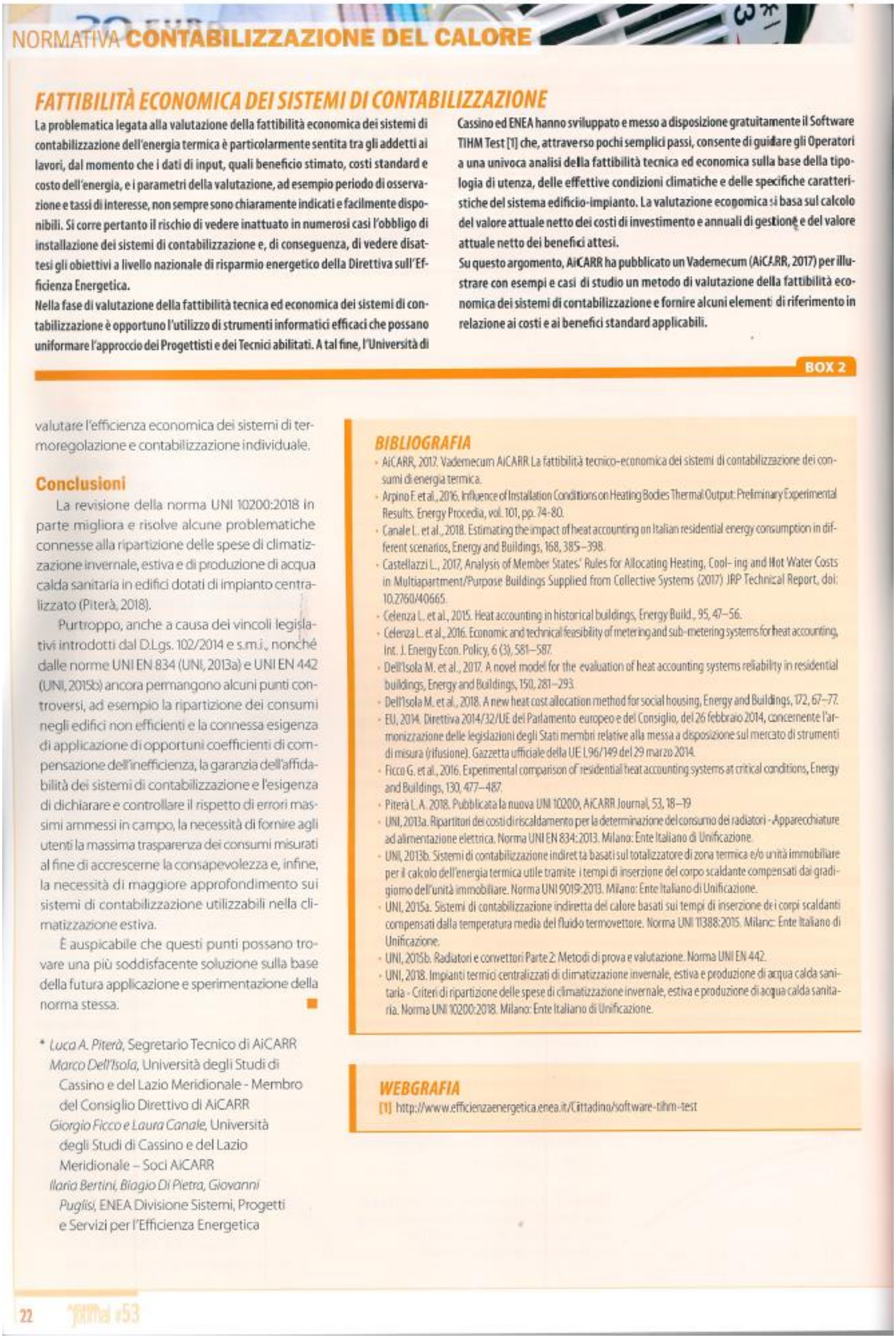


Figura 1 - Andamento dell'incertezza di ripartizione al variare della correlazione degli appartamenti nell'edificio e del numero di appartamenti



FATTIBILITÀ ECONOMICA DEI SISTEMI DI CONTABILIZZAZIONE

La problematica legata alla valutazione della fattibilità economica dei sistemi di contabilizzazione dell'energia termica è particolarmente sentita tra gli addetti ai lavori, dal momento che i dati di input, quali beneficio stimato, costi standard e costo dell'energia, e i parametri della valutazione, ad esempio periodo di osservazione e tassi di interesse, non sempre sono chiaramente indicati e facilmente disponibili. Si corre pertanto il rischio di vedere inattuato in numerosi casi l'obbligo di installazione dei sistemi di contabilizzazione e, di conseguenza, di vedere disattesi gli obiettivi a livello nazionale di risparmio energetico della Direttiva sull'Efficienza Energetica.

Nella fase di valutazione della fattibilità tecnica ed economica dei sistemi di contabilizzazione è opportuno l'utilizzo di strumenti informatici efficaci che possano uniformare l'approccio dei Progettisti e dei Tecnici abilitati. A tal fine, l'Università di Cassino ed ENEA hanno sviluppato e messo a disposizione gratuitamente il Software TIHM Test [1] che, attraverso pochi semplici passi, consente di guidare gli Operatori a una univoca analisi della fattibilità tecnica ed economica sulla base della tipologia di utenza, delle effettive condizioni climatiche e delle specifiche caratteristiche del sistema edificio-impianto. La valutazione economica si basa sul calcolo del valore attuale netto dei costi di investimento e annuali di gestione e del valore attuale netto dei benefici attesi.

Su questo argomento, AiCARR ha pubblicato un Vademecum (AiCARR, 2017) per illustrare con esempi e casi di studio un metodo di valutazione della fattibilità economica dei sistemi di contabilizzazione e fornire alcuni elementi di riferimento in relazione ai costi e ai benefici standard applicabili.

BOX 2

valutare l'efficienza economica dei sistemi di termoregolazione e contabilizzazione individuale.

Conclusioni

La revisione della norma UNI 10200:2018 in parte migliora e risolve alcune problematiche connesse alla ripartizione delle spese di climatizzazione invernale, estiva e di produzione di acqua calda sanitaria in edifici dotati di impianto centralizzato (Piterà, 2018).

Purtroppo, anche a causa dei vincoli legislativi introdotti dal D.Lgs. 102/2014 e s.m.i., nonché dalle norme UNI EN 834 (UNI, 2013a) e UNI EN 442 (UNI, 2015b) ancora permangono alcuni punti controversi, ad esempio la ripartizione dei consumi negli edifici non efficienti e la connessa esigenza di applicazione di opportuni coefficienti di compensazione dell'inefficienza, la garanzia dell'affidabilità dei sistemi di contabilizzazione e l'esigenza di dichiarare e controllare il rispetto di errori massimi ammessi in campo, la necessità di fornire agli utenti la massima trasparenza dei consumi misurati al fine di accrescerne la consapevolezza e, infine, la necessità di maggiore approfondimento sui sistemi di contabilizzazione utilizzabili nella climatizzazione estiva.

È auspicabile che questi punti possano trovare una più soddisfacente soluzione sulla base della futura applicazione e sperimentazione della norma stessa. ■

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WEBGRAFIA

[1] http://www.efficienzaenergetica.enea.it/Cittadino/software-tihm-test

Climate control inside a greenhouse by means of a solar cooling system

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Abstract

Microclimate control in the greenhouse is important to improve yield and obtain low environmental impacts. Ventilation, shading, evaporative cooling and refrigeration are methods of controlling air temperature inside the greenhouse; nevertheless, ventilation and shading are often not sufficient to remove the excess heat, refrigeration is generally expensive and evaporative cooling is based on the use of large quantities of water. In order to enhance the sustainability of the greenhouse sector, renewable energy sources can be exploited with the application of solar absorption systems for greenhouse cooling in areas with high outdoor temperatures and solar insolation. This paper describes the application of a solar cooling plant with absorption chiller for thermal control of a greenhouse. The experimental system consisted of a Mediterranean greenhouse, with a surface of 300 m^2, and a single-effect LiBr-H_2O absorption chiller fed by evacuated-tube solar collectors, located at the University of Bari, Italy. The distribution system provides the cooling power only for the volume surrounding the crop. The research demonstrated that solar cooling systems provide an opportunity for reducing the air temperature around the crop, allowing the reduction of primary energy consumption by exploiting the contemporaneity between the cooling requirements and solar energy availability.

Keywords: absorption unit, evacuated-tube solar collectors, renewable energy sources

INTRODUCTION

Suitable growing conditions for greenhouse cultivation need optimized climatic management of the greenhouse environment, leading to both energy savings and safe working conditions (Von Zabeltitz, 1999; Vox et al., 2010). Sustainable greenhouse management is part of the wider issue of land conservation (Picuno et al., 2011; Campiotti et al., 2013, 2017; Díaz-Palacios-Sisternes et al., 2014; Vox et al., 2016). Several studies have been developed on the use of renewable energy sources in greenhouse industry (Vox et al., 2008; Campiotti et al., 2011; Castellano, 2014; Russo et al., 2014).

Cooling systems based on the use of non-renewable energy sources have a strong influence on the environmental sustainability of greenhouse production. In the Mediterranean area, the intense solar radiation in warm spring-summer periods induces the overheating of the indoor air and often overcomes critical temperature values for the crop. Different cooling systems are used to remove the thermal overload in order to obtain suitable climatic parameters inside the greenhouses. Greenhouse ventilation, natural or artificial, is the cheapest method of greenhouse cooling, but they are often not enough to remove the surplus energy. The use of conventional heat pumps in cooling is too expensive in terms of installation and operation costs, because of the large quantity of heat to be removed from the greenhouse (Vox et al., 2010; Davies, 2005; Kumar et al., 2009). The fan-pad and fog systems, known as evaporative cooling methods, control the internal air temperature efficiently in warm regions, requiring minimum power consumption.

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Nevertheless, they work best when evaporative cooling is maximum, which occurs in hot and semi-arid climates (Ahmed et al., 2011; Kumar et al., 2009); however, they mainly rely on the use of electrical energy and require large amounts of high-quality water. Other cooling methods are based on the exploitation of earth ground or of underground aquifer water, since they maintain a constant year-round temperature that, in warm periods, can be used profitably for greenhouse cooling; the underground energy is then used in ground heat exchangers or horizontal earth-tube systems (Mongkon et al., 2014). The application of these composite systems for greenhouse cooling has been widely researched (Ghosal and Tiwari, 2006; Ghosal et al., 2004; Sharan, 2009; Yıldız et al., 2012; Puglisi et al., 2015). Earth-to-air heat-exchanger systems perform better in regions where the heating and cooling demands are similar, to avoid long-term changes in ground temperature (Li et al., 2013).

The dynamics between solar energy availability and greenhouse cooling demand make solar-powered cooling systems suitable for greenhouse cooling. They could be a promising option to reduce the electricity consumption in regions with abundant solar energy and long daily sunny hours (El-Sharkawy et al., 2014; Al-Alili et al., 2012; Ghaddar et al., 1997; Chidambaram et al., 2011). Different kinds of solar cooling systems have been developed (Chidambaram et al., 2011; Hwang et al., 2008; Sarbu and Sebarchievici, 2013), particularly with thermally driven systems using solar thermal collectors. These systems consist mainly of solar thermal collectors to convert solar radiation into heat, a heat-storage tank for storing heat all day, a cooling machine generating chilled water, a cold distribution system, and a cooling tower to dispose of waste heat. The solar energy is employed to produce thermal energy for cooling through thermochemical or thermophysical processes in thermally driven cooling machines (Hwang et al., 2008; Sharma et al., 2011; Sarbu and Sebarchievici, 2013; Ghafoor and Munir, 2015). Among the solar collector-based thermally driven systems, the absorption cycle cooling system operates with some liquid materials able to absorb liquid through an exothermic reaction and to desorb steam through an endothermic reaction (Kalkan et al., 2012; Allouhi et al., 2015). The system typically consists of an absorber, a desorber, a pump, an expansion valve, a generator, a regenerator, an evaporator, a storage tank and a heater. The absorbent solution is diluted with the refrigerant in the absorber, generating an absorbent/refrigerant solution; in the generator, the solution is pumped to a higher pressure and heated. In the desorber, the refrigerant is separated from the solution by means of the desorption process by adding heat. The refrigerant vapor is then liquefied in the condenser, expanded through the expansion device, and evaporated in the evaporator in order to be absorbed again in the absorbent solution (Hwang et al., 2008; Kalkan et al., 2012). The cooling effect is obtained by the evaporation of the refrigerant (water) in the evaporator at very low pressure. The heat provided by the solar collectors is stored in a hot-water storage tank; stored hot water is later used when it is necessary. Solar cooling systems can be particularly interesting where there is abundant solar energy or in remote areas where conventional cooling is difficult.

This paper presents the results of a study on the application of a solar absorption cooling system to a Mediterranean greenhouse at the experimental farm of the University of Bari, where the integration of renewable energy sources for greenhouse heating and climate control has been widely investigated (Russo et al., 2014; Vox et al., 2008, 2014; Blanco et al., 2014, 2015). The present study aims to maximize solar energy use in the summer for air conditioning of the greenhouse, exploiting the coincidence between the period of the greenhouse cooling peak demand and that of greatest abundance of solar energy. The solar collector surface related to the greenhouse cultivated area and the cooling capacity were assessed.

MATERIALS AND METHODS

The experiments were carried out at the experimental center of the University of Bari in Valenzano (Bari, Italy), 41°05’N, 16°53’E, 85 m a.s.l.

The cooling system was designed and applied to reduce air temperature in summer inside an arched-roof greenhouse covered with plastic film (Vox et al., 2014).

Figure 1 shows the layout of the cooling system. The greenhouse was oriented northsouth, with a covered area of 300 m^2 (30 m long, 10 m wide), 4.45 m high along the ridge and 2.45 m along the gutters. The greenhouse covering film was an ethylene-vinyl acetate (EVA) copolymer, with a thickness of 200 µm, characterized by a solar total transmissivity coefficient of about 85% in the solar wavelength range 300-3000 nm.

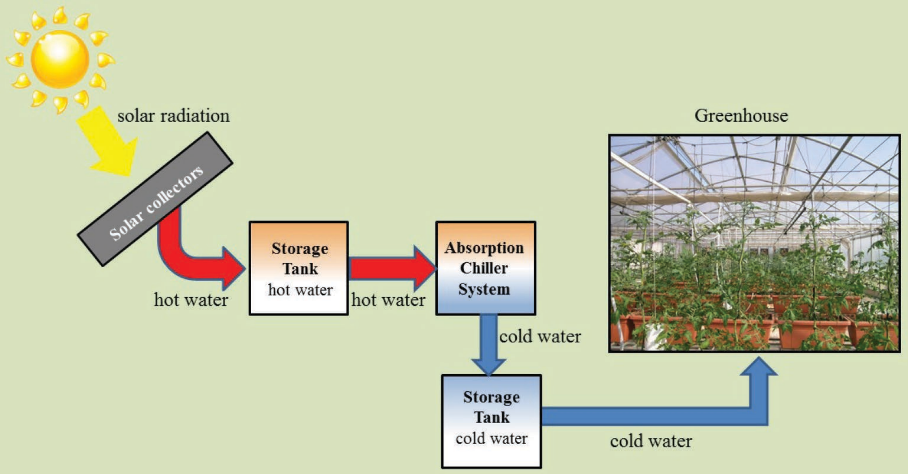

Figure 1. Layout of the solar cooling system.

Cultivation of cherry tomato took place in plastic pots (1.00×0.40×0.40 m) with a growing substrate made of a mixture of soil and peat.

The solar cooling system (Figure 2) consisted of the solar field, the absorption chiller, two tanks for hot and cold water, respectively, and a dry cooler.

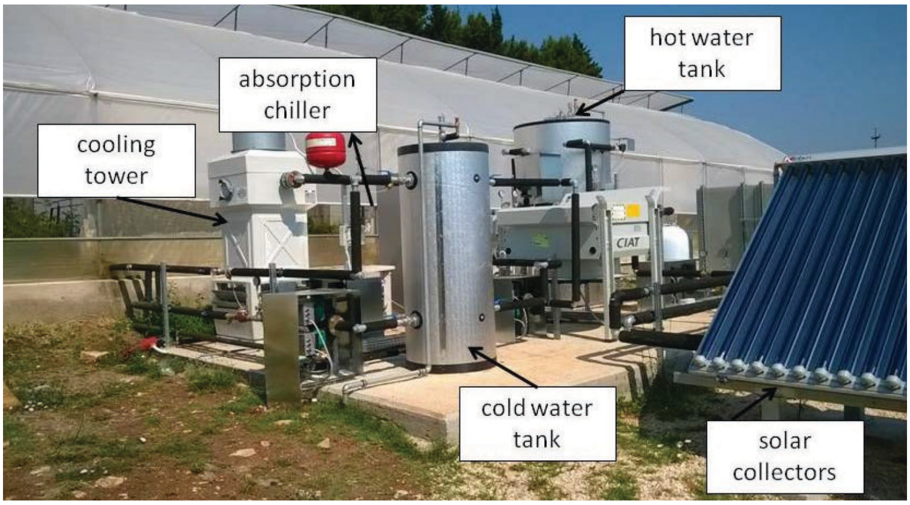

Figure 2. The solar cooling system at the experimental center of the University of Bari, Valenzano (Bari, Italy).

The hot-water tank model PVR (Pacetti, Ferrara, Italy) has a global capacity of 2000 L, while the cold-water tank model VT-V6GCA (Pacetti, Ferrara, Italy) has a global capacity of 500 L. The absorption chiller was a single-effect $LiBr-H_2O$ model WFC SC5 (Yazaki, Shizuoka-ken, Japan) fed only by the evacuated-tube solar collectors, having a COP thermal of 0.70, a cooling capacity of 17.6 kW with a heat input of 25.1 kW, outlet-inlet chilled water temperature of 7-12.5°C, electrical consumption of 48 W. The cooling water had an inlet temperature of 31°C and outlet temperature 35°C; a cooling tower with a heat rejection of 48 kW (MITA Siziano (PV), Italy) was used for this. The dry cooler was used to dissipate the excess power produced by the solar field.

The solar field consists of 15 Sky PRO CPC 58-1800-20 evacuated-tube collectors (Kloben, Verona, Italy). Each collector, placed on the ground with a tilt angle of 40°, has 20 pipes, a gross area of 4.28 m^2, an aperture area of 3.81 m^2 and an absorption area of 5.17 m^2.

The following variables were measured continuously during the testing period: air temperature by means of thermistors (Tecno.el s.r.l. Formello, Rome, Italy); temperature of the pipe water by means of PT100 sensors (Tecno.el s.r.l. Formello, Rome, Italy); and solar radiation in the wavelength range 0.3-3.0 µm by means of a pyranometer model 8-48 (Eppley, Newport, RI, USA). Measured data were collected at a frequency of 60 s, averaged every 15 min by means of a data logger (CR10X; Campbell Scientific, Logan, UT, USA). The plants were cooled by means of pipes located in the cultivation area (Figure 3). The chilled water circulated in the pipes inside the greenhouse when the air temperature around the crop was higher than 30.0°C.

Figure 3. The cooling pipes inside the greenhouse.

RESULTS AND DISCUSSION

Operation of the system was evaluated by means of the data recorded in the field. Figure 4 shows the temperature of the hot water provided by the thermal collectors, the cold water produced by the absorber and the water flowing from the absorber to the cooling tower.

The chilled water flows from the absorber to the cold boiler and its temperature decreases towards the required value of 7°C; at the same time, the warm water flows from the absorber to the cooling tower. Figure 5 shows the solar radiation, the temperature of a cooling pipe localized near the plants inside the greenhouse, of an uncooled pipe and of the greenhouse air. A difference of temperature between the cooled and uncooled pipe of up to 16.8°C was recorded during the working period of the cooling system on 14 June 2016.

Figure 5 shows the effectiveness of the cooling system that is in phase with the solar energy and consequently with the requested cooling energy around the plants. Figure 6 shows the effect of the cooling system on the air temperature around the crop in comparison with the greenhouse air temperature. The controlled temperature around the crop remained lower than 30°C, so in a suitable range for growth of the plants.

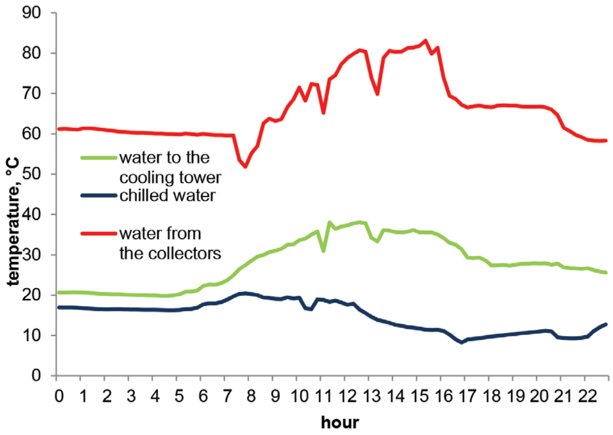

Figure 4. Temperature of the hot water provided by the thermal collectors, the cold water produced by the absorber and the water flowing from the absorber to the cooling tower. Data recorded on 14 June 2016.

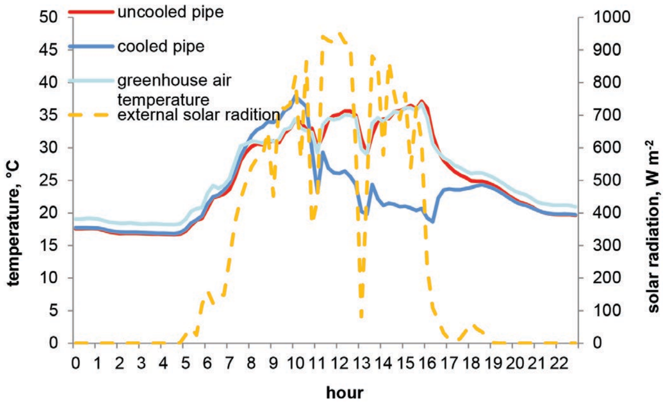

Figure 5. Solar radiation, temperature of the greenhouse air, of a cooled and of an uncooled pipe inside the greenhouse, data recorded on 14 June 2016.

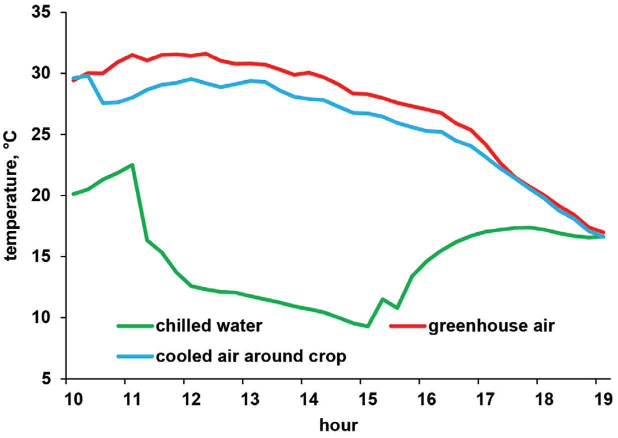

Figure 6. Air temperature of the greenhouse and around the crop, temperature of the chilled water. Data recorded on 22 September 2017.

The agronomic results showed that tomatoes grown in cooled air recorded a total yield equal to 403 g plant^{-1}, while it was equal to 334 g plant^{-1} for tomatoes grown without cooling.

CONCLUSIONS

Our research showed that the solar absorption cooling system is suitable for greenhouse cooling, allowing a reduction in primary energy consumption by exploiting the contemporaneity between greenhouse cooling requirements and solar energy availability. This solution is particularly effective in the Mediterranean area, where greenhouse cooling is necessary in summer in the presence of high levels of solar radiation.

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Green façades to enhance climate control inside buildings

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Abstract

Green technology can represent a sustainable solution for construction of new buildings and for retrofitting of existing buildings, in order to reduce the energy demands of the buildings' cooling systems, to mitigate the urban heat island and to improve the thermal energy performance of buildings. Green walls can allow the physical shading of the building, promote evapotranspiration in summer and increase thermal insulation in winter. An experimental test was carried out at the University of Bari (Italy) for 2 years. Three vertical walls, made with perforated bricks, were tested: two were covered with evergreen plants (*Pandorea jasminoides* and *Rhyncospermum jasminoides*), while the third wall was kept uncovered and used as a control. Several climatic parameters concerning the walls and the ambient conditions were collected during the experimental test. Daylight temperatures observed on the shielded walls during warm days were lower than the respective temperatures of the uncovered wall by up to 9.0°C. Night-time temperatures during cold days for the vegetated walls were higher than the respective temperatures of the control wall by up to 6.0°C. The absence in the literature of data concerning different seasons of the year is overcome in order to obtain a complete picture of building thermal performance in the Mediterranean climate region.

Keywords: urban agriculture, green walls, air-conditioning, energy savings, microclimate, urban heat island

INTRODUCTION

The urban heat island (UHI) is one of the most typical phenomena of climate in cities and metropolises, where the air temperature is up to 6°C higher in comparison with the surrounding suburban and rural areas (Kanechi et al., 2014; Santamouris, 2014; Vox et al., 2015; Schettini et al., 2016). The UHI has several causes, including the following: the non-reflective and water-resistant construction materials of building surfaces and pavements accumulate and store incident solar radiation during the day and then release heat at night (Vox et al., 2016); the decrease of urban green areas induces a reduction of shade and radiation interception; the limited circulation of air in urban canyons; the elevated production of waste heat from cooling systems, motorized vehicular traffic and industrial processes; the reduced ability of the emitted infrared radiation to escape to the atmosphere (Santamouris, 2012; Campiotti et al., 2013). The UHI adversely affects outdoor comfort conditions, as well as inducing greater use of air conditioning systems, with a rise in peak electricity demand. Nowadays, energy use in buildings accounts for up to 36% of Europe's CO_2 emissions (Cabeza et al., 2010). Concerning the consumption of heating oil for buildings, new buildings generally need 3-5 L m^{-2} $year^{-1}$, while older buildings can consume 25-60 L m^{-2} $year^{-1}$ (EU Energy, 2017).

Environmental and sustainable technology to improve the energy efficiency of urban buildings involves the implementation of green infrastructure in order to reduce energy

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consumption for air conditioning in summer and to increase thermal insulation in winter (Cheng et al., 2010; Pérez et al., 2011; Perini et al., 2011; Cameron et al., 2014; Kazemi and Mohorko, 2017). Greening systems have additional benefits such as mitigation of greenhouse gas emissions, improving air quality and water management, and reducing noise (Cuce, 2017).

Buildings and paved surfaces in cities are increasing, thus ground space for urban greening is scarce; moreover, large portions of the roof area can be occupied by building services, while the surface area of the building envelope is generally left bare (Jim, 2015; He et al., 2017). Vertical green systems can be a solution for greening cities, offering several benefits on the façade itself, on the building and on its surrounding urban environment, as well as social, environmental and aesthetic benefits, depending on the climatic conditions of the area, the greening technology design, the building characteristics and the urban context (Wong et al., 2010; Perini et al., 2011; Fernandez-Cañero et al., 2013; Berardi et al., 2014).

According to construction techniques and characteristics, green vertical systems or green walls are classified into green façades and living walls (Cuce, 2017; He et al., 2017; Riley, 2017). Green façades are characterized by plants, rooted in the ground or in pots at different heights of the façade, that climb on the building façade directly through morphological features (such as aerial roots, leaf tendrils and adhesion pads) or indirectly on a structural support (such as wire, mesh and trellis) located a small distance from the wall. Living walls are classified as continuous or modular: the former are based on lightweight and permeable screens in which plants are inserted individually; the latter are composed of modular elements that include the growing medium in which the plants grow (Manso and Castro-Gomes, 2015). The modular elements can be trays, vessels, planter tiles and flexible bags; the elements are fixed to a wall or a free-standing frame with an artificial irrigation and fertigation system. The presence of a gap between the building wall and the greening system (generally from 3 to 15 cm) acts as a thermal buffer, improving its thermal insulation impact on the building (Pérez et al., 2014).

In the literature, there are experimental data at real scale concerning short periods; more data are from the summer rather than the whole year (Pérez et al., 2014; Coma et al., 2017; Vox et al., 2017). In summer, greenery systems are effective for all climatic areas of the world, while the performance of greenery systems is strongly influenced by climatic conditions in winter (Pérez et al., 2014).

The aim of this paper was to analyse experimental data for a long period in the Mediterranean region. Summer and winter results are analysed. Two different climbing plants were tested as green façades during a whole year at the University of Bari, south Italy. Several climatic parameters concerning walls equipped with greenery systems and data on ambient conditions were collected to estimate variations of the wall surface temperature.

MATERIALS AND METHODS

From June 2014 to December 2016, experimental research was conducted on the prototype of walls built following typical Mediterranean building solutions at the University of Bari in Valenzano (Bari, Italy), 41°05’N 16°53’E, 85 m a.s.l. This area has a Mediterranean climate classified as Csa, according to the Kopper-Geiger climate classification (Kottek et al., 2006), characterized by a warm temperate climate with dry and hot summer; the winter months are much rainier than the summer months, and the average annual temperature is 16.1°C.

Three walls, each 1.00 m wide, 1.55 m tall and 0.22 m thick, were built facing south with perforated bricks joined with mortar. The bricks used (0.20×0.25×0.25 m) have a thermal conductivity λ (UNI, 2012) of 0.282 W m^{-1} K^{-1}, a specific heat capacity C of 840 J kg^{-1} K^{-1}, and an average density of the masonry work (including plaster) of 695 kg m^{-3}. On the back of the wall, a sealed structure was made with sheets of expanded polystyrene, having a thickness of 30 mm and a thermal conductivity of 0.037 W m^{-2} K^{-1}, in order to insulate and evaluate the influence of the vegetation layer on the wall. A shading net was positioned on the structures to reduce the effect of incident solar radiation on the sealed structure. An iron net was placed as the plant supporting structure, 15 cm from the wall.

Two different evergreen climbing plants were transplanted on 18 June 2014 (Figure 1): variegated *Pandorea jasminoides* and *Rhyncospermum jasminoides*. Each plant grew along a wall, covering it. A third wall was kept uncovered as a control. These plants were selected as greenery vertical system components because of their ease of climbing the wall and their adaptation to the climatic conditions of the experimental area. The plants were irrigated with the drip method.

Figure 1. The three walls at the experimental field of the University of Bari. The right wall is covered with *Rhyncospermum jasminoides*, and the central wall with variegated *Pandorea jasminoides*; the left wall is the uncovered control.

Different climatic parameters, such as the solar radiation incident on the vertical surface, the external air temperature, and the surface temperature of the wall on the external plaster exposed to solar radiation, were measured during the test. The external air temperature was measured with a Hygroclip-S3 sensor (Rotronic, Zurich, Switzerland); it was adequately shielded from solar radiation. The temperature of the external plaster surface exposed to solar radiation was measured using thermistors (Tecno.el s.r.l. Formello, Rome, Italy). The solar radiation normal to the walls was measured using a pyranometer (model 8-48; Eppley Laboratory, Newport, RI, USA) in the wavelength range 0.3-3 mm. Data were measured at a frequency of 60 s, averaged every 15 min and stored in a data logger (CR10X; Campbell, Logan, UT, USA).

RESULTS AND DISCUSSION

The Mediterranean climate is characterized by warm and wet winters and calm, hot and dry summers, and by a notably variation of solar radiation intensity with season. In the period from January 2015 to December 2016, the experimental field was characterized by external air temperatures ranging from -0.3 to 41.4°C, average yearly cumulative solar radiation of 5205 MJ m^{-2}, average monthly cumulative solar radiation of 434 MJ m^{-2}, with monthly solar radiation ranging from 177 MJ m^{-2} in January 2016 to 802 MJ m^{-2} in July 2015.

In order to characterize the impact of ambient conditions on the thermal insulation performance of green façades, different weather scenarios were analysed: a sunny summer day, a cloudy summer day, a sunny winter day and a cloudy winter day. One representative day of each weather scenario has been selected and the results are presented and discussed.

During sunny days, in both summer and winter, the external solar radiation recorded on a vertical wall displayed a typical bell shape.

As shown in Figure 2, on a sunny summer day, the differences between the curves of surface temperature of the two green façades on external plaster exposed to solar radiation and of the control wall without greening cladding were greater in the morning, while they tended to converge in the late afternoon. During the daytime, the external temperature of the control wall was always higher than the external wall temperature of the green façades. The presence of the vegetation layer mitigated the temperature of the external plaster of the walls. The cooling effect of the green façades begins after sunrise, and becomes more prominent from 9:30 to the late afternoon. The amount of vegetative cooling was within the range of 4-5°C. During night-time, the external wall temperatures of the green façades were up to 2°C higher in comparison with the external wall temperature of the wall without plants.

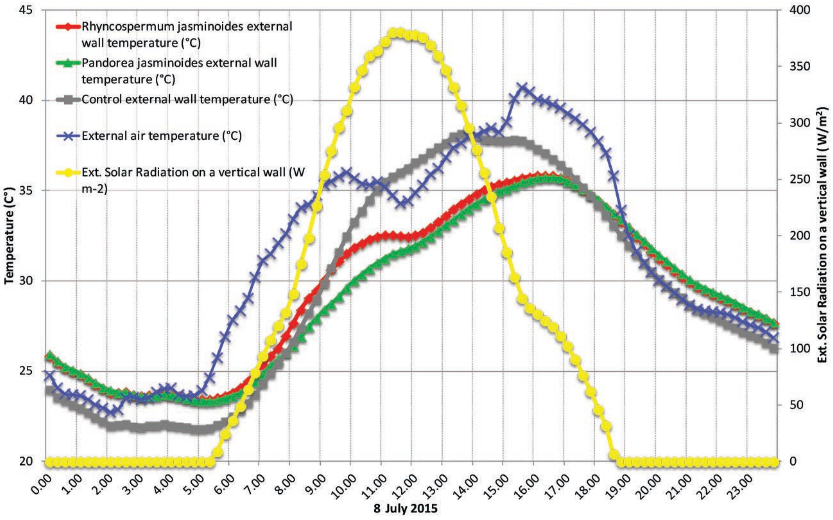

Figure 2. Surface temperature of the external plaster of the three walls exposed to solar radiation and solar radiation normal to the wall on a summer sunny day, 8 July 2015.

The maximum reduction of temperature between the control wall without greening and the covered walls was 9.0°C and was recorded on 31 August 2015 at 13.00 h for the wall protected with variegated *Pandorea jasminoides*.

During the daytime of a cloudy summer day (Figure 3), the external wall temperatures of the two green façades closely followed the external wall temperature of the wall without plants. In the afternoon and during the night-time, the external wall temperatures of the two green façades were higher than the external wall temperature of the control; the amount of vegetative warming was within a narrow range of 1-2°C.

After both a sunny and a cloudy day, during night-time, the green wall acts as a thermal screen, and this behaviour in summer is not desired.

The thermal performance of the walls in winter is shown in Figures 4 and 5. On a sunny winter day (Figure 4), during daytime, the external wall temperature of the control wall was 3-5°C higher than the external wall temperature of the green façades. After sunset and during night-time, the external wall temperatures of the two green façades were 1-2°C higher than the external wall temperature of the control. After sunset, the vegetation layer increased the insulation performance of the walls.

The highest increase of temperature of the external covered surface in comparison with the control wall without greening, 6.0°C, was recorded during a cold wave on 1 November 2015 at 04:15 h for the wall covered with variegated *Pandorea jasminoides*.

On a cloudy winter day (Figure 5), during daytime, all the temperature curves clustered together. At night-time, the vegetation layer increased the insulation performance of the walls, and the amount of vegetative warming was up to 1°C.

During night-time, the green wall acts as a thermal screen, and this behaviour in winter is advantageous.

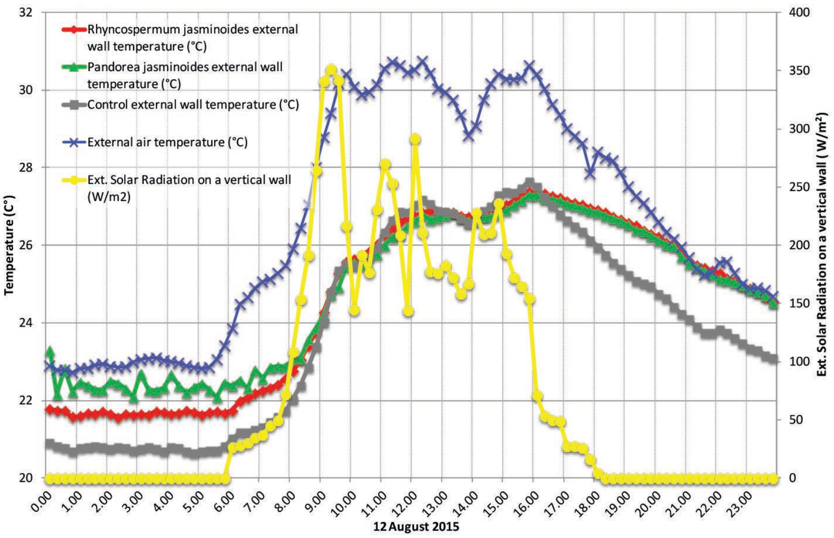

Figure 3. Surface temperature of the external plaster of the three walls exposed to solar radiation and solar radiation normal to the wall on a summer cloudy day, 12 August 2015.

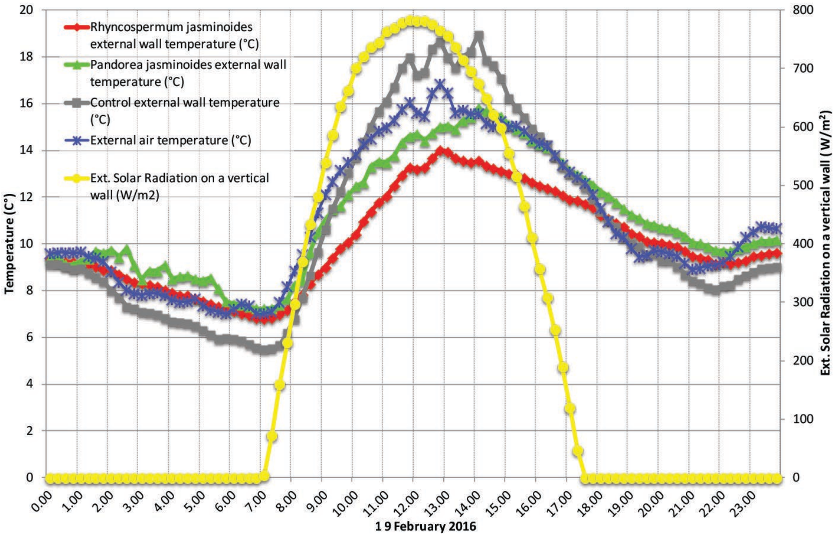

Figure 4. Surface temperature of the external plaster of the three walls exposed to solar radiation and solar radiation normal to the wall on a winter sunny day, 19 February 2016.

Comparison between the performance of the green layers under different weather scenarios confirms that the cooling green layer effect is higher when radiation and air temperature are high (Nori et al., 2013).

In the literature, few authors have reported experimental data under similar climatic conditions (Csa). Pérez et al. (2014) reported the following reductions in the external building surface temperature: from 1.7 to 13°C in a warm temperate climate region and from 7.9 to 16°C in a snow climate region in the case of a wall covered with traditional green façades during summertime. Susorova et al. (2013) reported an average decrease of the façade surface temperature due to the presence of vegetation on the façade from 1.0 to 9.0°C during summer on the external surface of brick infills. For a living wall system in a hot and humid climate, Chen et al. (2013) reported a reduction of the exterior wall temperature by a maximum of 20.8°C and of the interior wall by 7.7°C.

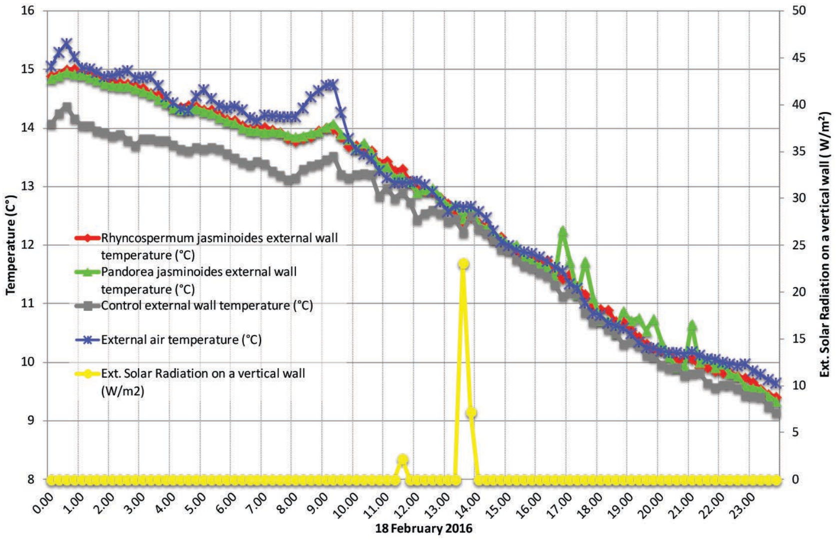

Figure 5. Surface temperature of the external plaster of the three walls exposed to solar radiation and solar radiation normal to the wall on a winter cloudy day, 18 February 2016.

CONCLUSIONS

The data recorded during the experimental test are useful to assess temperature regimes under different weather scenarios in the Mediterranean climate region. The absence in the literature of data concerning different seasons of the year is overcome to obtain a complete picture of building thermal performance. Future research should evaluate throughout the year whether and to what extent the resulting decrease in the summer cooling load counterbalances the increase in the winter heating load, if present.

In conclusion, the presence of the green layer provides the benefit of decreasing the exposure of the building envelope to direct solar radiation and to large temperature fluctuations that can cause its early deterioration.

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