Agenzia nazionale per le nuove tecnologie,
l'energia e lo sviluppo economico sostenibile

Ministero dello Sviluppo Economico

Ricerca di Sistema elettrico

Raccolta delle principali attività di diffusione

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RACCOLTA DELLE PRINCIPALI ATTIVITA' DI DIFFUSIONE

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Report Ricerca di Sistema Elettrico

Accordo di Programma Ministero dello Sviluppo Economico - ENEA
Piano Annuale di Realizzazione 2015
Area: Efficienza energetica e risparmio di energia negli usi finali elettrici e interazione con altri vettori energetici
Progetto: Tecnologie per costruire gli edifici del futuro
Obiettivo: F "Comunicazione e diffusione dei risultati"
Responsabile del Progetto: Giovanni Puglisi, ENEA

Indice

1. INTRODUZIONE

Il presente 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 2015.

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,
- organizzazione di convegni.

In questo rapporto non è inclusa l'attività svolta in ambito IEA, in quanto riportata in un apposito rapporto, a cui si rimanda (Report RdS/PAR2014/161).

2. ELENCO PUBBLICAZIONI

Di seguito è presentato l'elenco delle pubblicazioni suddiviso per ogni linea e successivamente sono riportati gli articoli pubblicati.

OBIETTIVO A: SOLUZIONI INNOVATIVE PER L'EFFICIENTAMENTO DEGLI EDIFICI.

1) **"Aumento dell'autoconsumo fotovoltaico attraverso innovativi metodi di gestione per pompe di calore e chiller negli edifici"**, 33° Convegno Nazionale AICARR, Padova, 9 Giugno 2016, Biagio Di Pietra, Giovanni Puglisi, Danilo Sbordone, Giuseppe Emmi, Gioacchino Morosinotto.
2) **"ICT Applications for Improving the Generation and Distribution Efficiency of a Small Mediterranean Island"**, IEEE International Conference on Environment and Electrical Engineering (EEEIC 2016), 6 – 8, June, 2016, Florence, Italy, M. Beccali, I. Ciulla, M.G. Ippolito, D. La Cascia, G. Leone, V. Lo Brano, G. Zizzo C. Bommarito, B. Di Pietra, F. Monteleone.
3) **"Increase of photovoltaic self-consumption through innovative managing methods of heat pumps and chillers in buildings"**
proceedings of the 12th REHVA World Congress, CLIMA 2016, 22-25 Maggio 2016, Aalborg, Denmark, Biagio Di Pietra, Giovanni Puglisi, Danilo Sbordone, Giuseppe Emmi, Gioacchino Morosinotto.

OBIETTIVO B: RETI TERMICHE DISTRIBUITE.

1) **“Introducing distributed solar thermal power in small-scale district heating systems”**, Heiselberg, P. K. (Ed.) (2016). CLIMA 2016 - proceedings of the 12th REHVA World Congress: volume 3. Aalborg, Denmark: Aalborg University, Department of Civil Engineering, F. Zanghirella, J. Canonaco, G. Puglisi, B. Di Pietra, 2016.

2) **“Utilities Substations in Smart District Heating Networks“**, 2015,Energy Procedia, vol. 81, pp. 597-605, M. A. Ancona, B. Di Pietra, F. Melino, G. Puglisi and F. Zanghirella.

3) **“An evaluation of distributed solar thermal "net metering"** in small-scale district heating systems”, Energy Procedia, vol. 78, pp. 1859-1864, B. Di Pietra, F. Zanghirella and G. Puglisi, 2015.

4) **“Net metering in small-scale district heating systems”**, Microgen IV: Proceedings of the 4th International Conference, on Microgeneration and Related Technologies (Tokyo, 28–30 October 2015), ID 103, pp 35-43, Biagio Di Pietra, Giovanni Puglisi, Fabio Zanghirella.

OBIETTIVO C: TECNOLOGIE “GREEN” PER GLI EDIFICI.

1) **“Wood Biomass as Sustainable Energy for Greenhouses Heating in Italy”**, Agriculture and Agricultural Science Procedia 8 (2016) 637 – 645, Carlo Bibbiani,Fabio Fantozzi, Caterina Gargari, Carlo Alberto Campiotti, Evelia Schettini and Giuliano Vox.

2) **“Simulation of the thermal behaviour of a building retrofitted with a green roof: optimization of energy efficiency with reference to italian climatic zones”**, Agriculture and Agricultural Science Procedia 8 (2016) 628 – 636, Caterina Gargari, Carlo Bibbiani, Fabio Fantozzi, Carlo Alberto Campiotti.

3) “**Performance evaluation of a solar cooling plant applied for greenhouse thermal control”**, Agriculture and Agricultural Science Procedia 8 (2016) 664 – 669, Carlo Alberto Campiotti, Gioacchino Morosinotto, Giovanni Puglisi, Evelia Schettini, Giuliano Vox.

4) **“Identifying strategies for energy consumption reduction and energy efficiency improvement in fruit and vegetable producing cooperatives: a case study in the frame of TESLA project”**, Agriculture and Agricultural Science Procedia 8 (2016) 657 – 663, Arianna Latini, Carlo Alberto Campiotti, Enrico Pietrantonio, Corinna Viola,Victor Peral, Joaquín Fuentes-Pila, Juan Sagarna.

5) **“Green control of microclimate in buildings”**, Agriculture and Agricultural Science Procedia 8 (2016) 576 – 582, Evelia Schettini, Ileana Blanco, Carlo Alberto Campiotti, Carlo Bibbiani, Fabio Fantozzi, Giuliano Vox,.

6) **“Environmental impact of Green roofing: the contribute of a green roof to the sustainable use of natural resources in a life cycle approach”**, Agriculture and Agricultural Science Procedia 8 (2016) 646 – 656, Caterina Gargari, Carlo Bibbiani, Fabio Fantozzi, Carlo Alberto Campiotti.

7) **“Evaluation of wall surface temperatures in green facades”**, Proceedings of the Institution of Civil Engineers - Engineering Sustainability, September 06, 2016, DOI: 10.1680/jensu.16.00019, Giuliano Vox MSc, Ileana Blanco, Silvana Fuina, Carlo Alberto Campiotti, Giacomo Scarascia Mugnozza, Evelia Schettini.

OBIETTIVO E: ANALISI E BENCHMARK DI CONSUMI ENERGETICI DEGLI EDIFICI NEI SETTORI ECONOMICI.

1) **“A methodology for the generation of energy consumption profiles in the residential sector”** International journal of heat and technology, ISSN: 0392-8764 , Vol. 34, No. 3, September 2016, pp. 491-497 DOI: 10.18280, Giovanni Puglisi, Fabio Zanghirella, Paola Ungaro, Giuliano Cammarata.

OBIETTIVO F: COMUNICAZIONE E DIFFUSIONE RISULTATI

1) **"I meccanismi di incentivazione per l'efficienza energetica"**, Energia, ambiente e innovazione, 2/2016, DOI 10.12910/EAI2016-022, A. Federici, C. Martini, P. Falconi, A. N. Negri.
2) **2/2016, editoriale**, "Energia, ambiente e innovazione", Giovanni Puglisi, Laura M. Padovani.
3) **"La contabilizzazione accurata e trasparente dell'energia"**, Energia, ambiente e innovazione, 2/2016, DOI 10.12910/EAI2016-023, M. Dell'Isola, L. Celenza, G. Ficco, P. Vigo.
4) **"Efficienza energetica: la strada per innovare il sistema agricolo-alimentare"**, Energia, ambiente e innovazione, 2/2016, DOI 10.12910/EAI2016-025, Carlo Alberto Campiotti, Germina Giagnacovo, Arianna Latini, Matteo Scoccianti, Corinna Viola.

Di seguito gli articoli per esteso.

"Aumento dell'autoconsumo fotovoltaico attraverso innovativi metodi di gestione per pompe di calore e chiller negli edifici"

Abstract
I sistemi di climatizzazione con pompa di calore integrati ad impianti fotovoltaici rappresentano una soluzione impiantistica che nell'ultimi anni è stata oggetto di molti studi nonché di applicazioni reali. L'utilizzo abbinato di queste tecnologie rappresenta una promettente soluzione per la climatizzazione degli edifici in un'ottica globale di riduzione dei consumi energetici e di emissioni di CO_2 in ambiente. L'obbiettivo di questo studio è quello di analizzare ed ottimizzare gli effettivi benefici sia dal punto di vista energetico che economico ottenibili dallo sviluppo di innovativi metodi di gestione delle unità di climatizzazione al fine di aumentare la quota di energia rinnovabile impiegata dall'impianto.
Lo studio del comportamento di questi sistemi che adottano nuove strategie di controllo è stato sviluppato mediante simulazioni di tipo dinamico sviluppate in ambiente Matlab-Simulink. Il caso studio analizzato considera un edificio residenziale con un impianto fotovoltaico e unità di climatizzazione del tipo aria-acqua.
I risultati ottenuti dalle simulazioni effettuate mostrano dei significativi effetti benefici dovuti alla gestione dell'impianto di climatizzazione grazie alle strategie di integrazione impiantistica proposte e inducono a riflessioni circa le modalità di regolazione in relazione alla stagione ed al contesto climatico di riferimento.
summary
Solar assisted heat pump system are a typical technology and subject of many studies in recent years. It represents an important integration in the air-conditioning of buildings in order to achieve the energy and environmental goals envisaged. The aim of this study is to understand the energy and economic benefits obtained from new and innovative management methods of the conditioning units in order to increase the share of renewable energy used.
Detailed dynamic simulations in Matlab-Simulink were conducted to quantify the benefits of such control configurations. A residential building with air conditioning system and photovoltaic plant was considered in different climatic regions.
The results confirm the important energy benefits of using integration strategies and induce reflections on how to adjust depending on the season and the climatic context.
Finally the simulation models developed lend themselves to the study and evaluation of the influence of other regulation systems in order to determine the optimal configuration and the resulting benefits
Parole chiave: climatizzazione residenziale, sviluppo energetico sostenibile,sistemi integrati.
Key words: residential air conditioning, sustainable energy development, integrated systems.

1. INTRODUZIONE

La tecnologia degli impianti fotovoltaici ha visto un crescente sviluppo a partire dagli anni 70 fino ai giorni nostri in cui l'efficienza di conversione delle celle fotovoltaiche è aumentata notevolmente. A favorirne lo sviluppo e la diffusione di impianti anche di piccola taglia sono state le azioni di supporto da parte dei governi nonché la riduzione drastica dei costi di realizzazione della materia prima e conseguentemente dei costi di installazione. L'Italia ad esempio ha visto una crescita del numero di installazioni di questi impianti soprattutto nell'ultimo decennio a causa dell'introduzione di sostegni economici da parte dello Stato (vedi Figura 1). Un altro motivo di attrazione verso questa tecnologia è a carattere ambientale ed è dovuto essenzialmente alla possibilità di produrre direttamente energia elettrica senza nuocere direttamente all'ambiente nella zona di produzione.

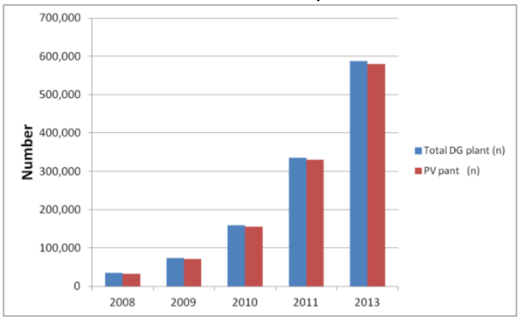

Figura 1 – Numero di impianti fotovoltaici installati in Italia

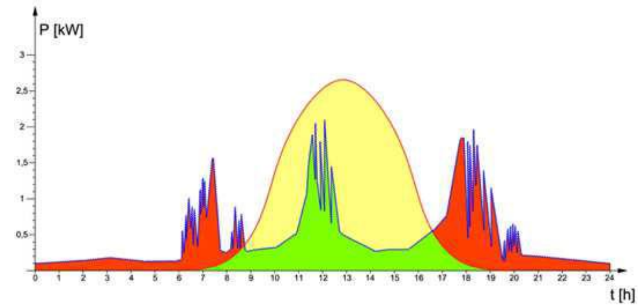

Figura 2 – Tipica configurazione di produzione/consumo domestica

L'autoconsumo energetico degli edifici rappresenta indubbiamente una caratteristica fondamentale e necessaria affinché le nuove costruzioni contribuiscano a limitare le emissioni in ambiente e i cambiamenti climatici. Gli enti normatori europei promuovo questa tipologia di approccio (European Commission,2014) e le nuove normative puntano verso questa visione. È inoltre riconosciuto come la convenienza di installare un sistema fotovoltaico dipenda in larga misura dall'autoconsumo che si è in grado di ottenere. In genere, considerando un normale impianto domestico, si raggiunge un autoconsumo del 20-30 %. Implementando un sistema di programmazione dei carichi si può arrivare ad un 50-60 % di autoconsumo mentre con un sistema ad accumulo elettrochimico si può raggiungere, in alcuni periodo dell'anno, autoconsumi anche del 100 %. È comunque consigliabile utilizzare l'energia in autoconsumo diretto in quanto l'utilizzo diretto dell'energia autoprodotta ha basse perdite di trasformazione (i migliori inverter hanno efficienze superiori al 97%) mentre l'accumulo e il successivo riutilizzo introducono maggiori perdite a causa delle fasi di carica e scarica delle batterie.

L'alternativa all'autoconsumo è l'immissione in rete, l'energia immessa in rete viene valorizzata con il meccanismo dello scambio su posto a circa il 50-70% rispetto al costo dell'energia prelevata.

Diversi studi hanno indagato la possibilità di integrare la produzione di fotovoltaico con l'alimentazione di unità di climatizzazione invertibili a compressione di vapore, la maggior parte di questi studi ha indagato unità del tipo acqua/acqua con l'utilizzo di accumuli elettrochimici (Thygesen R., Karlssson B,2014) (Franco F., Fantozzi F, 2015).

Altri studi prendono in considerazione l'allacciamento alla rete delle unità nell'ottica delle "Smart Grid Ready" (Schibuola L et al,2014).

Lo scopo del presente lavoro è l'analisi e l'applicazione di innovativi metodi di controllo atti a consentire una più completa integrazione tra la tecnologia del fotovoltaico e quella delle unità di climatizzazione ad inverter che costituiscono senza dubbio lo standard impiantistico attuale a maggior efficienza e di maggior sviluppo negli anni futuri.

Il lavoro proposto prende in considerazione, a differenza dei lavori di cui sopra, una tipo di controllo che integra l'impianto fotovoltaico e l'unità di climatizzazione tramite un accumulo di tipo termico. Un accumulo di questo tipo è utilizzabile da subito ed è caratterizzato da costi ridotti sicuramente più accessibili rispetto ai precedenti. L'unità di generazione è una unità pompa di calore del tipo aria/acqua, sicuramente la soluzione economicamente più vantaggiosa e ovunque utilizzabile in riferimento alle diverse

tipologie di pompe di calore disponibili che non utilizzano aria. Una macchina che utilizza aria esterna come sorgente è in grado di operare con COP migliori durante il periodo diurno (temperatura della sorgente aria favorevole). E'infatti questo il periodo in cui si vuole far operare maggiormente la macchina allineando così la produzione fotovoltaica al funzionamento della pompa di calore. Infine sono stati considerati esclusivamente metodi e componenti standard disponibili nel mercato in modo da rendere l'eventuale messa in pratica di quanto analizzato possibile senza particolari difficoltà dovute al reperimento di prodotti customizzati.
Sono presenti in commercio molti sistemi che gestiscono l'attivazione di determinati carichi connessi a prese elettriche comandate, in presenza di elevata produzione da fotovoltaico. Queste tipologie di controllori vanno generalmente a gestire carichi che sono per loro natura limitati nel tempo (lavatrice, lavastoviglie, accumulo acqua calda sanitaria elettrico o in pompa di calore, ecc). Viceversa il controllo qui proposto ha lo scopo di incrementare l'autoconsumo fotovoltaico in modo continuo e duraturo in tutto il periodo di produzione. Per ottenere questo si è agito sui parametri di set della macchina e sulle logiche di accensione il tutto in funzione del comportamento dell'impianto fotovoltaico.

2. modello di simulazione

Il modello di simulazione è stato sviluppato in Matlab-Simulink, si tratta di un interfaccia grafica di Matlab dove è possibile utilizzare diversi elementi (chiamati blocchi) che permettono di creare dei modelli per simulare un sistema dinamico; un sistema cioè che può essere rappresentato da un modello di equazioni differenziali la cui variabile indipendente è il tempo.

2.1. Dati climatici

I dati climatici costituiscono l'input principale per i modelli di simulazione. Per questo lavoro sono stati utilizzati i dati relativi all'anno tipo per alcune località e, dove disponibili, sono stati utilizzati i dati realmente misurati da centraline climatiche regionali. Questo permette di operare delle simulazioni aderenti e rispondenti alla realtà.

2.2. Edificio

Il modello dell'edificio è stato definito partendo dalle caratteristiche degli elementi opachi e trasparenti (dimensioni e caratteristiche fisiche). L'edificio è stato modellizzato come una zona termica in cui i fabbisogni energetici sono calcolati in modo da mantenere le condizioni di comfort interne (Ceravolo F., Di Pietra B.,Margotta F.,Puglisi G., 2010).

Table I:Dimensioni e dati catteristici dell'edificio

Superficie climatizzata	m²	400
Volume	m³	1150
Fattore di forma		0,7
Piani	n°	2
Trasmittanza strutture opache verticali	W/ m²K	0,310
Trasmittanza strutture trasparenti	W/ m²K	2,616
Trasmittanza solai intermedi	W/ m²K	0,362
Trasmittanza copertura	W/ m²K	0,357
Trasmittanza pavimento contro terra	W/ m²K	0,326

2.3. Impianto fotovoltaico

Il modello simula un impianto fotovoltaico connesso alla rete. Le variabili in input che ne caratterizzano il funzionamento e la conseguente produttività sono la radiazione solare disponibile e la temperatura esterna (Di Pietra B., Sbordone D., 2015).

Table II:dati tecnici dei moduli fotovoltaici

Tecnologia		Silicio monocristallino
NOCT	°C	44

Potenza modulo	W	240
Tilt	°	35
Azimut	°	0
Numero di moduli		25
Dimensioni	m	1.58x0.8x0.035

2.4. Unità di climatizzazione

L'unità di climatizzazione viene simulata in accordo agli algoritmi suggeriti dalle normative tecniche di settore (UNI EN 15316, UNI TS 11300 e EN 14825) tramite una matrice che determina la prestazione dell'unità in funzione della temperatura dell'acqua in ingresso, la temperatura esterna e il grado di carico.

Table III:Dati tecnici della pompa di calore A/W

Riscaldamento		
Potenza termica	kW	31.5
Potenza elettrica	kW	10.70
COP (EN14511:2011)		2.93
Raffrescamento		
Potenza termica	kW	29.1
Potenza elettrica	kW	12.70
EER (EN 14511:2011)		2.29

2.5. Modalità di controllo

Le modalità di controllo sono state sviluppate seguendo due principi base: comfort dell'utenza e sicurezza. Le unità infatti non sono comandate dalla disponibilità di energia elettrica di origine fotovoltaica ma mantengono in ogni condizione la loro regolazione di base in modo da coprire costantemente il carico termico richiesto.

Le modalità di controllo hanno lo scopo di far lavorare l'unità di climatizzazione in condizioni particolari nei periodi in cui è disponibile energia elettrica prodotta da fotovoltaico. Il controllo di articola in due fasi:

1. variazione del set point di lavoro dell'unità;
2. adeguamento della potenza elettrica assorbita.

La variazione del set point di temperatura è calcolata in maniera proporzionale alla disponibilità di energia elettrica da fonte solare, questa variazione incrementa il set point in modalità di funzionamento riscaldamento o acqua calda sanitaria mentre lo riduce in modalità raffrescamento. La proporzionalità tra disponibilità di energia elettrica e variazione del set point non è costante ma è definita in modo che per ridotti valori di disponibilità di energia elettrica la variazione sia coerente, infatti con bassa disponibilità di energia elettrica da fotovoltaico non è conveniente avere modifiche al set point tali da avviare l'unità, nel caso in cui sia spenta, rischiando di consumare una quota di energia elettrica maggiore rispetto a quella disponibile per il periodo di start-up vincolato. Inoltre questo potrebbe innescare dei dannosi start and stop dell'unità. Viceversa, se nell'atto della modifica del set point l'unità risulta già in attività l'aumento ridotto di set point ha l'effetto di mantenere l'unità in funzione per un tempo maggiore rispetto a quello che si avrebbe per il raggiungimento del set point di base (senza influenza della generazione da fotovoltaico). Se la disponibilità di energia elettrica cresce aumenta anche la variazione di set point tale da poter indurre anche l'accensione dell'unità.

È importante evidenziare come l'energia disponibile sia identificata come l'energia immessa in rete e non come l'energia prodotta dall'impianto fotovoltaico, considerando quindi i consumi elettrici dell'edificio

prioritari rispetto ai consumi dell'unità di climatizzazione. Il sistema di controllo perciò non dovrà essere collegato direttamente all'inverter fotovoltaico ma tramite dei lettori TA sulle linee elettriche sarà in grado di definire l'energia immessa in rete.
Il controllo della potenza elettrica va a adeguare il consumo totale dell'unità alla potenza realmente disponibile agendo sulla modulazione inverter del compressore. Questo permette di mantenere l'unità in funzione per il periodo di produzione fotovoltaica senza superare la soglia di disponibilità.
I due controlli proposti sono tra loro interconnessi e si completano a vicenda, se fosse attivo solamente il controllo sul set point il rischio è quello di indurre delle variazioni di set point tali da portare l'unità a consumare più energia di quella disponibile in quanto viene chiamata a soddisfare un salto termico più elevato. Il solo controllo in potenza non avrebbe senso in quanto se l'unità raggiunge il set point impostato va in spegnimento (magari alle prime ore della mattina) e il limite sulla potenza assorbita risulta inutile in quanto l'unità risulterebbe spenta o in funzionamento a carcio parziale per mantenere il set point voluto. Il controllo in parallelo permette di porre l'unità in condizione di attività creando una richiesta indotta dalla variazione di set point, questa richiesta difficilmente verrà soddisfatta in quanto il controllo in potenza limiterà la velocità del compressore e obbligando l'unità a funzionare favorendo quindi l'autoconsumo.
Questa tipologia di controllo risulta facilmente implementabile nei software di gestione delle unità sia internamente alle unità stesse sia tramite controllore esterno in collegamento all'unità tramite i protocolli di comunicazione più diffusi (Modbus, Bacnet, ecc…).
Per quanto riguarda gli aspetti legati alla sicurezza i controlli proposti non vanno ad influire sulla gestione dell'unità in quanto questi non vanno in alcun modo a by passare i controlli di sicurezza previsti. È bene chiarire a questo scopo che il controllo sulla potenza elettrica non va direttamente a comandare il numero di giri del compressore ma bensì la variabile di potenza elettrica assorbita. L'unità adegua poi il numero di giri del compressore al limite previsto mantenendo attivi i tutti controlli previsi come per esempio il controllo inviluppo, fondamentale per far lavorare in compressore sempre in zona di sicurezza. Questo controllo opera diverse operazioni fondamentali in vari elementi dell'unità a seconda della condizione di funzionamento anomala rilevata:

- riduzione della potenza tramite controllo della valvola di espansione il caso di basso rapporto di compressione, elevata pressione di aspirazione, elevato assorbimento di corrente, ecc...
- riduzione della potenza tramite controllo del compressore in caso di alta pressione/temperatura di scarico, bassa pressione di aspirazione, ecc…
- variazione delle rampe di accelerazione/decelerazione del compressore per evitare di uscire dalle zone di sicurezza.

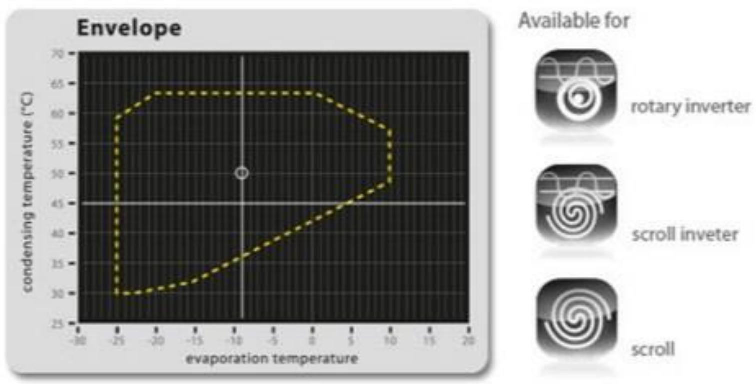

Figura 3 – Esempio di inviluppo

Lo studio qui presentato si focalizza sull'integrazione con un impianto fotovoltaico installato nello stesso edificio servito dall'unità di climatizzazione. In un'ottica più ampia si può pensare che la stessa sequenza di controlli qui proposta possa essere attivata da segnale tramite smart grid. Numerosi sono in tal senso gli studi che propongo la trasmissione attraverso rete di telecomunicazione di determinate informazioni come

per esempio il prezzo dell'energia (real time pricing) o l'indice di sostenibilità dell'energia elettrica trasmessa. Ecco che prevedendo queste innovazioni è facile pensare allo sfruttamento dei controlli qui proposti in un'ottica di integrazione a livello di rete elettrica.
Si accenna ad un altro effetto indiretto legato alla modalità di controllo proposta ovvero alla diminuzione dell'indice TEWI dell'unità legato al fatto di utilizzare energia elettrica prevalentemente proveniente da risorsa rinnovabile. L'indice TEWI tiene conto della qualità dell'energia elettrica che alimenta l'unità di climatizzazione in funzione della massa di CO_2 emessa nell'atmosfera per unità di energia elettrica consumata. Nel caso in cui l'edificio sia sottoposto a certificazione LEED o simili la riduzione dell'indice TEWI porta senza dubbio a un miglioramento dell'indice di certificazione.
Le simulazioni effettuate hanno riguardato le località di Milano e di Copenaghen, per entrambe sono state considerate due differenti tipologie impiantistiche (ventilconvettori e pavimento radiate).

2.6. Indici di autoconsumo

Per effettuare le valutazioni necessarie al presente studio sono stati definiti degli indici di autoconsumo per il funzionamento dell'unità in modalità pompa di calore e in modalità chiller. Tale indice rappresenta il rapporto tra la quota parte di energia utilizzata di origine fotovoltaica e il totale dell'energia elettrica utilizzata dell'unità di climatizzazione (0: tutta l'energia elettrica è prelevata dalla rete, 1: tutta l'energia elettrica è di origine fotovoltaica). Si riporta un esempio nel caso di funzionamento dell'unità in modalità pompa di calore.

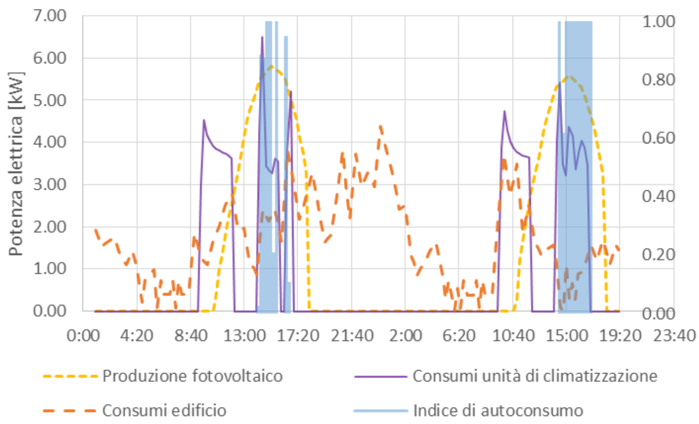

Figura 4 – Calcolo dell'indice di autoconsumo fotovoltaico

4. Risultati e commenti

Si riportano di seguito i risultati delle simulazioni effettuate divise per i casi esaminati:
Caso A: Località Milano, impianto con ventilconvettori, accumuli standard (1000 litri impianto, 500 litri acqua calda sanitaria) e accumuli ottimizzati (5000 litri impianto, 2000 litri acqua calda sanitaria);
Caso B: Località Copenaghen, impianto con ventilconvettori, accumuli standard (1000 litri impianto, 500 litri acqua calda sanitaria) e accumuli ottimizzati (5000 litri impianto, 2000 litri acqua calda sanitaria);
Caso C: Località Milano, impianto con pannelli radianti a pavimento, accumuli standard (1000 litri impianto, 500 litri acqua calda sanitaria) e accumuli ottimizzati (5000 litri impianto, 2000 litri acqua calda sanitaria);
Caso D: Località Copenaghen, impianto con pannelli radianti a pavimento, accumuli standard (1000 litri impianto, 500 litri acqua calda sanitaria) e accumuli ottimizzati (5000 litri impianto, 2000 litri acqua calda sanitaria).
I grafici riportano degli istogrammi mensili di confronto con il totale consumato diviso tra autoconsumo e prelievo dalla rete, viene poi rappresentato dalle linee spezzate l'energia fotovoltaica mensilmente esportata.

Figura 5 – Risultati delle simulazioni per i casi indagati

Le simulazioni effettuate evidenziano la quota di risparmio ottenibile dall'adozione delle metodologie di controllo adottate in differenti climi e con differenti tipologie di impianto. Analoghi risultati si sono avuti nell'applicazione delle stesse metodologie di regolazione nel caso di un ampliamento di un edificio scolastico servito da una pompa di calore A/W nella provincia di Vicenza.

5. conclusioni

Lo studio presentato ha lo scopo di indagare i benefici ottenibili dall'adozione di innovativi sistemi di gestione per unità di climatizzazione in pompa di calore con sorgente aria al fine di aumentare l'autoconsumo di energia elettrica generata da impianto fotovoltaico.

È stato creato un modello di simulazione nella piattaforma Matlab-Simulink in grado di utilizzare i controlli qui proposti. Tramite la definizione di indici di autoconsumo è stato possibile discriminare la quota parte di energia elettrica di origine fotovoltaica utilizzata dall'unità di climatizzazione o consumata dai carichi interni all'edificio.

Le simulazioni sono state condotte considerando un edificio di riferimento in due diverse località (Milano e Copenaghen). Per entrambe le località è stata definita la condizione di base (controlli disattivati) e la condizione con controlli attivati. Quest'ultima è stata ripetuta nel caso di accumuli standard e nel caso di accumuli di taglia maggiore (determinati tramite processo di ottimizzazione). Infine le simulazioni sono state ripetute per due layout impiantistici differenti: ventilconvettori e sistema radiante.
I risultati evidenziano come i controlli proposti, facilmente implementabili nei software di gestione delle unità presenti nel mercato, portano a significativi riduzioni dell'energia fotovoltaica immessa in rete anche nel caso in cui gli accumuli termici non vengano ottimizzati. I risultati migliori si hanno con la configurazione impianti stia del pavimento radiante in quanto i bassi set ponti di lavoro permettono un ampliamento della banda di controllo dell'unità.
Ulteriori studi futuri potranno sviluppare questo tipo di controlli in abbinamento a accumuli a cambiamento di fase o con lo sviluppo delle smart grid.

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"ICT Applications for Improving the Generation and Distribution Efficiency of a Small Mediterranean Island"

Abstract— The paper presents a study on the opportunities offered by ICT for improving the efficiency of the generation and distribution system of a small island. The island taken into consideration is the Italian Lampedusa island. In the paper, the power distribution system of the island is described and the summer and winter daily load profiles are examined in order to define the more suitable control actions for improving the generation and distribution efficiency of the power system. Finally the architecture of an idoneous control system for the smart grid is proposed and an evaluation of the purchase and installation costs of components and devices for the transition of a traditional house towards a smart house is presented.
Keywords—ICT; Power losses; Micro-grids.

Introduction

Small Mediterranean islands are characterized by the greatest amount of renewable sources but, it is well-known that at the same time, they also give the highest contribution to environmental pollution and fossil fuel exploitation [1, 2].
Indeed, small Mediterranean islands produce electric energy having recourse to very obsolete and less efficient diesel generators, with very high generation cost, while the economy of small islands is almost totally based on low remunerative activities, like fishing and tourism (the latter only in the summer periods).

Italy has established a support mechanism in order to reduce the end-user electricity cost for small islands inhabitants. This mechanism still exists and is currently paid by all the electricity consumers through the UC4 additional item cost [2].
Nevertheless, because of the existence of this support mechanism, small islands generation and distribution Utilities had no interest in the use of renewable and clean energy sources and of technological solutions for improving generation and distribution efficiency of their power plants.
The Italian Authority for Electric Energy and Gas started in 2014 a review process of this support mechanism with the Deliberation 447/2014/R/EEL [3]. According to the 598/2014/R/EEL Document [4], starting from 1 January 2015, small islands Utilities are obliged to launch a 5 years long process in order to enhance the efficiency of their distribution and generation systems.
A great contribution to this process can be given by new Information Communication Tehcnology (ICT) application to distribution grids and generation units, as showed in [5, 9].
In this paper the authors:

- show the European and Italian legal legal framework on ICT and automation;
- describe the structure of the Medium Voltage (MV) network of Lampedusa;
- propose an architecture of the ICT system most suitable for implementing the improvement of the generation and distribution efficiency of the island;
- present an economical evaluation of the purchase and installation cost of components and devices for the transition of a traditional house toward a smart house.

The work presented in the paper is part of the research project "Tecnologie per costruire gli edifici del futuro" ("Technologies for the construction of the buildings of the Future") led by ENEA and developed in collaboration with the DEIM of the University of Palermo.

Legal Framework on ICT

According to the definition given by the European Smart Grid Task Force "Smart grids are electricity networks that can efficiently integrate the behaviour and actions of all users connected to it in order to ensure an economically efficient, sustainable power system with low losses and high quality and Security of supply and safety" [10].
The integration of the action of the different users need a rapid exchange of information between all the involved nodes of the MV and LV grid, even in the case of significant distances. The use of ICT in power systems comprises various areas:

- Load control;
- Generation control;
- Providing ancillary services;
- Electric Energy Storage (EES) management;
- Monitoring and metering;
- Signal processing and transmission.

In the last few years some EU Directive and technical standards have faced the issue of automatic control, and smart monitoring and metering in buildings.
The Directive 2009/72/EC [11], concerning common rules for the internal market in electricity requires EU-Member States to replace at least 80% of electricity meters with smart meters by 2020, in the case of positive cost-benefit analysis. Moreover EU-Member States must implement intelligent metering systems.
Also the Energy Performance of Buildings Directive 2010/31/EU [12] specifies that EU-Member States have to encourage the introduction of active control systems and intelligent meters in the case of construction or major renovation of buildings.
The Energy Efficiency Directive 2012/27/EU [13] supports the implementation of new energy services based on data collected from smart meters, demand response and dynamic prices.
Smart meters for EU Countries must comply with the Measuring Instruments Directive 2004/22/EC [14] and the Recommendation 2012/148/EU [15] specifies the minimum functionalities that smart metering systems should provide for consumers.

The European Standard EN 15232 [16] devises terminology, rules and methodologies for extimating the impact of Building Automation and Control (BAC) and Technical Building Management (TBM) systems on energy performance and energy use in buildings.
In Italy the CEI GUIDE 205-18 provides practical functional scheme for the installation of BAC and TBM systems in buildings [17].

The Distribution System

SELIS S.p.A. is the Utility which manages the generating plants and also the distribution MV and LV networks of Lampedusa and other three Mediterranean islands (Linosa, Pantelleria and Marettimo).
SELIS S.p.A. has recently recognized the economic and social importance of improving energy efficiency of its networks and, as a consequence, it has made available to the DEIM all the data for applying the analysis methodology proposed in this paper.
Lampedusa MV network has a radial structure supplied by a unique thermal power plant. The rated voltage is equal to 10 kV. Currently, Lampedusa is totally dependent on external energy sources: diesel, oil and GP fuels. The thermal generation power plant is composed by six generator groups, for a total installed power equal to 16.5 MVA.
The MV simplified network scheme is reported in Fig. 1.

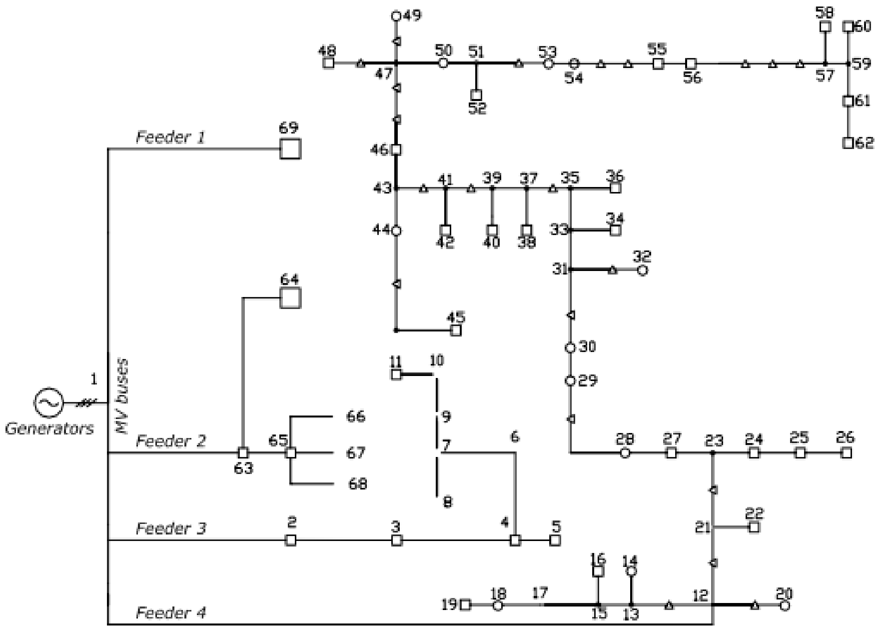

Fig. 1. Circuit scheme of the MV network.

From the power station, 3 MV cable lines (feeders 1, 2, 3) and 1 MV overhead line (feeder 4) spread out. Each line is equipped at the beginning with maximum current and ground fault protection systems. The electrical distribution system has several points where it is possible to radially counter-supply the lines, or where it is possible to create a meshed configuration. Some of these sectionalizing points are located inside remotely controllable substations.
The network has 69 nodes, whose 39 are kiosk substations and 13 are pole-mounted substations.
The network supplies about 4000 end-users [18]. Even if the total load demand is modest, especially during winter period, the dislocation of some important loads (airport, desalination plant, radar, etc.) has caused,

in the last years many problems in the distribution: very high voltage drops, voltage collapse in peripheral zones, cables overheating, etc.
In Fig. 2 example winter and summer load profiles are represented for a substation supplying residential loads.

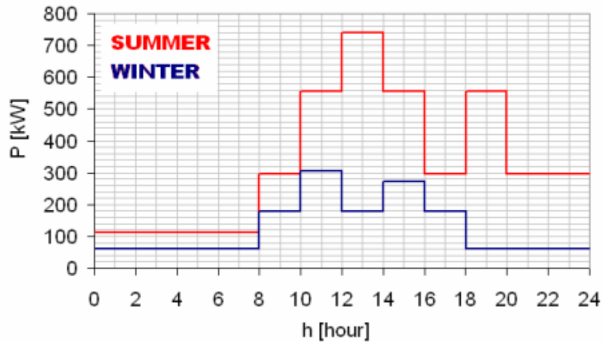

Fig. 2. Typical summer and winter load profile of a secondary substation supplying residential loads.

Typical summer and winter load profile of a secondary substation supplying residential loads.
Figure 2 shows a significant difference between typical summer and winter profiles of domestic users. During summer months the power peak is up to more than twice the power peak in the winter period. Similarly, the rate between the global summer power peak and the global winter power peak measured at the central generation plants is about 1.8 [18]. This implies a consequent higher stress on generators, transformers and cables during summer.
In these conditions, a communication between the end-users, the distributed generation (DG) units and the main power plant, in order to implement Peak Shaving or Load Shifting control logics, can reduce the load on the system's components, in particular during summer.

Architecture of the Control and Communication System
Taking into consideration the various tasks in a smart-grid, an effective control system should comprise:

- a communication system able to connect every point of the island;
- network components and devices for data exchange;
- human interfaces where needed;
- Decision Support Systems (DSS);
- smart meters installed at every monitored and controlled bus;
- sensors for monitoring specific relevant data (current, votages, power flows, power factors, etc).

One of the most difficult issue to face in the design of the control system is the management of a very high number of devices. Indeed, in MV and LV distribution networks the buses to be monitored can be thousands.
For this reason the control system should include also calculators having very great memory space, a great amount of storage during the solution of the problem and very low computational time.
Moreover, the designer of the control system, must select, among all the measured parameters, those to analyze for every different purpose of the control system.
This can be done by dividing the control system into tiers or levels as represented in Fig. 3.

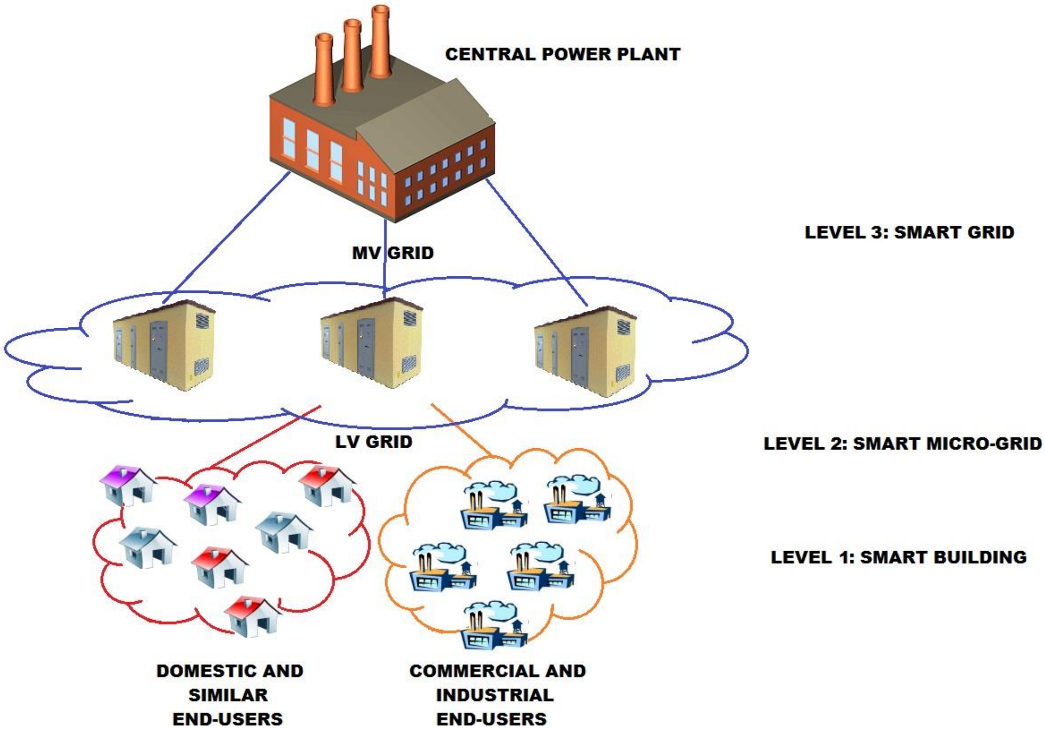

Fig. 3. Structure of the control system.

The more suitable structure for the control system of a little island like Lampedusa, with only two different voltage level, can be characterized by a gerarchic structure like that represented in Fig. 3 with three levels:

- Level 1: Smart Building;
- Level 2: Smart Micro-Grid;
- Level 3: Smart Grid.

Level 1 (Smart Building level) is related to the single building, both domestic/residential and commercial/industrial. Level 1 is characterized by a Building Management System (BMS), one or more smart meters installed within the main electric boards, sensors, controlled sockets, dimmers, controlled switch and a local communication system.

The communication system can be wired using an Ethernet port for sending the data outside the building thanks to an internet connection and single or multiple twisted pair cables for connecting the devices and sensors inside the building.

Another possibility is the use of a wireless communication system. In this second case, the BMS can use the Wi-Fi LAN of the building itself (very rare) for the transmission/reception of signals from the devices and sensors or, more commonly, a ZigBee or a Z-Wave protocol.

ZigBee is very flexible and is used for home automation, security and smart grid. It is an open wireless standard based on the IEEE 802.15.4 personal-area network (PAN) radio standard [19]. ZibBee operates usually at 2.4GHz and its action range is about 10m.

The Z-Wave protocol is an interoperable, wireless, RF-based communications technology designed specifically for control and monitoring applications and devices in residential and commercial buildings.

Z-Wave operates usually at 900MHz and its action range is about 30m.

The International Telecommunications Union (ITU) has included Z-Wave as an option in the international standard G.9959, devoted to provide guidelines for sub-1-GHz wireless devices [20].

Wireless systems have the potential of being the most used inside buildings. Indeed wireless needs a non-invasive installation process, which eliminates the need to run new cables for connecting the devices and sensors.
Level 2 (Smart Micro-Grid level) is related to the LV system between a MV/LV substation and all the supplied buildings.
A data concentrator (DC) is installed in every substation and exchange data and command signals with the buildings and with the central power plant. Pole-monted substations are not appropriate for the installation of a sensitive device like the DC, therefore it is preferable to install the DC only inside kiosk substations.
For implementing DR actions and providing ancillary service to the power system, every smart building will send to the DC in the substation its flexible (FLEX) and not-flexible power profiles, as represented in Fig. 4.
Data coming from clusters of homogeneous users are collected by the DC in order to create a database of aggreagated loads (FLEX, NOFLEX and TOTAL).
Figure 5 shows the aggregated FLEX, NOFLEX and TOTAL load profiles of a cluster with N=100 homogeneous domestic loads, found by applying the bottom-up approach described in [22].
Usually the components can be installed in any wall switch box, and can be also easily removed and installed in a new location if the needs of control or monitoring change [21].
Level 1 can comprise also particular Energy Management Systems (EMS) included in small generating units (Photovoltaic or Wind systems prevalently) or EES systems.
The substations and the buildings are in a Neighborhood Area Network (NAN).
The communication infrastructure of the NAN can be realized adopting various solutions [23]:

- Power Line Communication (PLC);
- Optical Fiber;
- Wi-Fi systems;
- WiMax systems;
- the 3G, LTE or GPRS mobile phone network.

In particular the latter three technologies offer the possibility of usig existing networks, with a relevant reduction of development and installation costs.

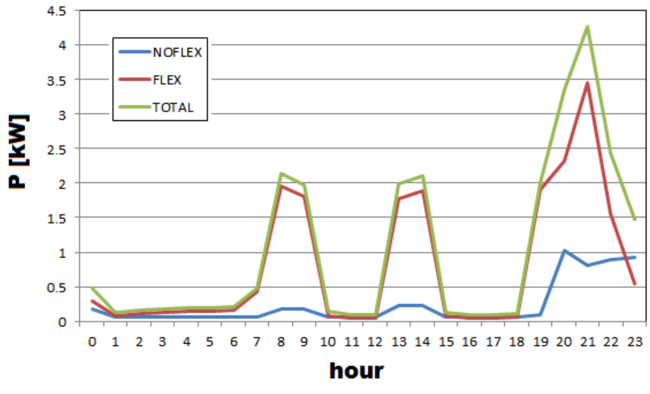

Fig. 4. Example of Flexible (FLEX), Not-flexible (NOFLEX) and Total load profiles of a domestic user.

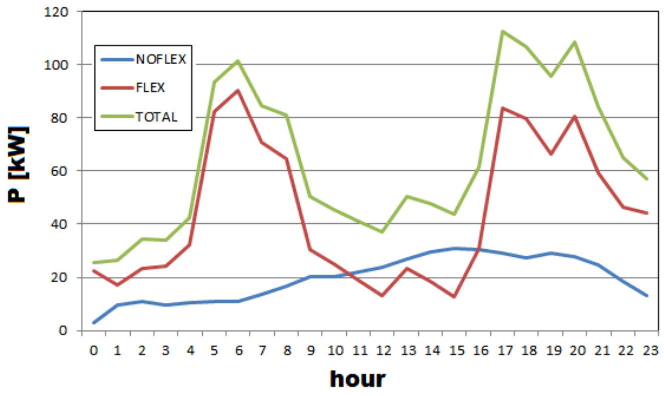

Fig. 5. Example of Flexible (FLEX), Not-flexible (NOFLEX) and Total aggregated load profiles of a cluster of N=100 domestic user.

In Table 1 a summary of the frequency band and limitation of each technology is shown.

TABLE I. FREQUENCY BAND AND LIMITATIONS OF VARIOUS COMMUNICATION TECHNOLOGIES.

Technology	Frequency Band [GHz]	Limitations
3G	1.9-2.2	High frequency band fees
GPRS	0.9-1.8	Low data rates
GSM	0.9-1.8	Low data rates
PLC	0.001-0.03	Noise sensitivity
WiMax	2.5, 3.5, 5.8	Not widespread

Level 3 (Smart Grid Level) is related to the MV system between the central power plant and the MV/LV substations.
The connection between each substation's DC and the Main Controller (MC) installed inside the power plant can be done using optical fiber cable.
The MC receives from the EMSs only information related to aggregated loads and has to elaborate a smaller amount of data.
For example, in the case of Lampedusa having almost 4000 end-users and 39 kiosk substations, each substation's DC has to collect the data coming from an average of 100 BMS and the MC has to elaborate the data coming from almost 40 DC.

Economic Evaluation

The transformation of a traditional house into a smart house needs the installation of sensors, components and devices able to: receive and transmit command signals and data, control specific loads,
Table II shows the systems and components to be installed in a medium size house of about 80 m^2 floor area, indoor and outdoor lighting system and an electric storage water heater.
In Table III the costs for the purchase and the installation of such components and systems are reported.
The costs are average market costs of monitoring, control and automation systems based on Z-wave technology.

TABLE II. COMPONENTS TO INSTALL IN A SMART HOUSE

BMS	Central unit Power supply Web interface Smart meter
TEMPERATURE CONTROL DEVICES	Indoor temperature sensors in every room Magnetic contacts for the detection of the open or closed position of windows Outdoor temperature sensor Controlled switches for conditioning units
LIGHTING CONTROL DEVICES	Motion and light sensor in every room Controlled switches for the lighting system
LOADS CONTROL DEVICES	Controlled sockets Current sensor

TABLE III. COSTS FOR THE PURCHASE AND THE INSTALLATION OF THE COMPONENTS OF THE BAC SYSTEM OF THE TEST HOUSE

Component	**Unit price [€]**	**Quantity**	**Total price [€]**
Power supply	80	1	80
Contact interface	30	4	120
Temperature sensors	40	4	160
Magnetic contacts	3	4	12
Motion and light sensor	27	4	108
Controlled switches for the lighting system	45	4	180
Controlled sockets	45	4	180
Controlled switches for conditioning units	55	3	165
Display and Touchscreen	150	1	150
Central unit	500	1	500
Smart meter	100	1	100
Web interface	150	1	150
Installation, general costs and gain of the contractor			800
TOTAL			*2705*

The cost for the end-user can be reduced up to the 50% of the total cost reported in Table III thanks to the Italian Legislation that promote the installation of BAC and TBM system with a tax deduction.

Conclusion

The paper has presented the first part of a project on the application of ICT in small island for improving the generation and distribution efficiency of the power system.

The structure of the power generation and distribution system of the island of Lampdeusa and of a suitable control system have been presented.

Finally an extimation of the costs for the transformation of a traditional house in a smart house has been given.

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“Increase of photovoltaic self-consumption through innovative managing methods of heat pumps and chillers in buildings”

Abstract
Solar assisted heat pump system is a technology many discussed in recent years. It represents an important integration in the air-conditioning of buildings due to the following advantages: high renewable energy share, low electricity demand, low primary energy demand, and low CO_2 emission depending on the electricity mix feeding to the heat pump.
The objective of this study is to investigate the benefits obtained from the adoption of innovative methods of managing heat pumps in order to increase the consumption of electricity produced from renewable sources. The logics of management induce to use the thermal units largely in times when sustainability of power generation is high by a photovoltaic plant on the building (or by another renewable source connected to the electric smart grid). The logic of the management plan to maintain internal comfort in any condition and manage the thermal storage to accumulate the energy produced that is not immediately used.
The study confirms the importance of using integrated management methodologies in order to increase the share of renewable sources used for the energy demand of the new buildings and also in energy-efficient retrofit of existing ones. It was possible to evaluate the influence of operating procedures in different case studies by determining the optimal configuration and its energy benefits.

Keywords - *Solar energy utilization, sustainable energy for buildings, energy efficient in heating and cooling systems component.*

Introduction
The European directive EPBD of 2010/31 declare that all new buildings will have to be Near Zero Buildings (NZB) up to 2016. The NZB energy needs very low or almost zero should be covered in a very significant extent by energy from renewable sources, including energy from renewable sources produced on site or nearby.
In the last years, the big attention given to the environmental problems involved in a huge diffusion of the Renewable Energy Resources (RESs) power plants. Among the different technologies (biomass, wind, solar, etc.), the photovoltaic (PV) systems are the most widespread, mainly for economic reasons (national incentives) and simplicity of installation and integration in buildings and other civil structures in urban context.
In particular, as showed below, in Italy most of Dispersed Generation (DG plants connect to low voltage) are PV plants (about 98.5%).

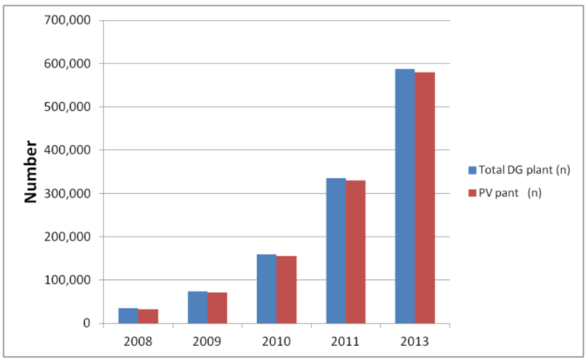

Fig 6: DG and PV plants in Italy: number installed in the last 7 years

Most of these PV systems (90.5 %) are small size plants with a nominal power less than 20 kW, and so they are connected to LV grids owned and managed by final users so called prosumers.

Table 1: PV plants in Italy: number installed for different nominal power in the 2014 [1]

Nominal power	PV plants [n]	%
1-3 kW	213157	32,87
3-20 kW	374474	57,75
20-200 kW	49158	7,58
200-1000 kW	10503	1,62
1000-5000 kW	943	0,15
>5000 kW	183	0,03

The high PV penetration levels may be cause for the many problem in regards to: difficulties when managing the grid, transmission lines congestion, power flow inversion (from LV to HV), hosting capacity problems in critical area (south of italy), overvoltage in many nodes of distribution lines (violation of EN 50160 prescriptions).
So the need of making regulated the interaction between these new widespread users and the main grid has become mandatory. The level of interaction with the electrical grid of prosumers is function of the effective flexibility of the power demand and local production.
The flexibility can be increase thanks to the integration in building of Energy Storage System. Different papers are recently published different models and applications of electrical storage system in order to increase self consumption of energy supplied by PV plants [2,3,4].
Currently in Italy the self-consumption of energy supplied by PV plants amounted to 3000 GWh (only 16% of the total energy produced by installed photovoltaic systems).
The aim of this paper is to investigate the benefits obtained from the adoption of innovative methods of managing heat pumps and thermal storage system, in place of electrical storage system, in order to increase the self-consumption of electricity produced from PV palnts with low investment cost.

Simulation numerical model

The model is made of different blocks, each one modelling the physical components of the system; the main ones are:

- building: to simulate heating and electric load in one year [5];
- thermal storage systems;
- heat generator: to simulate the heat pump and other heat supplier;
- PV model: to simulate the effect of a photovoltaic field;
- weather generator: to simulate hourly meteo input.

The model is developed in Matlab-Simulink and is able to simulate the thermal behaviour and the energy performance of building-plant system both in heating and cooling configuration. The tool allows to analyse various scenarios and different control strategies in order to study and to evaluate primary energy saving and performances in each case.
The main heating output variables of the model are:

- average inner temperature both of the building and the tank;
- COP, thermal and electrical power of the heat pump;
- energy parameter for building load and PV production.

Buildings and Thermal storage

In the model each building is defined starting from its opaque and transparent envelope: size and thermal-physics characteristics (e.g. layer stratigraphy, layer conductance etc.). Details about the type of emission system are needed too. Each building is considered as a single thermal zone and the space heating and cooling demands are calculated in order to maintain the indoor air temperature within a certain range around the seasonal temperature set-point. The mathematical model of the indoor air temperature of each building is made with a set of differential equations in time domain, with variables parameters, and is based on knowledge of the physic that governing the processes of heat exchange of all variables that influence the thermal behavior of buildings.

The energy balance equation used to describe the building model takes into account:

- heat input due to solar radiation on glass and opaque surfaces (Qg)
- presence of people, lighting and electrical appliances (Qi)
- heat loss through the building envelope (Qdisp) and ventilation (Qv)
- power supplied by heating or cooling systems (Qaux)

according to the following relation:

$$CAP * \frac{dT_r}{d\tau} = Q_{aux} + Q_g + Q_i - Q_{disp} - Q_v \qquad (1)$$

where CAP is the total thermal capacity of building and Tr is internal temperature of building.

To take into account the time delay and the attenuation of the heat flux between internal and external surfaces due to the fact that while convective part of heat gain become immediately cooling load, radiative part is first absorbed by wall and then, after time delay, transferred by convection to room air, the time series coefficients are introduced (Ashrae, 2009). This coefficients (called conduction time factors, CTFS) are applied to the Qdisp component of the energy balance and distribute heat gain over time; they also reflect the share of heat gain of a wall or roof that becomes heat gain.

The heat and cool distribution system of each building is considered as an equivalent thermal storage (which can include also an actual thermal storage, if present), to which the heat is provided or subtracted by a heat exchanger connected to the district thermal network, in heating and cooling mode respectively. The presence of the equivalent thermal storage allows to separate from a thermal point of view the distribution system of each building from the thermal network of the district, allowing each building's distribution system to operate at independent operating temperatures.

In each building the needed heating or cooling flow is provided by the equivalent thermal storage, whose temperature varies between set-point values. The temperature of the equivalent thermal storage is calculated by the same differential equation described in (1). Table 2 shows the figures for the residential building used in the simulations.

Table 2: Dimension of the building and U-values for the different building components used in the simulation

Height	m	10
Lenght	m	8
Depth	m	6
Total heating surface	m²	180
Volume	m²	300
Form factor		0,6
Floors	n°	2
Walls trasmittance	W/ m²K	0,310

Windows trasmittance	W/ m²K	2,616
Intermediate floor trasmittance	W/ m²K	0,362
Ground floor trasmittance	W/ m²K	0,357
Roof trasmittance	W/ m²K	0,326

Heat pump and managing

The model developed provides the performance of the inverter-heat pump from the nominal data for air-water configurations. In particular, we have implemented in accordance with the algorithms provided by the technical regulations (UNI EN 15316, UNI TS 11300 and EN 14825) correction matrices that determine the performance parameters of a heat pump in function of the variation:

- return water temperature
- outdoor air temperature
- percentage of load

Such matrices have been determined from experimental performance data of a sample of commercial heat pumps.

The output parameters provided by the model are: Coefficient of Performance (COP), thermal and electrical power. Table 3 shows the nominal data of operation, the model you have entered all the data to the various regimes of operation of the compressor (in the range 30% -100%) provided and certified by the manufacturer.

Table 3:Technical data about A/W heat pump

Heating		
Heat power	kW	31.5
Electric power	kW	10.70
COP (EN 14511:2011)		2.93
Cooling		
Cooling Power	kW	29.1
Electric power	kW	12.70
EER (EN 14511:2011)		2.29

In the management configuration of unit was inserted a photovoltaic control. This control allows the unit to vary its operating set point in proportion to the availability of electrical energy produced by the photovoltaic plant. It is a very simple ad economic control and it can also be implemented in existing plants, in the case of energy retrofitting. In fact, for its operation it is sufficient to know the available electric power, for example through the measuring transformers installed in the building electrical line, and change the set point of operation via the unit software or through communication using a communication protocol (like BMS, BACnet, Konnex).

PV model

The model simulate a grid connected PV plant throw parametric curve of commercial mono and polycrystalline module [6]; the output generated is the electric power of each module in Maximum Power Point inverter configuration, which is function of irradiation and outdoor temperature and take in account:

- pv generator losses
- overheating losses
- reflection losses
- losses in CC/CA conversion

Table 4:Technical data photovoltaic modules *Weather Generator*

Technology		monocrystalline silicon
NOCT	°C	44
Nominal Electric power per module	W	240
Tilt angle of module	°	35
Azimut angle of module	°	0
Number of modules		25
Dimensions	m	1.58x0.8x0.035

Temperature and radiation input to the model are produced by a climatic data generator, called Neural Weather Generator (NWG) developed by ENEA. Unlike common models, in which data are given by a database of historical values of several locations, the NWG estimates climatic values through neural evolutive networks. This networks are trained with weather data (mean monthly values) of Italian provinces (UNI 10349) and verified by ENEA's solar radiation atlas. For this work were used climate data refer to the city of Milan for the year 2015, they have been directly measured. The use of real data (instead of the year type) allows to obtain very realistic simulations as shown in another paper [7]. Figure 2-3 show the outside temperature and solar radiation considered.

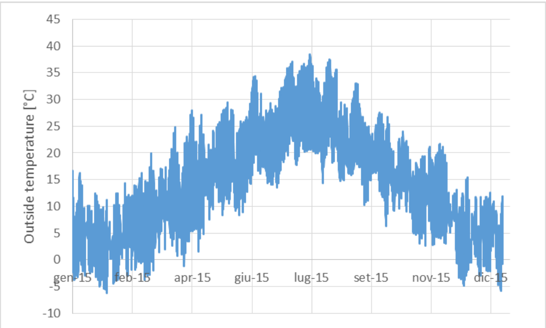

Fig 2: Outside temperature

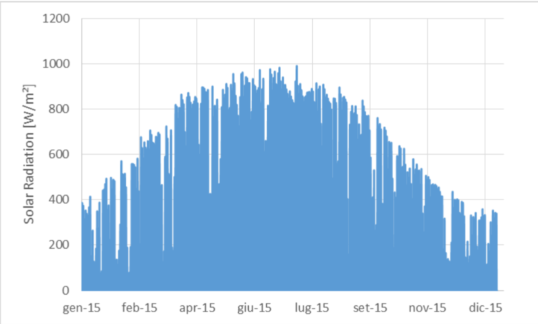

Fig 3: Solar radiation

Result

The results obtained show how the simple and cheap monitoring system proposed can lead to good benefits. The following charts are shown for each month: the photovoltaic electricity used by the unit, the amount of photovoltaic electricity get into the grid and the efficiency of the operation of the unit. The basic configuration foresees the use of the two systems independently (no communication between photovoltaic plant and heat pump) as happens in most cases. In other cases it has been implemented the control system to increase the self-consumption and after has been increased the size of the thermal storage to allow greater heat storage. Months of May and September are not showing because in these months there are not heating or cooling demand so the unit doesn't work.

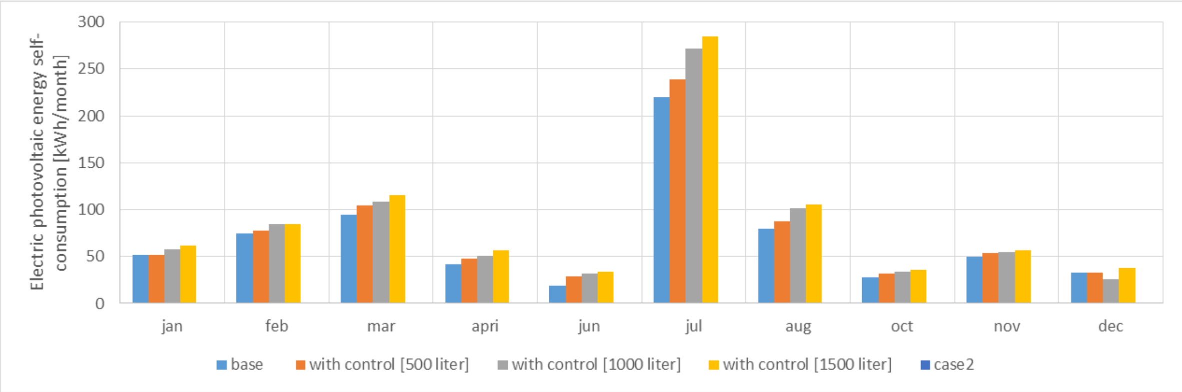

Fig 4: Photovoltaic electricity used by the unit

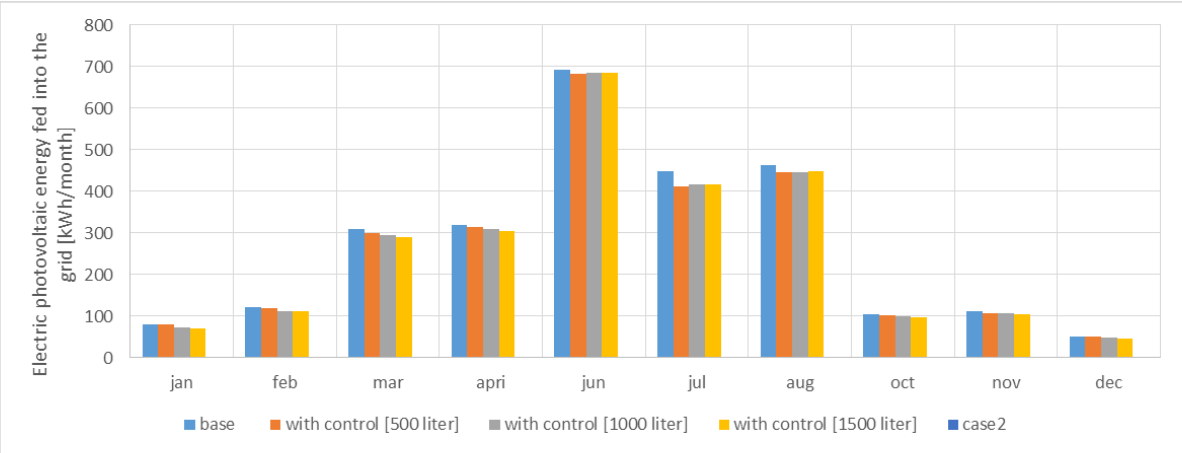

Fig 5: Photovoltaic electricity get into the grid

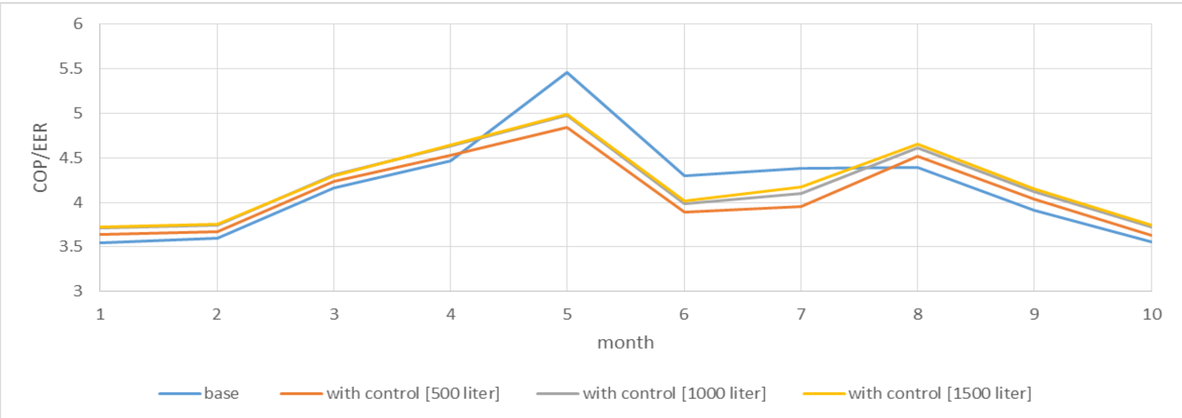

Fig 6: Efficiency of unit (COP or EER)

Discussion and conclusion

Dynamic simulations carried out have had as subject a residential building has a photovoltaic system and an inverter air / water heat pump. In most cases it happens that these two systems do not communicate between them and then the photovoltaic energy is get into the grid without own consumption and the heat pump is powered by energy source not totally renewable. To overcome this inefficiency has been implemented an adjustment mechanism which allows the heat pump to work more when it has available energy from renewable sources. In this case renewable energy is that produced directly from the building but in the future may be the one transported by the electric smart grid (smart grid ready heat pumps). The suggested type of control is very simple, inexpensive and can also be implemented in existing systems. Simulations showed that increasing the size of the accumulation heat the self-consumed energy share increases (and consequently decreases the share of photovoltaic energy get into the grid). An indirect consequence very positive is the increase of the COP of the unit during winter operation, in fact the heat pump induced to work more during the day, with a greater outside temperature and therefore with a greater efficiency. The detail and the precision with which it was developed the simulation model will surely deepen the theme and to study new configuration setting in order to obtain results even more satisfying.

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"Introducing distributed solar thermal power in small-scale district heating systems"

Abstract

District Heating Systems (DHS) connected to distributed solar collectors may contribute in reaching, especially in areas with high population density, the target of 50% of the heat demand for domestic hot water, space heating and cooling provided by renewable sources, which will be mandatory in Italy, from January 1, 2017, for new and deeply renovated buildings. By means of a software platform, developed by the Energy Efficiency Department of ENEA, a small-scale district heating system located in a suburb in the Municipality of Bologna (Italy) and including residential buildings, schools, public buildings and a commercial building and heated by gas boilers was simulated. The introduction, in the simulated DHS, of one or more solar thermal fields integrated on the roofs of the buildings was studied, and sensitivity analysis on the effect of the number and the size of the solar fields on the energy and economic performance of the DHS was carried out. The energy performance of the DHS integrated with the solar fields reaches its optimum in the configuration that maximizes the local self-consumption of the produced solar energy. Using the DHS as a vector to share solar energy, the increase in the thermal losses of the DHS can be considered acceptable in the configurations with a solar production equal to or lower than the domestic heat water loads plus the heat losses of the whole DHS in summer.

Keywords - District heating, Solar thermal, Distributed generation

Introduction

As a consequence of the transposition of the European Directive 2009/28/CE, the Italian regulation on energy efficiency will require, from January 2017, that thermal energy plants for new buildings or for buildings subjected to a deep renovation, will have to be designed and built to ensure that at least 50% of the heat demand for domestic hot water, heating and cooling will be met by renewable sources. This target could be particularly ambitious, especially in areas with high population density, where the installation of technologies to produce the required heat demand from renewable sources might be difficult due to lack of space or for integration problems. These difficulties could drive designers to invoke the presence of technical constraints. District Heating Systems (DHS) connected to distributed solar collectors could contribute in reaching this target, and especially in urban and densely built areas, could contribute to solve the possible technical constraints: the DHS can act as a virtual storage for the thermal energy produced and not immediately used, with the possibility to use it later and/or to share the renewable source production with the whole thermal network.

Methods

To evaluate the introduction in an existing DHS of one or more solar fields installed on the available building roofs, a numerical tool, described in [1], was used. A small-scale DHS located in a suburb in the Municipality of Bologna (Italy) was simulated.

1.1. TheAnalyzed Small-Scale District Heating System

The analyzed DHS consists of: 13 customer substations supplying 27 residential buildings, for approx. 88650 m^2; 2 customer substations supplying 3 schools and 1 gym, for approx. 8950 m^2; 1 customer substation supplying 2 public buildings, for approx. 7750 m^2; 1 customer substation supplying 1 commercial building, for approx. 4200 m^2 heated. The heat plant consists of 5 gas boilers with a total installed rated power of 14.5 MW, which can be modulated in 10 steps of 1.45 MW each. The energy thermal loads of the buildings are available by means of their energy signatures calculated in [2], based on a multi-year evaluation of the actual thermal energy consumptions of the buildings.

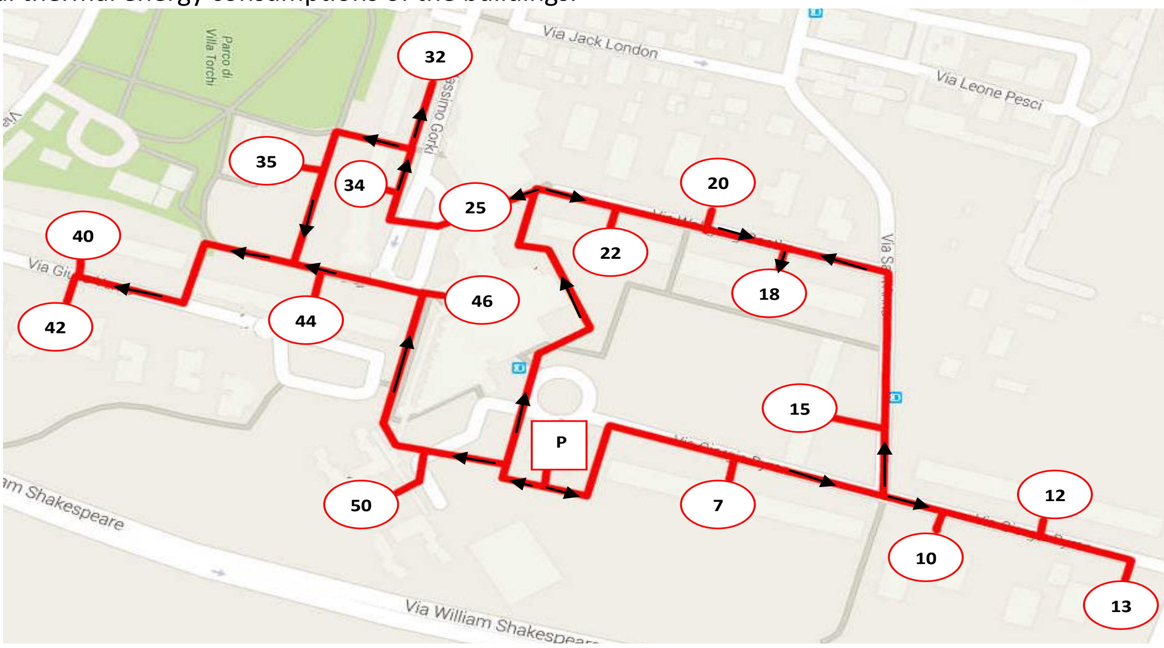

Fig. 1 Scheme of the DHS: supply scheme, gas boiler heat plant, substations

The set-points of the working feeding temperature during winter and summer are, respectively, 85±2°C and 60±2°C. The total extension of the DHS is approx. 1800 m. A scheme of the system is shown in Fig. 1. Further details on the analyzed DHS can be found in [2] and [3].

1.2. The Simulated Layouts

The connection of each solar plant to the DHS is thought by means of a thermal storage, part of each customer bi-directional substation, which collects the heat fluxes from the solar plants which supply the

substation, and from the DHS (when the heat request of the buildings is not satisfied by the solar production), and that delivers the heat loads to the supplied buildings or to the DHS. For the present case-study, the considered connection of the solar with the DHS is "supply to return" [4] and the energy is fed to the DHS when the temperature of the thermal storage in the customer substation exceeds the DHS supply temperature of at least 2°C. The regulation strategy of the bi-directional substation is described in [5].
The solar collectors can be potentially installed on the roofs of 33 buildings, supplied by 16 customer substations. The surface of solar collectors which can be potentially installed is approx. 3070 m^2, corresponding to a peak power of approx. 2200 kW. 77% of the potentially installable surface is facing south, the remaining 23% is facing South-East. The following solar plant layouts were simulated:

Layout 0 – Baseline: the actual DHS without solar plants.
Layout 1 – 25% Sol: DHS with installed 25% of the solar potential, corresponding to 765 m^2 and a peak power of 550 kW.
Layout 2 – 40% Sol: DHS with installed 40% of the potential, corresponding to 1240 m^2 and a peak power of 890 kW.
Layout 3 – 50% Sol: DHS with installed 50% of the potential, corresponding to 1530 m^2 and a peak power of 1100 kW.
Layout 4 – 60% Sol: DHS with installed 60% of the potential, corresponding to 1855 m^2 and a peak power of 1335 kW.
Layout 5 – 75% Sol: DHS with installed 75% of the potential, corresponding to 2300 m^2 and a peak power of 1655 kW.
Layout 6 – 40% Conc. Sol: DHS with installed 40% of the potential, corresponding to 1240 m^2 and a peak power of 890 kW, installed on a lower number of roofs (17 over 33).
In the layouts from 1 to 5 a share of the maximum installable solar surface was considered. The solar collectors were placed on all the 33 available roofs and their surface distribution among the roofs was, as far as possible, proportional to the energy consumption of the buildings, in order to maximize the self-consumption of the energy produced locally and to minimize, ultimately, the heat losses caused by the solar energy fed to the DHS. Based on the results of the layouts from 1 to 5, a further layout (*Layout 6*) was considered: the share of solar power which better fit the needs of the DHS without significantly increasing the heat losses was considered as installed on a number of roofs which minimizes the number of solar plants and, ultimately, the installation costs. The simulated period was one year.

1.3. *Energy Performance Indicators*

The most commonly used indicator to assess the performance of a DHS is the Primary Energy Factor (PEF), as defined in [6], but this indicator does not give a complete insight of the whole energy use of district heating networks [7] and it equates renewable and non-renewable primary energy. The characterization of the energy performance of the simulated layouts was therefore performed using the following energy indicators:

Non-Renewable Primary Energy Factor (PEF_{NR})

PEF_{NR} is defined according to [6]:

$$\mathrm{PEF_{NR}} = \frac{\text{Non Renewable Primary Energy for Thermal Production}}{\text{Delivered Energy}} \quad [-] \quad (1)$$

Where "Delivered Energy" is the energy delivered to the buildings by the thermal storage of the customer substation. This indicator PEF_{NR} takes into account only the fraction of fossil primary energy, therefore it considers indirectly the supply of thermal energy from non-fossil sources.

Non-Renewable Equivalent to Nominal Power Duration (H_{eq_NR})

This indicator expresses the equivalent number of operating hours at full load of fossil fuel generators in a year. It is defined as:

$$\mathrm{H_{eq\_NR}} = \frac{\text{Thermal Energy Produced from Fossil Fuels}}{\text{Rated Gas Boiler Heat Plant Power}} \quad [h] \quad (2)$$

Renewable Equivalent to Peak Power Duration (H_{eq_R})

It expresses the equivalent number of operating hours at peak load of the solar plants in a year. It is defined, as:

$$H_{eq\_R} = \frac{\text{Thermal Energy Produced from Renewable Sources}}{\text{Peak Power of Solar Fields}}\ [h] \qquad (3)$$

Renewable Utilization Factor (UF_R)

It's the ratio of the energy produced from renewable sources minus the losses caused by the installation of solar plants (this loss is calculated as the thermal losses in the considered layout minus the thermal losses in the baseline layout) and the energy produced from renewable sources. It is defined as:

$$UF_R = \frac{\text{Thermal Renewable Energy Produced} - \text{Increase in Th.Losses}}{\text{Thermal Renewable Energy Produced}}\ [-] \qquad (4)$$

It indicates the percentage of "useful" thermal energy from renewable sources or, rather, the percentage of the total produced renewable energy, reduced by the increase in the energy losses for dispersion introduced in the DHS by the energy supplied to the network by the installed solar fields.

Usable Equivalent to Peak Power Duration of Renewables (UH_{eq_R})

It is defined as:

$$UH_{eq\_R} = UF_R \cdot H_{eq\_R}\ [h] \qquad (5)$$

It's the product of UF_R and H_{eq_R}. This index represents the equivalent number of useful operating hours at peak load of the solar plants in a year, namely the total renewable energy produced, reduced by the increase in losses for dispersion introduced in the DHS by the installation of the solar fields.

1.4. Economic Indicator

The economic performance of the introduction of distributed solar plants, with respect to the actual DHS (baseline) was assessed using the net present value, defined as:

$$NPV(i, N) = \sum_{t=0}^{N} x_t * (1 + i)^{-t} - I_0 \qquad (6)$$

Where: *t* is the year of the cash flow, x_t is the cash flow during the year *t*, *i* is the discount rate, *N* is the total number of years, I_0 is the total initial investment cost.

The NPV was calculated assuming *i* = 5%, *N* = 10 years, considering an average present price for natural gas in Northern Italy (approx. 0.40 €/Sm^3) and an average selling price of the thermal energy provided by DHS in the area of the Municipality of Bologna (approx. 0,118 €/kWh). The initial investment cost was assessed considering an average price for evacuated tube collector plants: approx. 555 €/m^2 for the layouts from 1 to 5 and, as far as the layout 6 in concerned, the halved of the installed solar plants was evaluated with a decrease in the price of 20% (approx. 443 €/m^2).

Results and Discussion

The simulation of the DHS in its actual layout shows that the heat load request of the buildings reaches a peak of approx. 9.5 MW during the heating season and of approx. 500 kW during summer (Fig. 2).

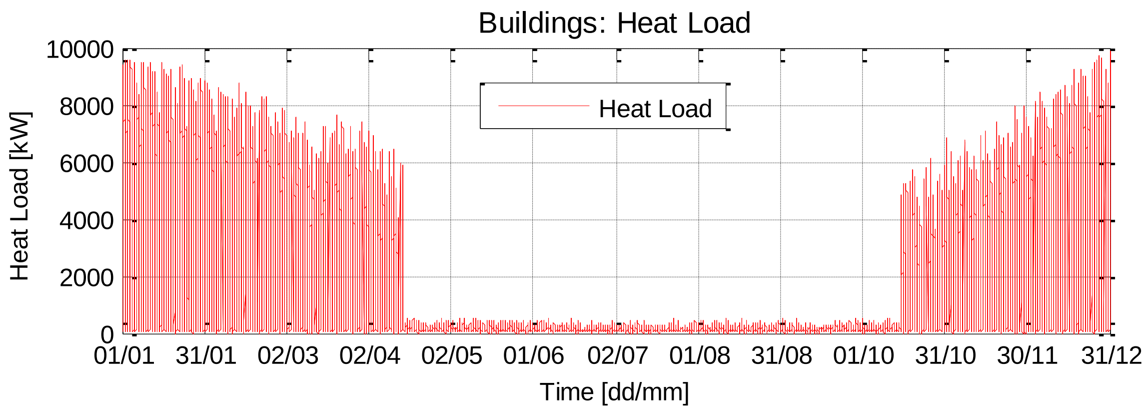

Fig. 2 Buildings Heat Load

The energy request during summer for domestic heat water (DHW) is 459 MWh, the thermal energy produced yearly by the gas boiler heat plant is approx. 16'500 MWh. The energy delivered to the buildings

is approx. 15’400 MWh, in this case totally produced by the gas boilers. The total yearly thermal losses are approx. 1’100 MWh and the sum of DHW loads and thermal losses during “summer” (indicating with “summer” the period when the space heating system is off) is 920 MWh (
Table 2).

Table 2. Main energy results for the different layouts, data given in MWh

	Baseline	**25%**	**40%**	**50%**	**60%**	**75%**	**40%C**
E_Gas_Boiler	16’462	15’899	15’581	15’420	15’315	15’226	15’602
E_DHS To Buildings	15’372	14’862	14’746	14’696	14’644	14’579	15’026
E_Sol_Prod	-	553	887	1’076	1’249	1’390	877
E_Sol_Prod Summer	-	438	700	846	970	1’046	689
E_Sol Self-Cons.	-	322	424	474	523	578	273
E_Sol To DHS	-	52	258	397	514	586	529
Heat Losses	1’146	1’146	1’153	1’181	1’249	1’300	1’163
Heat Losses Summer	461	461	466	495	563	613	478
DHW Loads + Heat Losses Summer	920	920	926	954	1’022	1’072	937

With the introduction of the solar plants, the energy produced by the gas boilers decreases of a value ranging between -3.4% for layout 1 and -7.5% for layout 5. In the layouts from 1 to 5, in which the self-consumption of the solar energy is advantaged, a reduction in the energy delivered by the DH network (E_DHS To Buildings) can be observed, ranging from -3.3% for layout 1 up to -5.2% for layout 5. The self-consumed share of the solar production reaches its peak with the smallest solar surface, 58% for layout 1, and it decreases with the increase of the installed solar: 42% for layouts 4 and 5. On the contrary, the share of the solar fed to the DH network increases with the installed surface: it ranges from 9.5% of the total solar production for layout 1 to 42% for layout 5.
As expected, the wider the installed solar surface is, the bigger the reduction in the energy produced by fossil fuel is observed. This is clearly shown in Fig. 3, where the thermal output of the gas boiler, during two summer days, for the different layouts, is plotted: in the baseline layout 11 outputs of the gas boiler can be observed, these are reduced to 5 outputs in layout 1 and to only 1 output for two days in layout 2; in the remaining layouts, the solar production seems to be sufficient to satisfy the thermal load request of the DHS in summer.

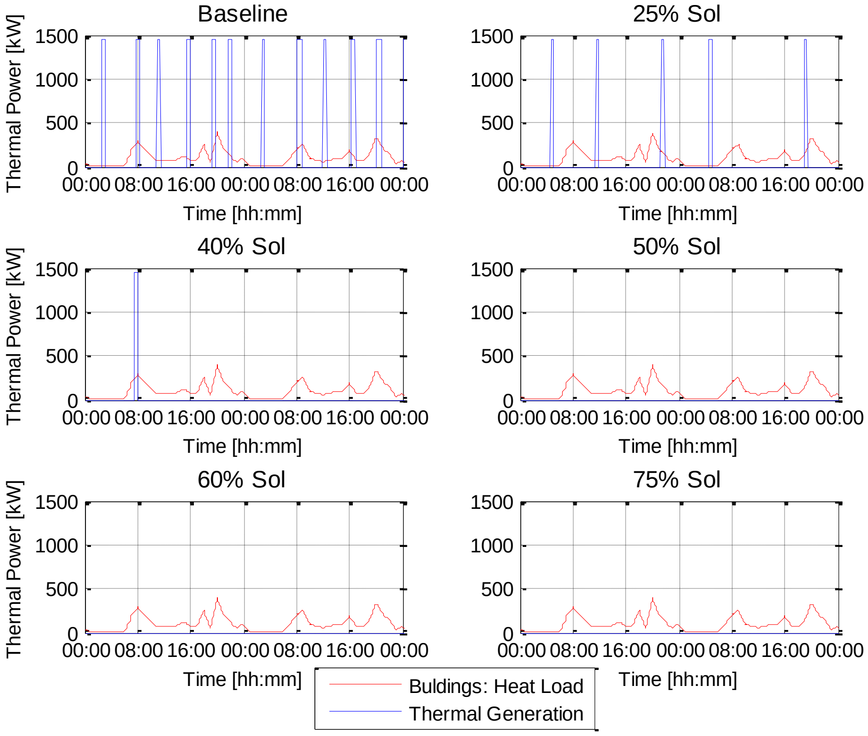

Fig. 3 Buildings' heat load and thermal output of the gas boiler for different layouts during two summer days

The reduction in the production by fossil fuels is also shown by the PEF_{NR} and H_{eq_NR} indicators (Table 3), whose decrease confirms the trend.

Table 3. Energy performance indicators for the different layouts

	Baseline	**25%**	**40%**	**50%**	**60%**	**75%**	**40%C**
PEF_{NR} [-]	1.176	1.137	1.113	1.100	1.088	1.078	1.114
$Heq\__{NR}$ [h]	1135	1096	1075	1064	1056	1050	1076
$Heq\__{R}$ [h]	-	1007	996	980	937	840	984
UF_{R} [-]	-	0.999	0.992	0.967	0.917	0.889	0.981
$UHeq\__{R}$ [h]	-	1005	988	948	859	747	965

However, bigger installed solar surfaces introduce two different problems: a limit in the solar production of the solar plant with respect to its potential, and an increase in the thermal losses in the overall DHS. The limit in the solar production is clearly shown in Fig. 4, where the thermal power produced by the solar plants, the self-consumed share and the share supplied to the DHS, for the different layouts in a summer day are plotted. For the layouts with an installed surface up to 50% of the maximum (layouts 1, 2, 3 and 6), no reduction in the solar production can be observed. For the layouts with the biggest installed surfaces, a decrease in the solar production can be observed. This happens when some of the thermal storages in the customer substations reach the upper temperature limit (approx. 95°C), stopping the production of the connected solar plants. In the same figure, the increase in the thermal power supplied to the DHS in accordance with the increase in the installed surface can be seen. The thermal power produced by the 25%

Sol layout (layout 1) is almost totally self-consumed and stored in the local thermal storage: the heat flux supplied to the DHS is limited and is present only in the afternoon.

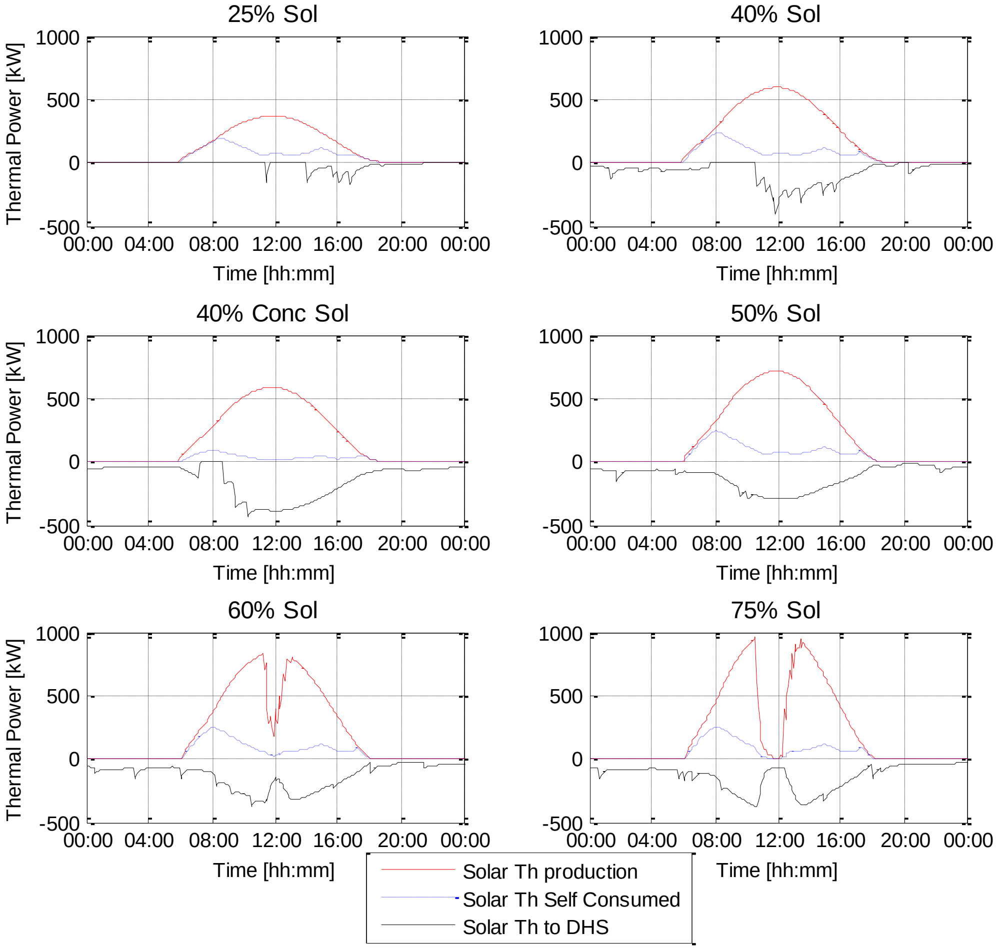

Fig. 4 Components of the solar thermal production for the different layouts, summer conditions

The same Fig. 4 shows the difference between a fully distributed and a more concentrated layout: the two 40% layouts (2 and 6) present the same solar production, but in the concentrated one (layout 6) the self-consumed share is much lower (since only half of the buildings are equipped with solar plants) and the thermal power supplied to the DHS is bigger in amplitude and duration. On a yearly basis, layout 6 produce 99% of the solar production of layout 2, but the self-consumption share is 31% instead of 48%, and its share supplied to the DHS is 60% instead of 29% (
Table 2).

The second problem is the increase in the temperature of the DH network during summer, and consequently in the heat losses. This phenomenon is shown in Fig. 5. Layouts 1 and 2 have practically no effect: the increase in the heat losses is lower than 1% (
Table 2). Whereas for the remaining layouts the temperature of the network is raising accordingly with the installed surface and remains higher for a longer period. The yearly heat losses are 1.5%, 3.5%, 9.0% and 13.5% higher, with respect to the baseline, respectively for the layouts 6, 3, 4 and 5.

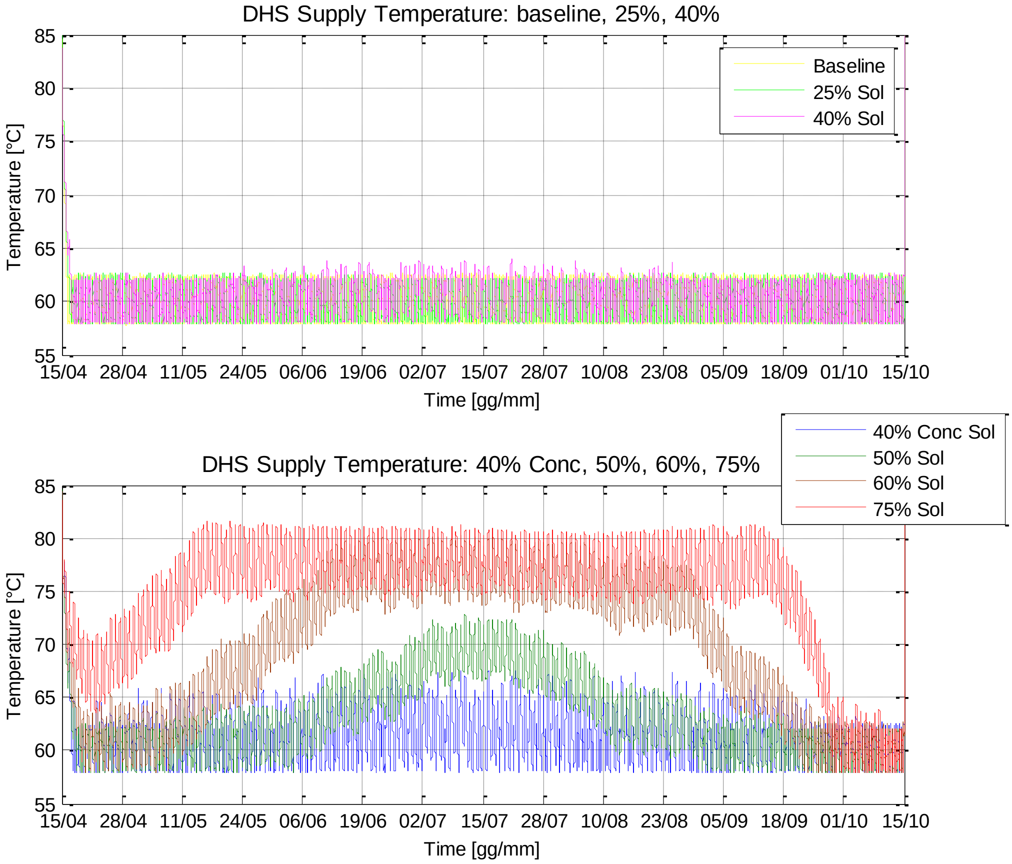

Fig. 5 DHS Supply temperature for different solar plant layouts

The limit in the solar production, particularly evident in layout 4 and 5, increasing with the installed surface, is shown also by the renewable equivalent to peak power duration: the highest value (1007 h) reached by layout 1, goes down by 1.1%, 2.3%, 2.7% , 6.9% and 16.5% with layout 2, 6, 3, 4 and 5 respectively. The renewable utilization factor, on the other hand, shows the share of produced solar energy which remains usable by the DHS, being its complement the solar energy lost in increased heat losses. For layouts 1 and 2 more than 99% of the produced solar remains usable by the DHS. The UH_{eq_R} is the indicator which includes both the limit in the production and the solar energy lost for the induced increased heat losses. Considering acceptable, for this indicator, a decrease lower than 5% with respect to the best performing layout (layout 1), and in order to minimize the limit in the production and the increased losses, but at the same time installing the biggest surface, the most interesting layout can be considered Layout 2, whose solar production is the closest to the sum of the DHW loads and the heat losses of the whole DHS in summer. A more "concentrated" layout was simulated (Layout 6) in order to evaluate the influence of reduced installation costs. The reduction in the installation costs (-20%) makes the more "concentrated" layout the only one with a positive net present value at 10 years (
Table *4*).

Table 4. Net Present Value for the different solar plant layouts, data given in thousands of euro

	Baseline	**25%**	**40%**	**50%**	**60%**	**75%**	**40%C**
NPV (5%, 10)	-	-42.4	-65.0	-96.2	-160.6	-268.2	65.1

Conclusions

Introducing distributed solar thermal power in a small-scale DHS and using the DHS as a vector to share the heat produced by solar, the limit in the solar production and the increase in the thermal losses of the DHS can be considered acceptable in the configurations with a solar production equal to or lower than the DHW loads plus the heat losses of the whole DHS in summer. The economic performance can be considered acceptable only for the layouts with a lower number of installed solar fields, with a consequent reduction in the installation costs.

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“Utilities Substations in Smart District Heating Networks“

Abstract

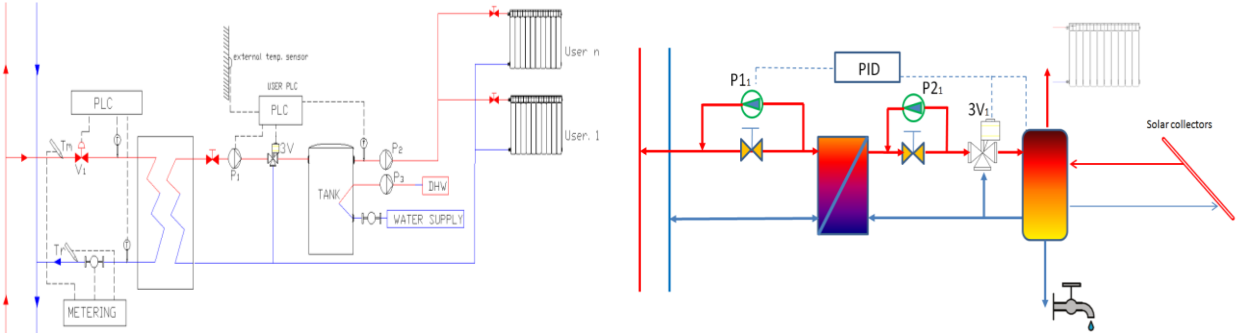
In this paper the presence of customers (prosumers), connected to a District Heating Systems (DHS), that not only can consume but also produce district heating by means of small-scale solar collectors, and that can use the DHS as a virtual storage for the thermal energy produced and not immediately used, with the possibility to use it later, is investigated. Three configurations were simulated: (1) absence of solar thermal system, (2) solar thermal system not connected to the DHS, (3) solar thermal system feeding a local heat storage, connected to the DHS by a single bi-directional heat exchanger. The results show that for the connected configuration, the thermal solar system can overcome the limited production of the isolated configuration during summer, producing thermal energy to feed the DHS, and that the thermal energy produced annually is more than 100% the annual energy needs of the single family house for space heating and domestic heat water.

1. Introduction

The goal of the paper is to identify energetic and economic benefits and to investigate the problems resulting from the grant of the thermal net metering to the users with solar thermal plants connected to district heating networks.

Gathering the definition used for power grids, thermal net metering can be defined as a mechanism that allows renewable energy producers to use the district heating network to which they are connected as a thermal storage for the energy produced and not self-consumed, in order to use it later.
The Italian Legislative Decree no. 28/11: implementation of Directive 2009/28/EC requires, since May 2012, that thermal energy plants for new buildings or for buildings subjected to a deep renovation, must be designed and built to ensure that at least 20% of the heat demand for domestic hot water, heating and cooling must be met by renewable sources; the limit will be increased to 50% from January 1, 2017. The targets of the decree could be particularly ambitious, especially in areas with high population density, where the installation of technologies to produce the required heat demand from renewable sources might be difficult due to lack of space or for integration problems. These difficulties could drive designers to invoke the presence of technical constraints. The aim of this work is to investigate solutions to solve these technical constraints.
On the other hand the installation of a solar thermal plant for heating and domestic hot water demand, may be oversized during periods of low heat demand (from March to September) in the absence of applications such as solar devices for cooling. In these conditions, the production of thermal energy from a renewable source is likely to be heavily penalized because, in absence of demand, the pumps of the solar circuit are switched off and the collectors covered to avoid the risk of stagnation of the fluid.
The district heating network, through a "net metering" management, could provide a daily and seasonal storage service for users with solar thermal systems, allowing to feed-in extra solar production and to supply all network users (such as domestic heat water in summer or space heating demand in winter), increasing in this way the share of energy demand from renewable sources provided to each building.
2. The bidirectional customer substation
The numerical tool used to simulate a small scale district heating system (DHS) in this paper is described in [1]. The software platform, developed in a Matlab/Simulink environment, is able to perform dynamic simulations of a small scale district heating, where a multi-building system (residential buildings, dwellings, office buildings, shopping centers, etc.), with inhomogeneous electric and heat loads, is served by thermal networks. The developed software takes into account heat generator models (CHP, gas boiler, solar plant), thermal network, building models, utilities substations and a wheather generator in order to analyze various scenarios and different control strategies for small-scale district heating. The main heating output variables, calculated hourly, are: indoor air temperature for each building, average fluid temperature of the network, fluid temperature at each node of the network, thermal power supply for each building and for the whole network, thermal losses along the network.
User substations are one of the most important components in a district heating system, because they represent the transfer point of thermal energy from the grid to the users. In this paper, a bidirectional substation is modeled in order to investigate the presence of customers, connected to a DHS, that not only can consume but also produce district heating by means of small-scale solar collectors. In this scenario, the energy and environmental benefit represented by DHS can be further enhanced with the concept of Smart District Heating (SDH). A smart district heating system replies, in the heating sector, the concept of distributed generation and of energy exchange between a prosumer (i.e. a producer and consumer of energy) and the grid, already known for the electrical sector [2] [3].
In the investigated “net metering” connection mode, the prosumer can use the SDH as a virtual storage for the thermal energy produced and not immediately used, with the possibility to use it later.
Figure 1-a shows the scheme of the modeled traditional substation of a building connected to a DHS and Figure 1-b shows the scheme of the modeled bidirectional substation of a prosumer connected to a DHS.
In the traditional substation, the valve V1 (network side) is controlled to keep a constant return temperature and variable mass flow rate. On the user side, a three way valve “3V” is controlled by a PID to keep the operating temperature (T3) set point according to the climatic curve supplied by the Italian National Standard UNI 8364-2:2007.
The proposed scheme for the bidirectional substation (Figure 1-b) is designed to introduce into the distribution network only the excess of thermal energy produced by a local source (solar thermal collector).

The operating principle of the bidirectional thermal exchange is "return to supply": it provides no impact on the district heating system return temperature and could be easily integrated with existing customer substations.



(a) (b)

Figure 7. (a) Scheme of a traditional substation; (b) Scheme of the bidirectional substation.

According to the solution of Figure 1-b, the solar system is connected directly to the thermal storage: it preheats the operating temperature during the winter season and it risks to overheat the water during the summer season.

The regulation strategy of the prosumer substation, showed in Figure 2, requires that the heat flux from the solar plant is firstly used to heat the fluid of the thermal storage. If the thermal load for space heating and domestic heat water (DHW) is not completely satisfied by the local production system (e.g. during winter) the PID controller closes the three way valve “3V1” to provide the residual heat by the thermal network (the DHS) leading the temperature of thermal storage to the set point according to the climatic curve. If the local production exceeds the thermal load (typically during summer and spring), the storage temperature exceeds the temperature of the supply network, and the control system activates the pump P2 and opens the three way valve “3V1” to its max position, in order to achieve the introduction of heat into the network. The pressure supplied by the pump P2 must overcome the pressure in the district heating network.

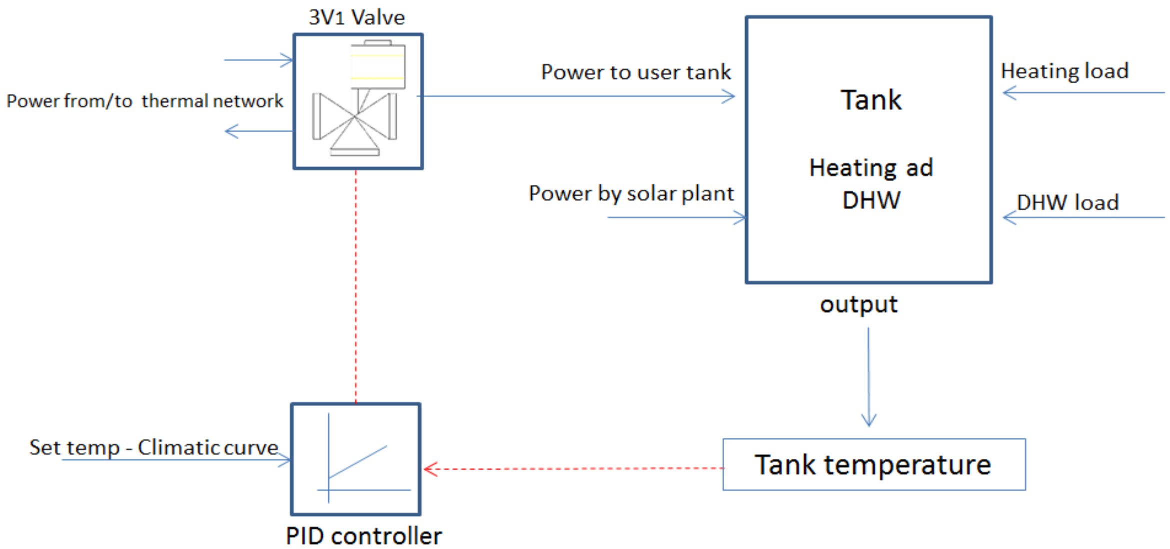


Figure 8. Regulation strategy for the bidirectional substation.

3. The simulated small-scale District Heating System

The presence of prosumers in a small-scale DHS has been investigated by means of the simulation of the small-scale DHS schematically represented in Figure 3. It is a tree type DH scheme, with centralized heat production, hypothetically located in Rome and with the following connected users:

- a single family house, 100 m2 of heated surface;
- a school, 1000 m2 of heated surface on two floors;
- an office building, 500 m2 of heated surface;
- a block of 5 single family dwellings, 100 m2 of heated surface each.

The centralized heat generator is a natural gas CHP unit, with a nominal thermal power of 250 kWt and nominal electric power of 170 kWe.
The main geometric features of the DHS, with reference to the scheme of Figure 3, are presented in Table1.

Table 1. Main geometric features of the DHS

Ø of the main pipe [m]	L_1 [m]	L_2 [m]	L_3 [m]	L_4 [m]	L_5 [m]	L_6 [m]	L_7 [m]	L_8 [m]
0.25	300	15	200	15	100	100	100	20

Further characteristics of the DHS are schematically summarized in Table 2

Table 2. Further features of the DHS

U-value of the main pipe [W/mK]	Volume of the centralized heat storage [m^3]	Overall volume of the heating fluid in the DHS [m^3]	Set-point of the working feeding temperature during winter [°C]	Set point of the working return temperature during winter [°C]
0.14	3	10	85±2°C	65±2°C

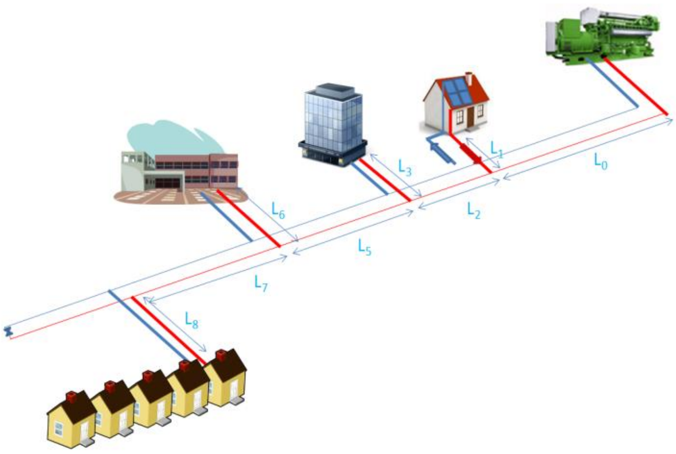


Figure 9. Scheme of the simulated small-scale District Heating System.

3.1. The simulated schemes

The 100 m2 single family house, connected to the DHS, has been simulated in three different configurations:

- without any solar thermal system;
- with a 50 m2 solar thermal system and a 3 m3 daily heat storage, in a stand- alone configuration (no connection of the solar system to the DHS);
- with a 50 m2 solar thermal system and a 3 m3 daily heat storage, connected to the DHS as described in §2.

The size of the solar thermal system (50 m2) was chosen, in the hypothesis of a two slope roof facing North and South, to cover almost completely the Southern slope. A common design practice for solar thermal would suggest to use a heat storage of about 4 m3 per 100 m2 of collectors, that would mean about 2 m3 for the simulated case. An increase to 3 m3 was chosen to increase the solar fraction from the solar system during summer. With the same purpose, the upper working limit temperature chosen for the pressured thermal storage was 110°C.

In the third configuration the single family house is a “prosumer” for the DHS.

4. Results and discussion

The simulation results show a dynamic behavior of the active user during the year. In Figure 4 the heat flux exchanged between the DHS and the bidirectional substation in case of solar system connected to the DHS is represented with a black line. A clear inversion of the heat flux can be observed on about the first week of April (the 2500th hour of the year). Between the first week of April and the end of September (about the 6900th hour of the year) the substation is feeding the DHS and the single family house is no longer a consumer, but a producer.

The switch from a consumer to a producer behavior is related to a rise of temperature of the heat storage over the working value of the feeding temperature of the DHS; this rise is caused by a heat production by the solar system that exceeds the energy needs of the single family house for space heating and DHW.

Figure 4 shows also the temperature reached by the heat storage in the three different simulated configurations. With the stand-alone configuration (green line) the temperature reaches the upper working limit for the solar system (110°C) during summer, stopping the operation of the solar plant and thus limiting its annual energy production.

Connecting the solar thermal system to the DHS (Figure 4, yellow line), the temperature of the heat storage remains below 90°C, feeding into the thermal net the thermal overproduction.

In the three simulated configurations, during winter, the heat storage temperature follows the reference temperature given by the climatic regulation curve according to the implemented Italian National Standard UNI 9317/89.

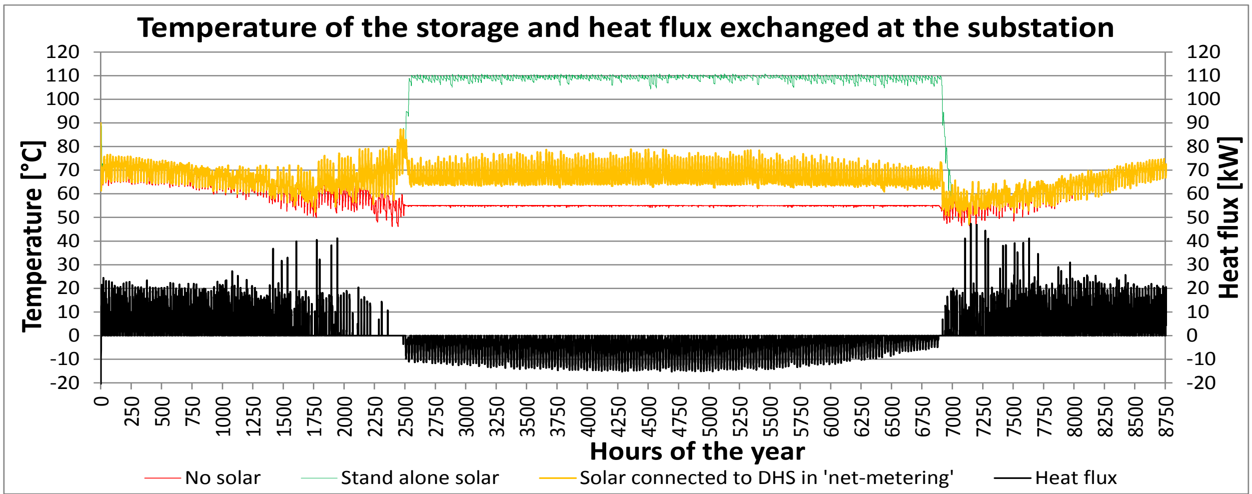
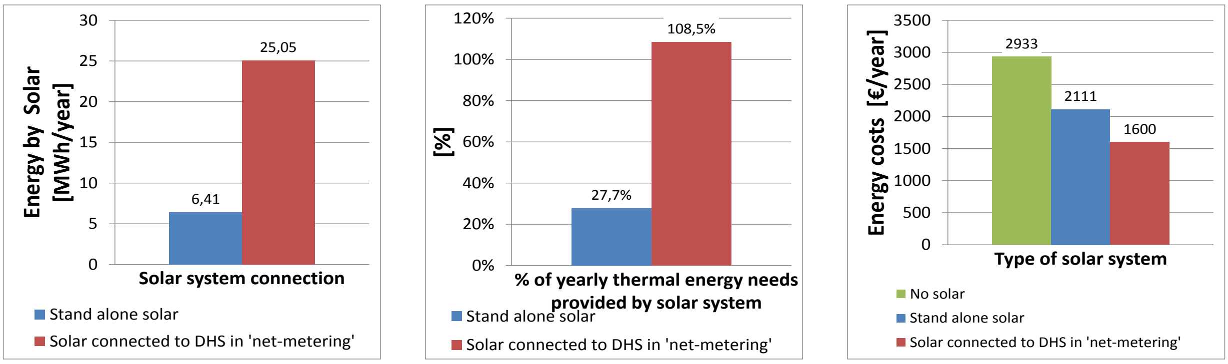


Figure 10. Temperature of the heat storage in the prosumer substation and heat flux exchanged with the DHS.

The effect, on the annual energy performance of the solar system, of the connection to the DHS in comparison to a stand-alone configuration is shown in Figure 5 (a) and (b). When connected, the solar system can use the DHS as a heat storage, and its energy production can continue throughout summer instead of being stopped for operational reasons. The consequence is that the total annual thermal energy production of the connected solution is about 4 times the annual production of the stand-alone configuration (Figure 5-a). Comparing the energy production to the annual energy needs of the single family house for space heating and DHW (Figure 5-b), the stand-alone configuration provides about 28%, whereas the connected solution can cover about 108% of the total needs. If a “thermal net-metering” tariff scheme would be adopted using the same ratio of the already existing electric net-metering, the additional 8% exceeding the annual energy needs of the prosumer, could be used as credit for the following year. The

results show also that the considered solar system, when in the stand-alone configuration, can satisfy about 19% of the needs for space heating and 100% of the needs for DHW, and it is therefore oversized considering only the summer heat demands.
A cost analysis has been performed, since the economic sustainability of the thermal net-metering solution depends on the price of both the energy bought from the DHS and sold to the DHS.
In a case of thermal net-metering already existing in Sweden [4], the price of the energy fed into the DHS is about 0.25 the cost of the energy bought from the DHS. Considering 0.09 €/kWh as the average price of the energy sold by the DHS utilities to the consumers in Italy, we used a ratio energy sold/energy bought of about 0.45 considered more suited to the Italian market, and thus we consider 0.04 €/kWh as the reference price of the energy sold by prosumers to the DHS utility.



(a) (b) (c)

Figure 11. (a) Total energy produced by the solar system; (b) Energy needs of the prosumers, provided by the solar system; (c) Annual cost of the energy for space heating and DHW for the three simulated schemes.

With the above hypothesized prices, as shown in Figure 5-c, the net-metering configuration allows a reduction of the heating bill of about 60% with respect to a passive user without solar system, and a reduction of about 44% with respect to the stand-alone solar system configuration.

5. Conclusions

The detailed reference substation model and the new model of bidirectional substation were integrated into the energy networks simulation platform, implementing a new software tool realized to evaluate (in the time domain) heat fluxes exchanged with the network by active users and the effects generated on the management strategy of centralized systems.
In the paper the presence of a prosumer with a 50 m2 solar field integrated in the roof, in a small-scale DHS is presented. The results of the simulations carried out show that the net-metering integrated solution would guarantee an increase in meeting the annual total heat demand of the building from 27% (for stand-alone solar system) to more than 100%, with a reduction of the heating bill of about 60%, compared to passive management of users.
Furthermore, the high thermal power fed into the grid from the solar field during the summer season allows a reduced use of the centralized systems which, due to the low demand (only for DHW), would work in conditions of low thermal efficiency.
The goal of the analysis was to evaluate the right implementation of the models and their integration in the simulation platform. For this reason it is not possible to generalize the results of the simulations in terms of energy and cost savings to other network configurations. However the value of energy savings obtained, suggests the potential benefit of applying the net-metering configuration for thermal distributed systems connected to DHS.

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“An evaluation of distributed solar thermal "net metering"

Abstract
In this paper the presence of customers (prosumers), connected to a District Heating Systems (DHS), that not only can consume but also produce district heating by means of small-scale solar collectors, and that can use the DHS as a virtual storage for the thermal energy produced and not immediately used, with the possibility to use it later, is investigated. Three configurations were simulated: (1) absence of solar thermal system, (2) solar thermal system not connected to the DHS, (3) solar thermal system feeding a local heat storage, connected to the DHS by a single bi-directional heat exchanger. The results show that for the connected configuration, the thermal solar system can overcome the limited production of the isolated configuration during summer, producing thermal energy to feed the DHS, and that the thermal energy produced annually is more than 100% the annual energy needs of the single family house for space heating and domestic heat water.

Introduction
1. The goal of the paper is to identify energetic and economic benefits and to investigate the problems resulting from the grant of the thermal net metering to the users with solar thermal plants connected to district heating networks.
Gathering the definition used for power grids, thermal net metering can be defined as a mechanism that allows renewable energy producers to use the district heating network to which they are connected as a thermal storage for the energy produced and not self-consumed, in order to use it later.
The Italian Legislative Decree no. 28/11: implementation of Directive 2009/28/EC requires, since May 2012, that thermal energy plants for new buildings or for buildings subjected to a deep renovation, must be designed and built to ensure that at least 20% of the heat demand for domestic hot water, heating and cooling must be met by renewable sources; the limit will be increased to 50% from January 1, 2017. The targets of the decree could be particularly ambitious, especially in areas with high population density, where the installation of technologies to produce the required heat demand from renewable sources might be difficult due to lack of space or for integration problems. These difficulties could drive designers to invoke the presence of technical constraints. The aim of this work is to investigate solutions to solve these technical constraints.
On the other hand the installation of a solar thermal plant for heating and domestic hot water demand, may be oversized during periods of low heat demand (from March to September) in the absence of applications such as solar devices for cooling. In these conditions, the production of thermal energy from a renewable source is likely to be heavily penalized because, in absence of demand, the pumps of the solar circuit are switched off and the collectors covered to avoid the risk of stagnation of the fluid.
The district heating network, through a "net metering" management, could provide a daily and seasonal storage service for users with solar thermal systems, allowing to feed-in extra solar production and to

supply all network users (such as domestic heat water in summer or space heating demand in winter), increasing in this way the share of energy demand from renewable sources provided to each building.

2. The bidirectional customer substation

The numerical tool used to simulate a small scale district heating system (DHS) in this paper is described in [1]. The software platform, developed in a Matlab/Simulink environment, is able to perform dynamic simulations of a small scale district heating, where a multi-building system (residential buildings, dwellings, office buildings, shopping centers, etc.), with inhomogeneous electric and heat loads, is served by thermal networks. The developed software takes into account heat generator models (CHP, gas boiler, solar plant), thermal network, building models, utilities substations and a wheather generator in order to analyze various scenarios and different control strategies for small-scale district heating. The main heating output variables, calculated hourly, are: indoor air temperature for each building, average fluid temperature of the network, fluid temperature at each node of the network, thermal power supply for each building and for the whole network, thermal losses along the network.

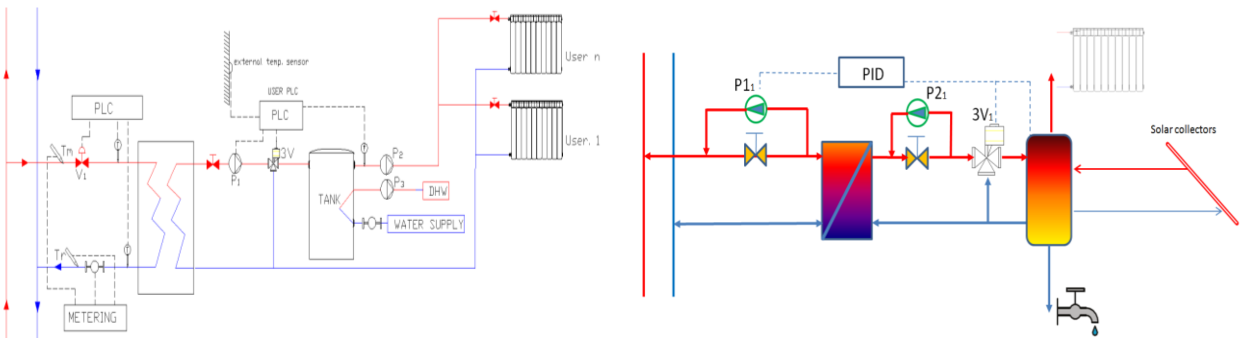
User substations are one of the most important components in a district heating system, because they represent the transfer point of thermal energy from the grid to the users. In this paper, a bidirectional substation is modeled in order to investigate the presence of customers, connected to a DHS, that not only can consume but also produce district heating by means of small-scale solar collectors. In this scenario, the energy and environmental benefit represented by DHS can be further enhanced with the concept of Smart District Heating (SDH). A smart district heating system replies, in the heating sector, the concept of distributed generation and of energy exchange between a prosumer (i.e. a producer and consumer of energy) and the grid, already known for the electrical sector [2] [3].

In the investigated “net metering” connection mode, the prosumer can use the SDH as a virtual storage for the thermal energy produced and not immediately used, with the possibility to use it later.

Figure 1-a shows the scheme of the modeled traditional substation of a building connected to a DHS and Figure 1-b shows the scheme of the modeled bidirectional substation of a prosumer connected to a DHS.

In the traditional substation, the valve V1 (network side) is controlled to keep a constant return temperature and variable mass flow rate. On the user side, a three way valve “3V” is controlled by a PID to keep the operating temperature (T3) set point according to the climatic curve supplied by the Italian National Standard UNI 8364-2:2007.

The proposed scheme for the bidirectional substation (Figure 1-b) is designed to introduce into the distribution network only the excess of thermal energy produced by a local source (solar thermal collector). The operating principle of the bidirectional thermal exchange is "return to supply": it provides no impact on the district heating system return temperature and could be easily integrated with existing customer substations.



(a) (b)

Figure 12. (a) Scheme of a traditional substation; (b) Scheme of the bidirectional substation.

1. According to the solution of Figure 12-b, the solar system is connected directly to the thermal storage: it preheats the operating temperature during the winter season and it risks to overheat the water during the summer season.

2. The regulation strategy of the prosumer substation, showed in Figure 13, requires that the heat flux from the solar plant is firstly used to heat the fluid of the thermal storage. If the thermal load for space heating and domestic heat water (DHW) is not completely satisfied by the local production system (e.g. during winter) the PID controller closes the three way valve “3V1” to provide the residual heat by the thermal network (the DHS) leading the temperature of thermal storage to the set point according to the climatic curve. If the local production exceeds the thermal load (typically during summer and spring), the storage temperature exceeds the temperature of the supply network, and the control system activates the pump P2 and opens the three way valve “3V1” to its max position, in order to achieve the introduction of heat into the network. The pressure supplied by the pump P2 must overcome the pressure in the district heating network.

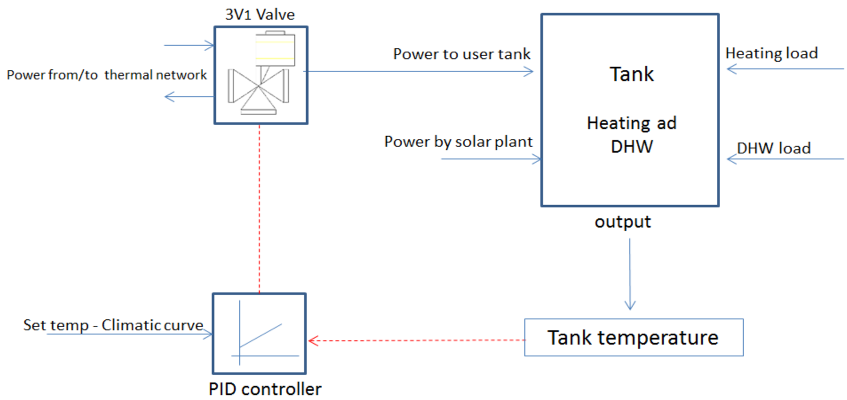


Figure 13. Regulation strategy for the bidirectional substation.

The simulated small-scale District Heating System

1. The presence of prosumers in a small-scale DHS has been investigated by means of the simulation of the small-scale DHS schematically represented in Figure 14. It is a tree type DH scheme, with centralized heat production, hypothetically located in Rome and with the following connected users:

a single family house, 100 m^2 of heated surface;
a school, 1000 m^2 of heated surface on two floors;
an office building, 500 m^2 of heated surface;
a block of 5 single family dwellings, 100 m^2 of heated surface each.

The centralized heat generator is a natural gas CHP unit, with a nominal thermal power of 250 kWt and nominal electric power of 170 kWe.

Table 5. Main geometric features of the DHS

Ø of the main pipe [m]	L_1 [m]	L_2 [m]	L_3 [m]	L_4 [m]	L_5 [m]	L_6 [m]	L_7 [m]	L_8 [m]
0.25	300	15	200	15	100	100	100	20

Further characteristics of the DHS are schematically summarized in **Errore. L'autoriferimento non è valido per un segnalibro.**

Table 6. Further features of the DHS

U-value of the main pipe [W/mK]	Volume of the centralized heat storage [m^3]	Overall volume of the heating fluid in the DHS [m^3]	Set-point of the working feeding temperature during winter [°C]	Set point of the working return temperature during winter [°C]
0.14	3	10	85±2°C	65±2°C

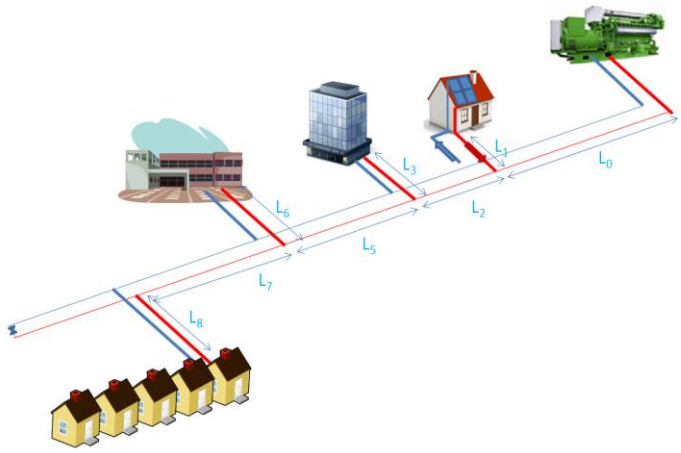


Figure 14. Scheme of the simulated small-scale District Heating System.

The simulated schemes

The 100 m^2 single family house, connected to the DHS, has been simulated in three different configurations:

without any solar thermal system;

with a 50 m^2 solar thermal system and a 3 m^3 daily heat storage, in a stand- alone configuration (no connection of the solar system to the DHS);

with a 50 m^2 solar thermal system and a 3 m^3 daily heat storage, connected to the DHS as described in §**Errore. L'origine riferimento non è stata trovata.**.

The size of the solar thermal system (50 m^2) was chosen, in the hypothesis of a two slope roof facing North and South, to cover almost completely the Southern slope. A common design practice for solar thermal would suggest to use a heat storage of about 4 m^3 per 100 m^2 of collectors, that would mean about 2 m^3 for the simulated case. An increase to 3 m^3 was chosen to increase the solar fraction from the solar system during summer. With the same purpose, the upper working limit temperature chosen for the pressured thermal storage was 110°C.

In the third configuration the single family house is a “prosumer” for the DHS.

Results and discussion

The simulation results show a dynamic behavior of the active user during the year. In Figure 15 the heat flux exchanged between the DHS and the bidirectional substation in case of solar system connected to the DHS is represented with a black line. A clear inversion of the heat flux can be observed on about the first week of April (the 2500th hour of the year). Between the first week of April and the end of September (about the 6900th hour of the year) the substation is feeding the DHS and the single family house is no longer a consumer, but a producer.

The switch from a consumer to a producer behavior is related to a rise of temperature of the heat storage over the working value of the feeding temperature of the DHS; this rise is caused by a heat production by the solar system that exceeds the energy needs of the single family house for space heating and DHW.

Figure 15 shows also the temperature reached by the heat storage in the three different simulated configurations. With the stand-alone configuration (green line) the temperature reaches the upper working limit for the solar system (110°C) during summer, stopping the operation of the solar plant and thus limiting its annual energy production.
Connecting the solar thermal system to the DHS (Figure 15, yellow line), the temperature of the heat storage remains below 90°C, feeding into the thermal net the thermal overproduction.
In the three simulated configurations, during winter, the heat storage temperature follows the reference temperature given by the climatic regulation curve according to the implemented Italian National Standard UNI 9317/89.

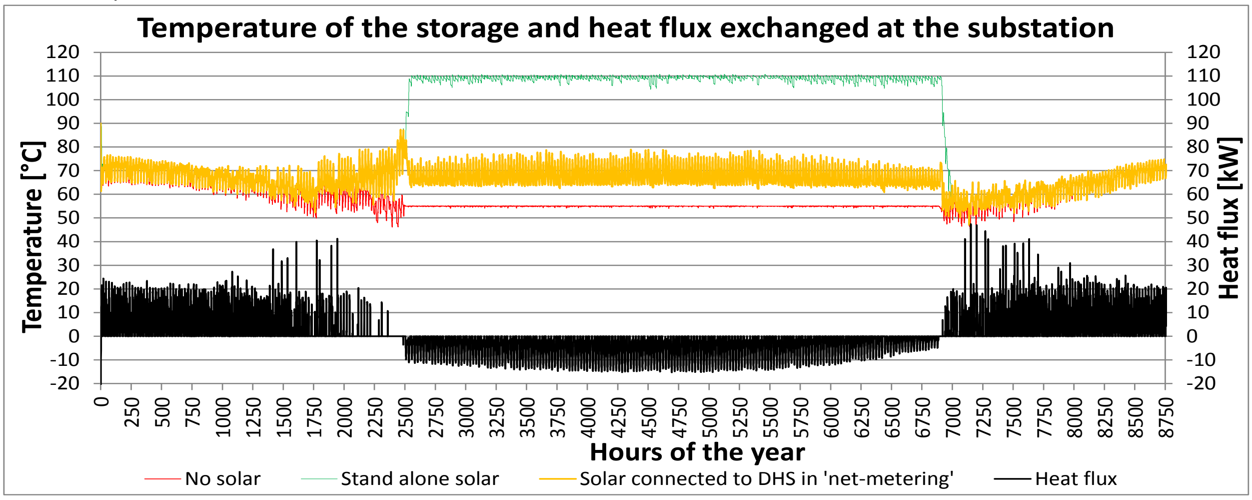
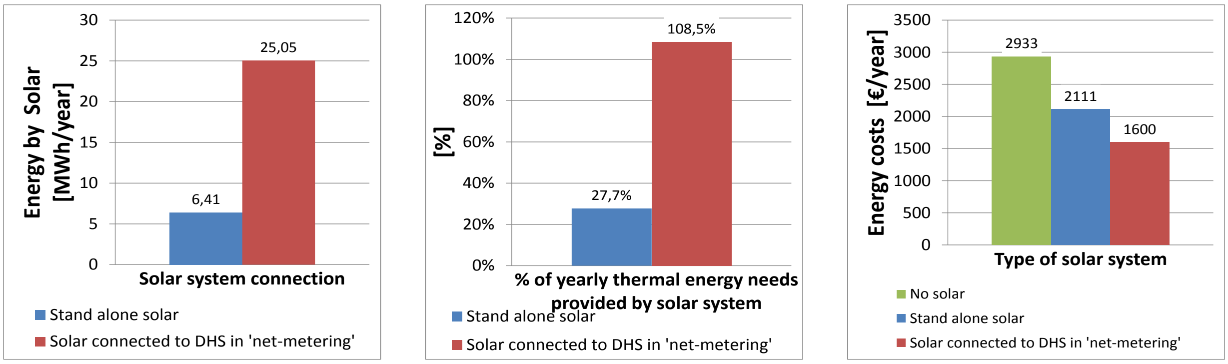


Figure 15. Temperature of the heat storage in the prosumer substation and heat flux exchanged with the DHS.

The effect, on the annual energy performance of the solar system, of the connection to the DHS in comparison to a stand-alone configuration is shown in Figure 16 (a) and (b). When connected, the solar system can use the DHS as a heat storage, and its energy production can continue throughout summer instead of being stopped for operational reasons. The consequence is that the total annual thermal energy production of the connected solution is about 4 times the annual production of the stand-alone configuration (Figure 16-a). Comparing the energy production to the annual energy needs of the single family house for space heating and DHW (Figure 16-b), the stand-alone configuration provides about 28%, whereas the connected solution can cover about 108% of the total needs. If a "thermal net-metering" tariff scheme would be adopted using the same ratio of the already existing electric net-metering, the additional 8% exceeding the annual energy needs of the prosumer, could be used as credit for the following year. The results show also that the considered solar system, when in the stand-alone configuration, can satisfy about 19% of the needs for space heating and 100% of the needs for DHW, and it is therefore oversized considering only the summer heat demands.
A cost analysis has been performed, since the economic sustainability of the thermal net-metering solution depends on the price of both the energy bought from the DHS and sold to the DHS.
In a case of thermal net-metering already existing in Sweden [4], the price of the energy fed into the DHS is about 0.25 the cost of the energy bought from the DHS. Considering 0.09 €/kWh as the average price of the energy sold by the DHS utilities to the consumers in Italy, we used a ratio energy sold/energy bought of about 0.45 considered more suited to the Italian market, and thus we consider 0.04 €/kWh as the reference price of the energy sold by prosumers to the DHS utility.



(a) (b) (c)

Figure 16. (a) Total energy produced by the solar system; (b) Energy needs of the prosumers, provided by the solar system; (c) Annual cost of the energy for space heating and DHW for the three simulated schemes.

With the above hypothesized prices, as shown in Figure 16-c, the net-metering configuration allows a reduction of the heating bill of about 60% with respect to a passive user without solar system, and a reduction of about 44% with respect to the stand-alone solar system configuration.

Conclusions

The detailed reference substation model and the new model of bidirectional substation were integrated into the energy networks simulation platform, implementing a new software tool realized to evaluate (in the time domain) heat fluxes exchanged with the network by active users and the effects generated on the management strategy of centralized systems.

In the paper the presence of a prosumer with a 50 m^2 solar field integrated in the roof, in a small-scale DHS is presented. The results of the simulations carried out show that the net-metering integrated solution would guarantee an increase in meeting the annual total heat demand of the building from 27% (for stand-alone solar system) to more than 100%, with a reduction of the heating bill of about 60%, compared to passive management of users.

Furthermore, the high thermal power fed into the grid from the solar field during the summer season allows a reduced use of the centralized systems which, due to the low demand (only for DHW), would work in conditions of low thermal efficiency.

The goal of the analysis was to evaluate the right implementation of the models and their integration in the simulation platform. For this reason it is not possible to generalize the results of the simulations in terms of energy and cost savings to other network configurations. However the value of energy savings obtained, suggests the potential benefit of applying the net-metering configuration for thermal distributed systems connected to DHS.

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“Net metering in small-scale district heating systems”

ABSTRACT

As a consequence of the adoption of the European Directive 2009/28/CE, the Italian regulation on energy efficiency requires a minimum contribution of renewable sources equal to 20% to the thermal energy needed for space heating, cooling and DHW, for new and renovated buildings. District Heating Systems (DHS) connected to solar collectors could contribute in reaching this target, and especially in urban areas, distributed small-scale solar collectors connected to the DHS with a “net metering” mode, can be an interesting solution. To analyze this scenario in realistic cases, ENEA has developed a software platform that allows to investigate the presence of customers, connected to a DHS, which not only can consume but also produce district heating by means of small-scale solar collectors. These costumers are called “prosumers” and in the investigated “net metering” connection mode they can use the DHS as a virtual storage for the thermal energy produced and not immediately used.
In order to investigate the effect of different connection schemes between the decentralized system and the DHS, were analyzed:

- two different configurations of substations "return to supply", and "supply to supply”;
- three different size of solar plant for each scheme.

The paper compares the results of the simulations carried out to assess the actual performance of prosumers connected to a hypothetical district heating network, in regards to the annual energy performance and to the DHS temperature leveles of the two scheme.

Keywords: district heating, distributed solar thermal, net metering, energy efficiency, bi-directional heat exchanger.

INTRODUCTION

The Italian Legislative Decree no. 28/11(implementation of Directive 2009/28/EC) requires since May 2012, that thermal energy plants for new buildings or for buildings subjected to a deep renovation, must be designed and built to ensure that at least 20% of the heat demand for domestic hot water, heating and cooling must be met by renewable sources; the limit will be increased to 50% from January 1st, 2017. The targets of the decree could be particularly ambitious, especially in areas with high population density, where the installation of technologies to produce the required heat demand from renewable sources might be difficult due to lack of space or for integration problems. These difficulties lead to find technological solutions that could help to reach the objectives of the Decree.

In this context the paper has the aim to evaluate the potential of district heating and cooling networks in net metering configuration: gathering the definition used for power grids, thermal net metering can be defined as a mechanism that allows renewable energy producers to use the district heating system they have connected to as a thermal storage for the energy produced and not self-consumed, in order to use it later.

The goal of the paper is to identify energetic and economic benefits and to investigate the problems resulting from the grant of the thermal net metering to the users with solar thermal plants connected to district heating networks.

The district heating network, through a "net metering" management, could provide a daily storage service for users with solar thermal systems, allowing to feed-in extra solar production and to supply all network users’ thermal energy needs (such as domestic heat water in summer or space heating demand in winter), increasing in this way the share of energy demand from renewable sources provided to each building.

A smart district heating system replies, in the heating sector, the concept of distributed generation and of energy exchange between a prosumer (i.e. a producer and consumer of energy) and the grid, already known for the electrical sector [4] [5].

In the investigated “net metering” connection mode, the prosumer can use the SDH as a virtual storage for the thermal energy produced and not immediately used, with the possibility to use it later

ENEA developed a software platform, named ENSim (Energy Network Simulator), in order to design and to perform dynamic simulations of an energy district network, where a multi-building system (residential buildings, dwellings, office buildings, shopping centers, etc.), with inhomogeneous loads, is served by advanced thermal networks. The platform is implemented in the Matlab/Simulink environment and is able to simulate the thermal behaviour and the energy performance of a polygeneration heating and cooling network including both traditional schedulable (CHP, heat pump, boiler) and not schedulable (solar heating, solar cooling, PV) energy systems, and both centralized and distributed heat production.

THE MODEL

The platform is made of different blocks, each one modelling the physical components of the network; the main ones are:

- building: to simulate heating and electric load in one year [1]
- storage systems: to simulate the network presence and its interaction with buildings and heat generators
- heat generator: to simulate the CHP and other heat supplier [2],
- solar cooling model to simulate a solar thermal plant both in heating and in cooling configurations,
- heating exchange: to manage the energy flow from building (with solar source) to the network and vice versa.

The platform is able to simulate different integrated heating sources, like boiler, CHP or solar energy plant and with the buildings' inner tanks can evaluate how the heat produced when the load is low and stored could be used in a better way. The tool allows to analyse various scenarios and different control strategies for district heating, in order to study and to evaluate primary energy saving and performances in each case.

The main heating output variables of the model are:

- average fluid temperature of the network;
- fluid temperature at each node of the network;
- thermal power supply for each building and for the whole network;
- thermal losses (district heating, exchange substations, etc)

The thermal network

The way the thermal network has been developed allows the buildings to interoperate with each other and with distributed energy resources through an equivalent thermal storage. The equivalent storage contains a volume equal to the total fluid inside the tubes. This allows to take into account the thermal inertia and the pipes losses of the network. The storage temperature is the average temperature on the entire network. The pipes are located underground at a depth greater than one meter, so the temperature can be assumed constant and independent of the outdoor temperature.

In order to study district heating in time domain, the average fluid temperature of the equivalent thermal storage, T0(t) is calculated by a differential equation :

$$\begin{cases} CAP \cdot \frac{dT_{0,t}}{dt} = Q_{aux}(t) - Q_{load}(t) - Q_{loss}(t) \\ Q_{loss}(t) = FF \cdot V_{acc} \cdot U \cdot \frac{T_{0,t} - T_c}{1000} \quad [kW] \end{cases} \qquad (2)$$

where:

- Qload is the heating load of the buildings, evaluated by buildings' model at each time step of simulation;
- Qaux is the power supplied by generators;
- Qloss represents the thermal losses of the equivalent storage
- CAP is the thermal capacity of the equivalent storage;
- FF is the storage shape factor, equal to the pipe shape factor;
- U is the pipes thermal transmittance;
- Vacc is the volume of the storage, equal to the total volume of the pipes;

The thermal losses all along the pipes have been calculated with a well-known mathematical formulation applied to hydraulic systems, considering:

- the temperature of the surrounding ground (Ta) constant and uniform;
- the fluid temperature (T) function of the distance (x) and independent from the section (S);
- T0,t fluid temperature at the x=0
- fluid thermo-physical properties unaffected by the temperature;
- steady state fluid flow rate;

- tubes with no slope;
- one dimensional flow: temperature may vary only along the tube length and not along the radius,

The fluid temperature, function of the length, can be expressed as[3]:

$$T(x,t) = T_a + \left(T_{0,t} - T_a\right) \cdot e^{\frac{2\cdot\pi\cdot r\cdot H}{G\cdot\gamma}\cdot x} \qquad (3)$$

where:
G: fluid flow rate [kg/s]
H: pipe transmittance [W/m2K]
r: pipe circular radius [m]
γ: specific heat [J/kg K]
x: distance [m]
This function has been used to calculate the temperature of the fluid along the whole network and, more specifically, in the derivation nodes at the inlet point of each building.
The described model was validated, comparing the measured performance of a real heating district located in the north of Italy with the ones simulated for the same DHS, by the platform. The district is made of 31 residential building and 1 office, supplied by a CHP (1 MWth) and 2 boilers (1 condenser boiler of 890 kW and 1 of 2.2 mW). The validation process was focused on the blocks regarding the network, because the other components were previously validated individually and has the aim to evaluate thermal inertia and to compare the time distributions of the output signals to verify if the model is able to reply the dynamical behaviour of a real heating district.
Figure 1 and 2 show how the model fit very well the performance of the real network; in particular were reported power supplied, inlet and outlet temperatures for CHP (figure 1) and for the whole power plant (figure 2).
The comparison between measured and simulated total energy supplied by the power plant (for the month analysed) shows an error of 7.3%:

- simulated supplied energy: 596 MWh
- measured supplied energy: 552 MWh

SMART DISTRICT HEATING CUSTOMER SUBSTATIONS
In case of bidirectional exchange of thermal energy between the network and the utility, the configuration of the traditional substation needs to be changed. Theoretically four different configurations can be considered: [6]

- scheme 1 (return to supply): the feed-in flow is taken from the network return circuit, heated by the decentralized production system (solar system) and reintroduced to the supply of the network.
- scheme 2 (supply to supply): this configuration is connected only with the supply circuit for what concerns the thermal energy
- scheme 3 (supply to return): in this scheme the mass flow rate from the supply of the network is heated by the decentralized production system before the reintroduction to the return circuit;
- scheme 4 (return to return): in this case, the introduction of the thermal energy from the decentralized production system to the network occurs only acting on the return circuit.

In order to investigate the effect of different connection schemes between the decentralized system and the DHS, two different configurations of substations were implemented in the Matlab/Simulink environment: "return to supply", showed in Figure 3, and "supply to supply", showed in Figure 4. Both the schemes are designed to introduce into the distribution network only the excess of the local thermal production.
“Return to supply” bidirectional substation
The "return to supply" substation works according to the layout of Figure 3.a (passive mode) if the solar power does not exceed the thermal load and the solar tank temperature is less than one of the supply circuit of the district heating.

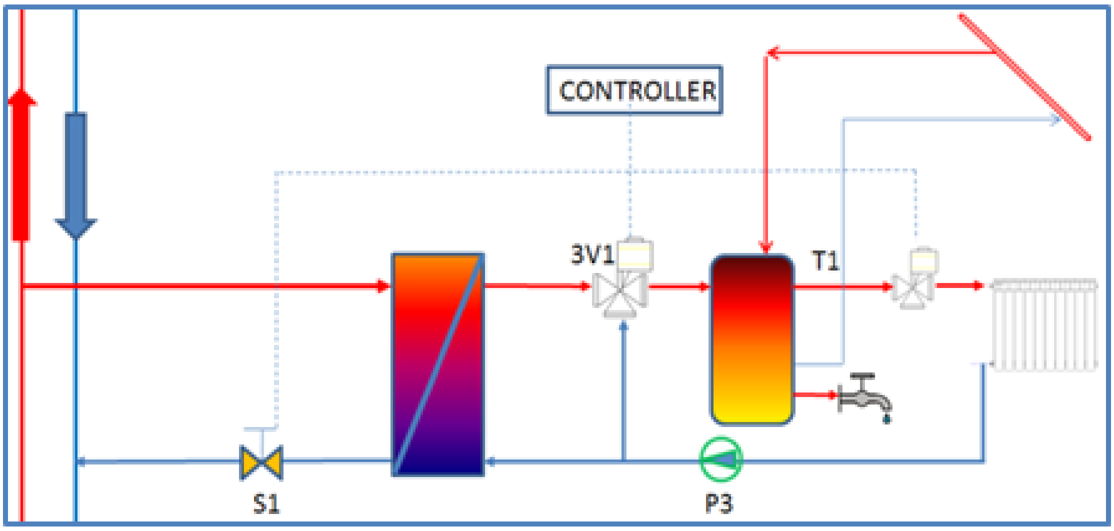

Figure 3.a: “Return to supply” substation scheme: passive mode

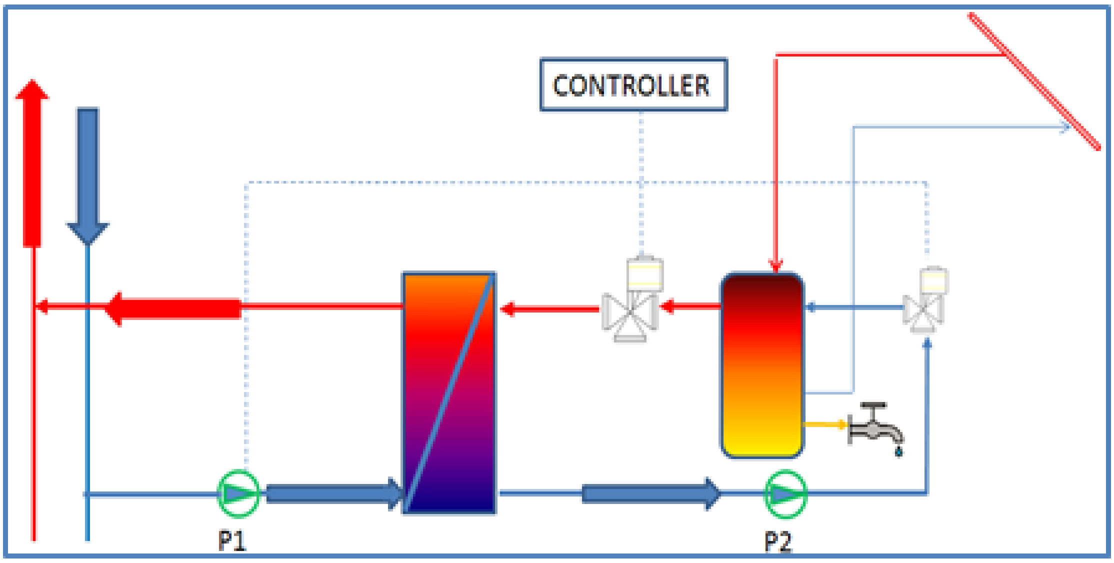

Figure 3.b : “Return to supply” substation scheme: active mode

Operation mode of the passive scheme meet the following working conditions:
- the pump P1 is stopped (Figure 3); - the valve S1 (network side) is opened to the heat exchange; this one is controlled to keep a constant return temperature and a variable mass flow rate (Figure 3.a);
- the three way valve “3V1” (user side) is controlled by a PID to keep the operating temperature (T1) equal to set point according to the climatic curve supplied by the Italian National Standard UNI 8364-2:2007 (Figure 3.a).
The "return to supply" substation works according to scheme of Figure 3.b if the local production exceeds the thermal load (typically during summer and spring) and the storage temperature exceeds the temperature of the supply circuit. To introduce into the distribution network the excess of solar thermal production the following conditions must be met (Figure 3.b):

- the pumps P1 and P2 are on
- the three way valve “3V1” is opened to its max position
- the three way valve “3V2” is closed
- the pressure supplied by the pump P2 must overcome the pressure in the district heating network.

The bidirectional thermal exchange "return to supply" provides low impact on the district heating temperature and could be easily integrated with existing customer substations. However the operating principle of "return to supply" causes regulation problem of the flow rate for the utility.
"Supply to supply" bidirectional substation
Substation "supply to supply" needs two heat exchangers as showed in Figure 4:
- exchanger 1 provides thermal energy for heating and domestic hot water, produced solar thermal power is only used for the utility needs (passive mode)
- exchanger 2 is designed to introduce into the supply circuit only the excess of thermal energy produced by a local source (solar thermal collector).
According to Figure 4.a, the solar system preheats the operating temperature during the winter season with the same operation mode of the return to supply connection scheme (Figure 3.a).
During summer and spring season the solar plant satisfies the domestic hot water and introduces into the distribution network the excess of thermal production through exchanger 2 according to scheme of Figure 4.b. the "supply to supply" operation mode meets the following working conditions:

- the valve S1 is closed • the pumps P1is stopped
- the pump P2 and P3 are on
- the three way valve "3V1" is opened to its max position
- the three way valve "3V2" is closed

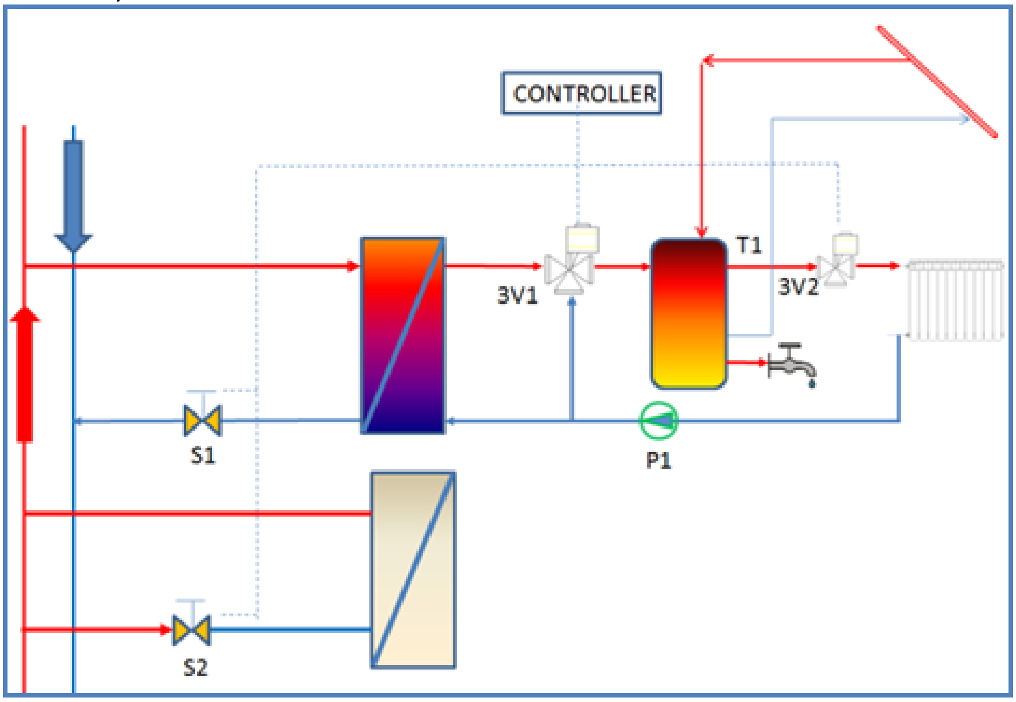

Figure 4.a: supply to supply substation scheme: passive mode

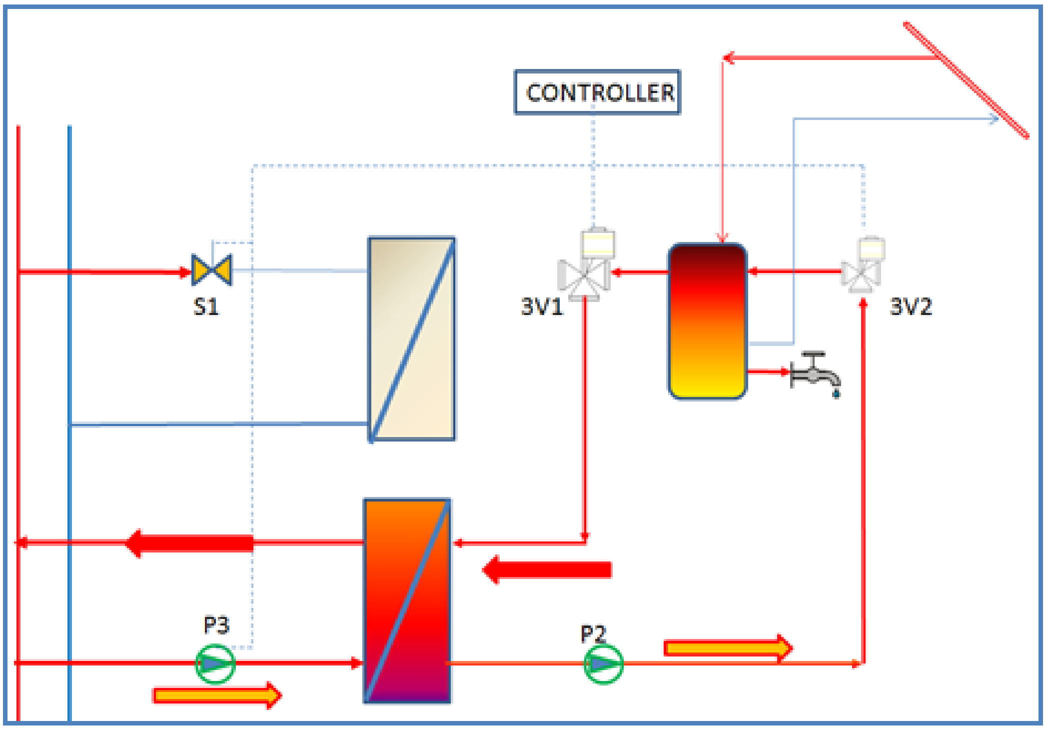

Figure 4.b: supply to supply substation scheme: active mode

The bidirectional thermal exchange "supply to supply" could involve overheat of the supply and return circuit during the summer season. Normally high supply temperature gives an unfavorable operating mode for a solar thermal system; moreover the increase of temperature of the return flow implies a decrease of the conversion efficiency of the central production systems due to its necessary regulation.

COMPARISON BETWEEN "RETURN TO SUPPLY" AND "SUPPLY TO SUPPLY" SUBSTATION: CASE STUDY

This session compares the results of the simulations carried out to assess the actual performance of prosumers connected to a hypothetical district heating network in two ways: "return to supply" and "supply to supply".

It is a tree type DH scheme showed in Figure 5, with centralized heat production and distributed generation, hypothetically located in Rome and with the following connected users:

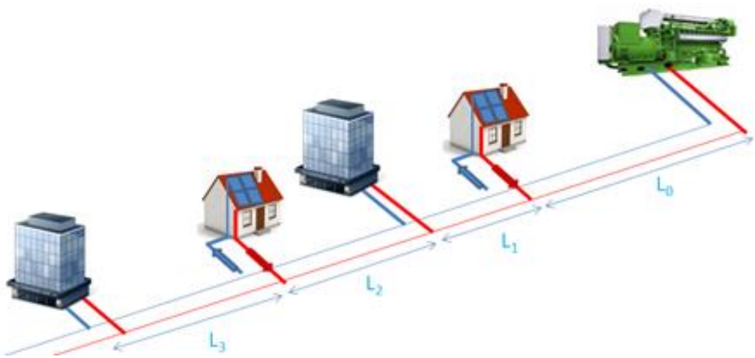

Figure 5: Scheme of the simulated small-scale District Heating System

Table 1. Main features of the connected building

	Heated surface [mq]	Thermal load - nominal condition [kW]	Heat exchange flow rate - designed point [kg/s]	Thermal storage [mc]
Building 1	600	52	0.62	5
Building 2	400	35	0.41	3
Building 3	400	35	0.41	4
Building 4	350	30	0.36	3

The centralized heat generator is a natural gas CHP unit, with a nominal thermal power of 250 kWt and nominal electric power of 170 kWe.
The main geometric features of the DHS, with reference to the scheme of Figure 5 are presented in Table 2.

Table 2. Main geometric features of the DHS

Ø of main pipe [m]	L_0 [m]	L_1 [m]	L_2 [m]	L_3 [m]	L_5 [m]	L_6 [m]	L_7 [m]	L_8 [m]
0.25	500	300	400	400	100	100	100	20

Further characteristics of the DHS are schematically summarized in Table 3

Table 3. Further features of the DHS

• U-value of the main pipe [W/mK]	• Set-point of the working feeding temperature during winter [°C]	• Set point of the working return temperature during winter [°C]
• 0.14	• 80±2°C	• 60±2°C

In order to investigate the effect of different connection schemes between the prosumers and the DHS three different size of solar plant installed in building 1 and in building 3 have been simulated as showed in table 4.

Table 4. Size of solar plant installed on Building 1 and Building 3

	Solar surface Building 1 [mq]	Solar surface Building 3 [mq]
configuration 1	0	40
configuration 2	60	40
configuration 3	140	40

RESULTS AND DISCUSSION

In Figure 6 the heat flux exchanged between the DHS and the bidirectional substation of building 1 for the two size of solar plant is represented. A clear inversion of the heat flux can be observed on about the first week of April. Between the first week of April and the end of September the substation is feeding the DHS and the building 1 is no longer a consumer, but a producer.

The switch from a consumer to a producer behavior is related to a rise of the temperature of the heat storage over the working value of the feeding temperature of the DHS; this rise is caused by a heat production by the solar system that exceeds the energy needs of the building 1 and for space heating and DHW (building 3).

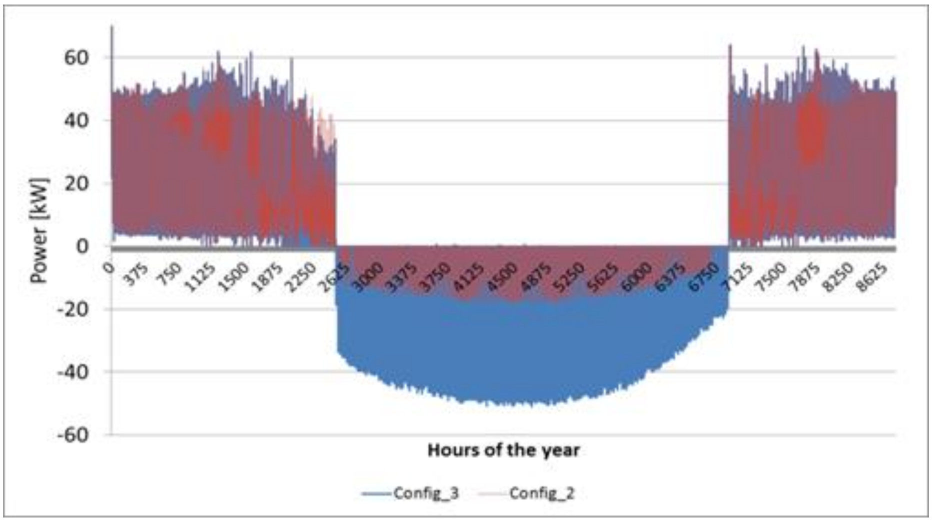

Figure 6: Thermal power exchanged between prosumer (Building 1) and district heating

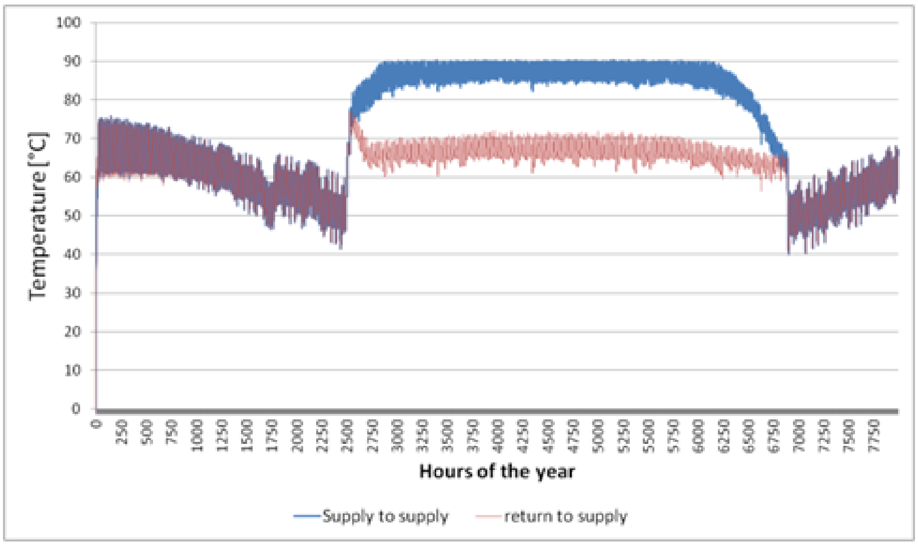

Figure 7: Comparison of annual storage temperature of building 3 - configuration 3

Figure 8: Temperature of supply circuit for two different connection schemes of prosumers

Figure 7 shows the temperature reached by the heat storage of building 3 in the two different simulated connection schemes: “supply to supply” and “return to supply”.
In all the simulated configurations, during winter, the heat storage temperature follows the reference temperature given by the climatic regulation curve according to the implemented Italian National Standard UNI 9317/89.
According to Figure 7 “supply to supply” scheme increases the temperature of storage up to the working limit for the solar system (90°C) during summer, stopping the operation of the solar plant.
The effect on the annual energy performance of “supply to supply” scheme in comparison to a “return to supply” scheme is shown in Figure 9 and in Figure 10.
The increased temperature of the district heating due to the “supply to supply” connection scheme provides with respect to the “return to supply” scheme a maximum decrease of the performance of the solar plant in building 3 of about 35% (figure 9), and a maximum decrease of the annual solar energy feed into district heating of about 55% (Figure 10).

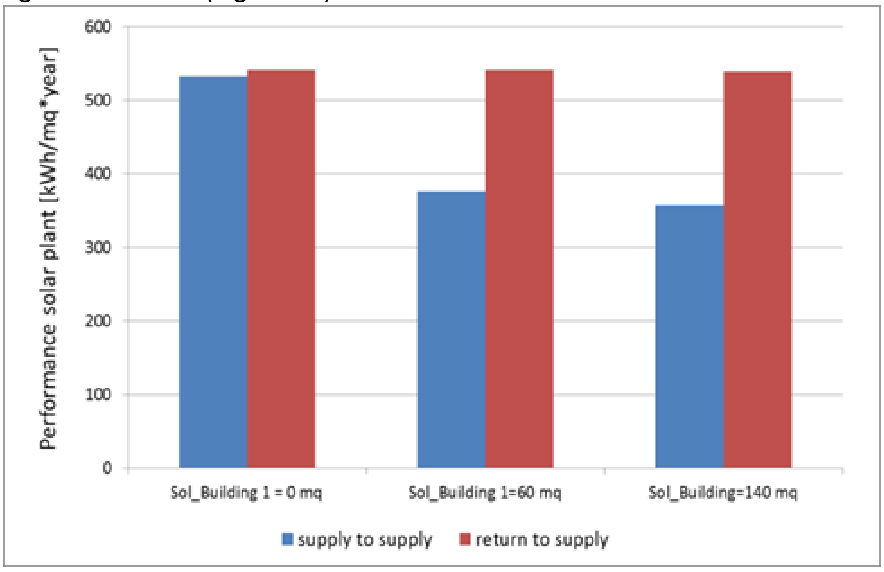

Figure 9: Performance solar plant of building 3 for different configuration

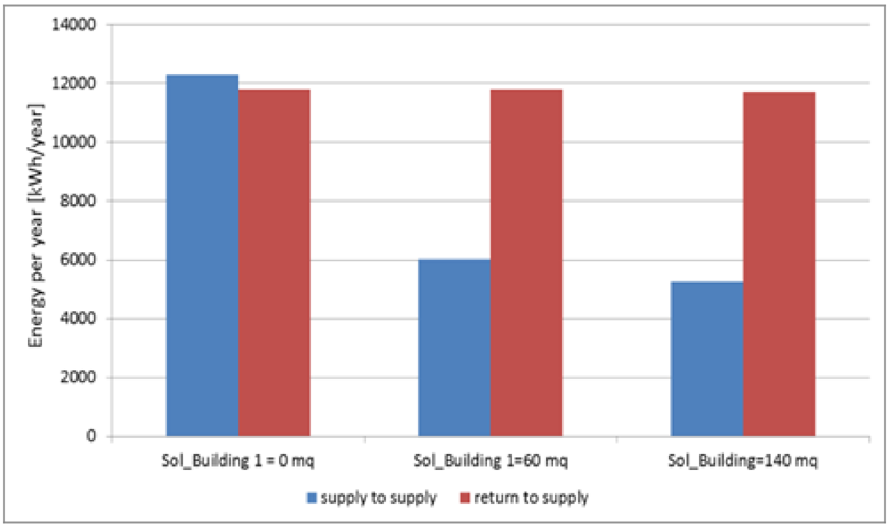

Figure 10: Annual solar energy of building 3 feed into district heating

Comparing the energy production to the annual energy needs of the building 3 for space heating and DHW (Errore. L'origine riferimento non è stata trovata.), the "return to supply" connection scheme in net metering mode provides about 28% of energy needs of the prosumers, whereas the "supply to supply" connection scheme can cover about 18% of the total needs in case of 140 m2 solar plant installed on Building 1 (Figure 11).

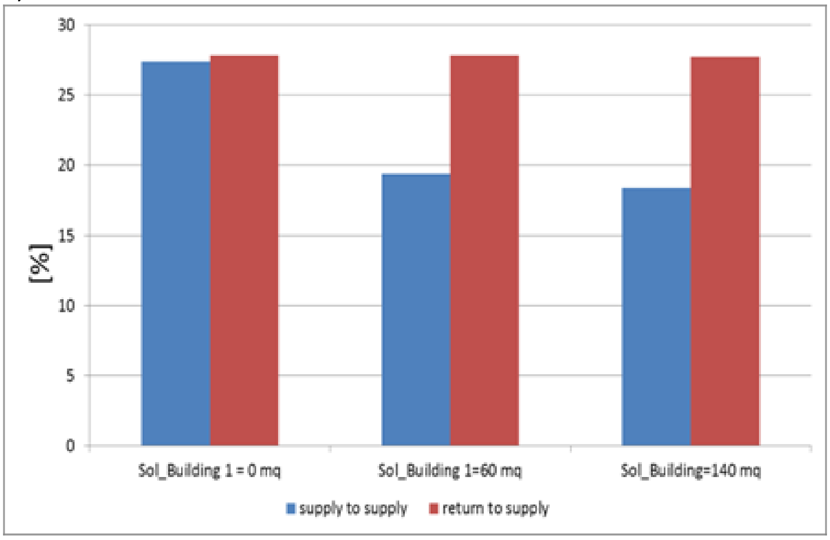

Figure 11: % of energy needs of the prosumers Building 3, provided by the solar system

CONCLUSION

In this paper is described a software platform that allows to investigate the presence of customers, connected to a DHS, which not only can consume but also produce district heating by means of small-scale solar collectors. These costumers are called "prosumers" and in the investigated "net metering" connection mode they can use the DHS as a virtual storage for the thermal energy produced and not immediately used. The software was implemented in the Matlab-Simulink enviroment and was validated, comparing the measured performance of a real heating district located in the north of Italy with the ones simulated for the same DHS with the software platform developed.

The paper compares the results of the simulations carried out to assess the actual performance of prosumers connected to a hypothetical district heating network, in regards to the annual energy performance and to the DHS temperature leveles of the two scheme.

The results simulation show that the “return to supply” connection scheme in net metering mode provides about 28% of energy needs of the prosumers, whereas the “supply to supply” connection scheme can cover about 18% of the total needs, for the same building and the same solar power installed.

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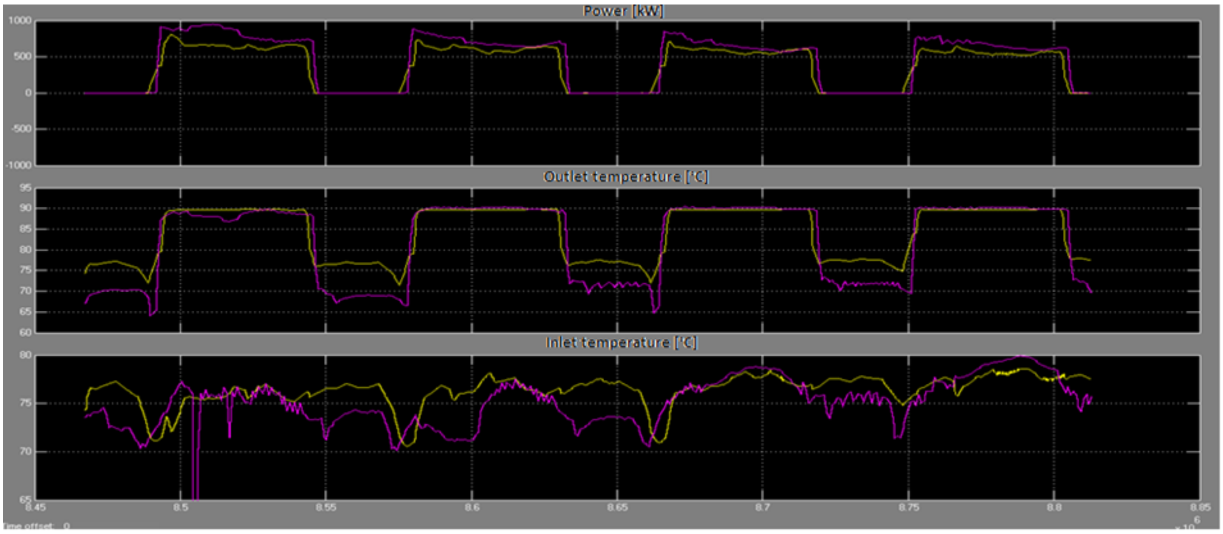

Figure 1: Power [kW], inlet and outlet temperatures for CHP (in yellow simulated and in magenta measured data)

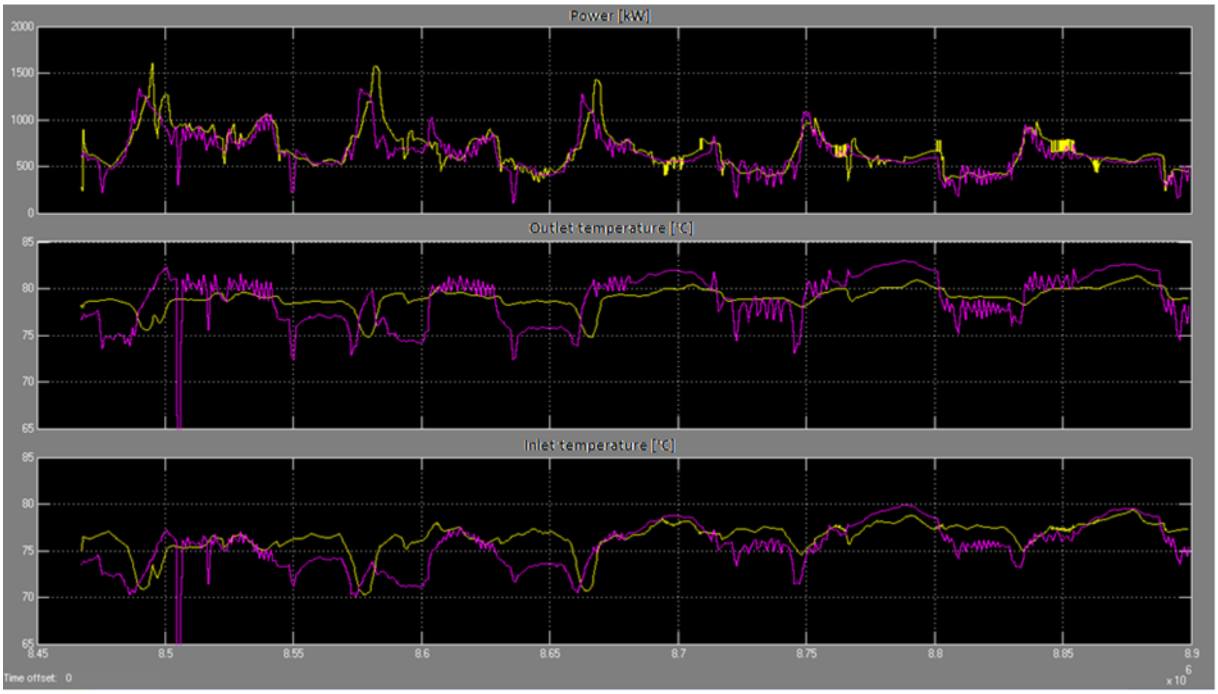

Figure 2: Power [kW], inlet and outlet temperatures for power plant (in yellow simulated and in magenta measured data

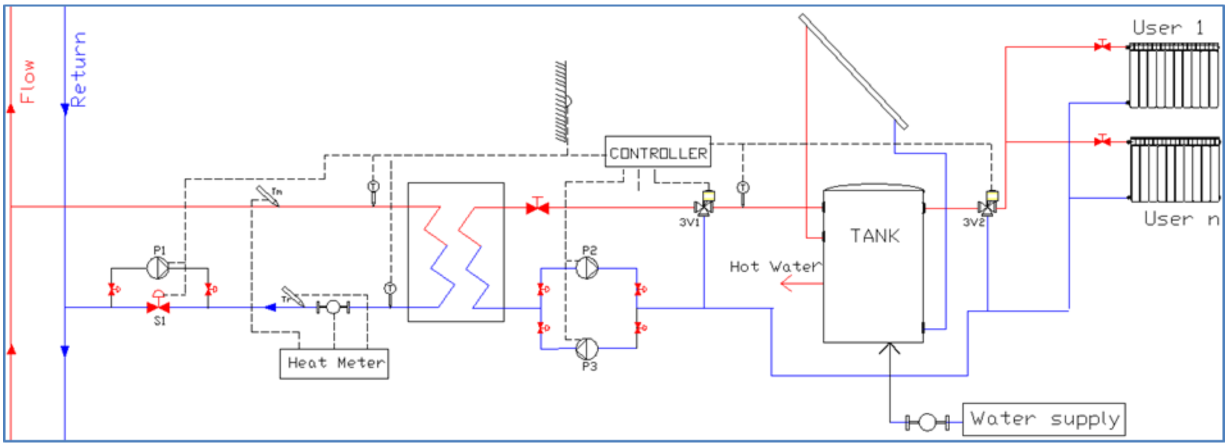

Figure 3: Return to supply bidirectional substation scheme

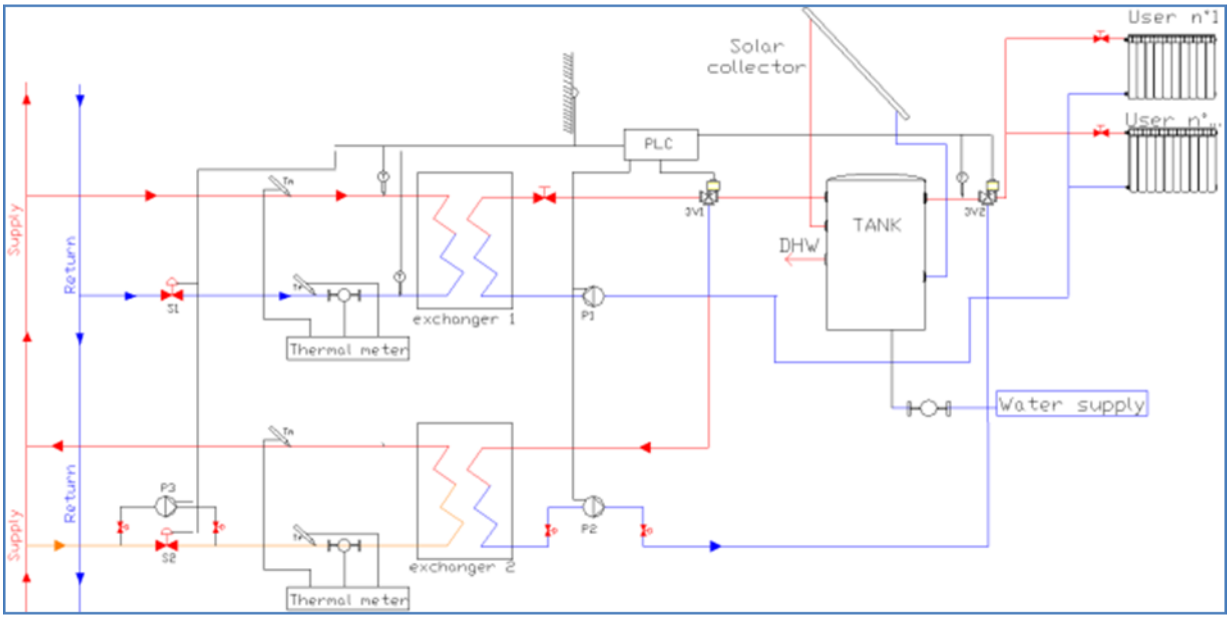

Figure 4: supply to supply bidirectional substation scheme

"Wood Biomass as Sustainable Energy for Greenhouses Heating in Italy"

Abstract

The Italian greenhouse vegetable industry is an important sector that requires thermal energy as much as 0.74 Mtoe, derived mostly from fossil fuels, which corresponds to 2 MtCO2 emissions. The Energy Strategy 2020 of the European Commission calls for increased use of renewable resources in the energy system, thus pushing the technology of wood biomass system for space heating of the greenhouses, since this resource is considered as 'greenhouse gas' (GHG) neutral when converted to heat, excluding the GHG generation during harvesting, transportation, and pre-processing of raw materials.

Taking into account the different climatic areas in the Italian peninsula, power energy load was estimated to be between 30 Wm-2
(in southern regions) and more than 175 Wm-2 (in northern regions), while the energy consumption was estimated in the range from 21 to 546 kWhthm-2year-1 according to different internal air temperatures. Moreover, the CO2 enrichment in greenhouses from the exhaust gas of a biomass heating system can bring benefits for greenhouse plant production, along with optimal management strategies to reduce fuel consumption.

Unfortunately, CO2 enrichment from the exhaust gas of biomass boilers is still challenging and expensive, considering that wood biomass boilers generate a higher volume of particulate matters (PM) and ash emissions than other fossil fuels. However, wet scrubbers and other recent flue gas conditioning devices could help to reduce costs and make this process more feasible.

Thus, a techno-economic assessment is highly recommended to ascertain the economic feasibility of wood biomass boilers for the greenhouse industry.

Finally, some economic considerations are provided to make cost-effective use of the solid biomass in relation to the economic incentives by the National Decree of 28 December 2012, so-called "White Certifies".

1. Introduction

The agro-food industry is the leading manufacturing sector in Europe, in terms of turnover, value added, employment and number of companies. In Europe, its turnover was around 950 billion Euros in 2010 and it employed nearly four million people. In general, the agro-food industry is composed by transformation companies, using products from agriculture (primary production) to supply the agro-food industry. As general figure, the Italian added gross value of the agro-food system, in its wider meaning of agriculture and food industry, has reached in 2011 a global economic value of 250 billions €, which correspondents to about 16% of the added gross value of Italian economic in 2010. About 12.9 million hectares is agricultural land in Italy.

According to Campiotti et al. (2011), the national agri-food system amounted to a total final energy consumption of 16.43 Mtoe (tonne of oil equivalent) (Tab. 1).

Table 1. Agriculture and energy consumption of productive sectors in Italy.

Productive sectors in the agro-food system	Energy consumption (Mtoe)
Direct consumption (irrigation, processing land, air heating, utilities)	3,03
Food industry	2,90
Indirect consumption (phytosanitary, fertilizers, plastics), transport, preparation, storage, distribution, storage, sales	10,50
Total	16,43

1. Greenhouse energy consumption in Europe

The EU greenhouse farming sector is facing a trend that responds to the changing consumer demands in a society that, globally, is increasingly affluent, and generate concerns and negative consequences, i.e.: high fossil energy- demand, energy consumption, environmental impacts, Carbon dioxide (CO_2) emissions. Greenhouses are used to control or modify the many environmental factors affecting plant growth, mainly temperature and relative humidity, rain, wind, hail and snow. As general statement, the most important climatic factors which influence the quality of the indoor microclimate are the quality of solar radiation and the temperature. Solar radiation is the main source of photosynthetic energy for plant growth and production. On the other hand, temperature is the most critical climatic factor for the greenhouse functionality. Therefore, the greenhouse design must follow regulations related to the local climate as well as the greenhouse heating technologies in order to maintain an optimal microclimate, especially as solar radiation and temperature, for the cultivated plants. Thus, the covering materials with their mechanical and radiometric properties determine the transmittance and the good insulation performance.

The greenhouse sector, with about 150,000 hectares of covered surface in Europe, represents one of the most intensive energy sector in the agro-food industry. In South Europe, about 5 ÷ 6 $kg.yr^{-1}.m^{-2}$ fossil fuel are required for keeping the inside air at around 15°C÷20°C; on the other side, in Central-North Europe, from 60 to 80 $kg.yr^{-1}.m^{-2}$ heating oil are required for maintaining optimal air temperature inside the greenhouse area. Estimation made in Spain, Italy, The Netherlands and Greece reported for these countries a greenhouse fossil energy consumption of about 4 Mtoe, with 11.3 $MtCO_2$ emissions, and a total yearly economy value in products and structures in the range of 12.5 billions € (Table 2).

Table 2. Greenhouse agriculture in Europe

Country	Greenhouse surface (ha)	Economic turnover (billions €)	Heating (MWh_{th})	Electricity (MWh_{el})
Italy	30,000	3	8,432,500	112,866
Netherland	10,311	6.8-7.7	29,510,800	3,723,000
Spain	43,964	1.5	989,627	33,623
Greece	5,646	0.5	87,644	1,700
Total	**89,921**	**About 12.50**	**39,020,571**	**3,871,189**
			3.35 Mtoe	0.77 Mtoe
			9.4 Mt_{CO_2}	2.1 Mt_{CO_2}

0.0860 toe = 1 MWh_{th} ; 0.201 toe = 1 MWh_{el} ; 1 toe equals to 2.81 t of CO_2 emissions.
(*Source*: Estimation of authors from data available on national data-bases, internet and EUROSTAT, 2008 and 2009.)

Table 2. Greenhouse agriculture in Europe

More in details, the Italian greenhouse is characterized with not less than 6,000 ha as permanent greenhouse structures, and equipped with fossil acclimatization systems, which accounts for a total energy consumption of about 0.74 Mtoe, predominantly coming from fossil fuel (Table 3).

Table 3 - Electrical and thermal energy consumption in greenhouse sector in Italy

Country	Greenhouse[a] surface (ha)	Heating[b] (toe)	Electricity[c] (toe)
Italy	6,000	706,786	24,830

a. plastic-greenhouses and glass-greenhouses;
b. yearly energy consumption;
c. yearly electricity demand of greenhouse users (ventilation, opening, pumping);
Source: The Regulatory Authority for Electricity and Gas of Italy, 2009.
Elaboration from national data and EUROSTAT 2008 and 2009.

The greenhouses are widespread all over the Italian peninsula with a greater concentration (about 60% of the total) in southern regions, where most of the greenhouses consist of low-cost structures covered with plastic films. They are usually provided with simple heating systems, while greenhouse acclimatization is mainly used in the northern areas of Italy, with most of the greenhouse structures covered with glass.
The Sankey diagram (Fig. 1) shows the direct energy inputs of Italian agriculture, with the greenhouse agriculture as one of the most intensive sub-sector in terms of direct energy consumption, mostly due to greenhouse acclimatization.

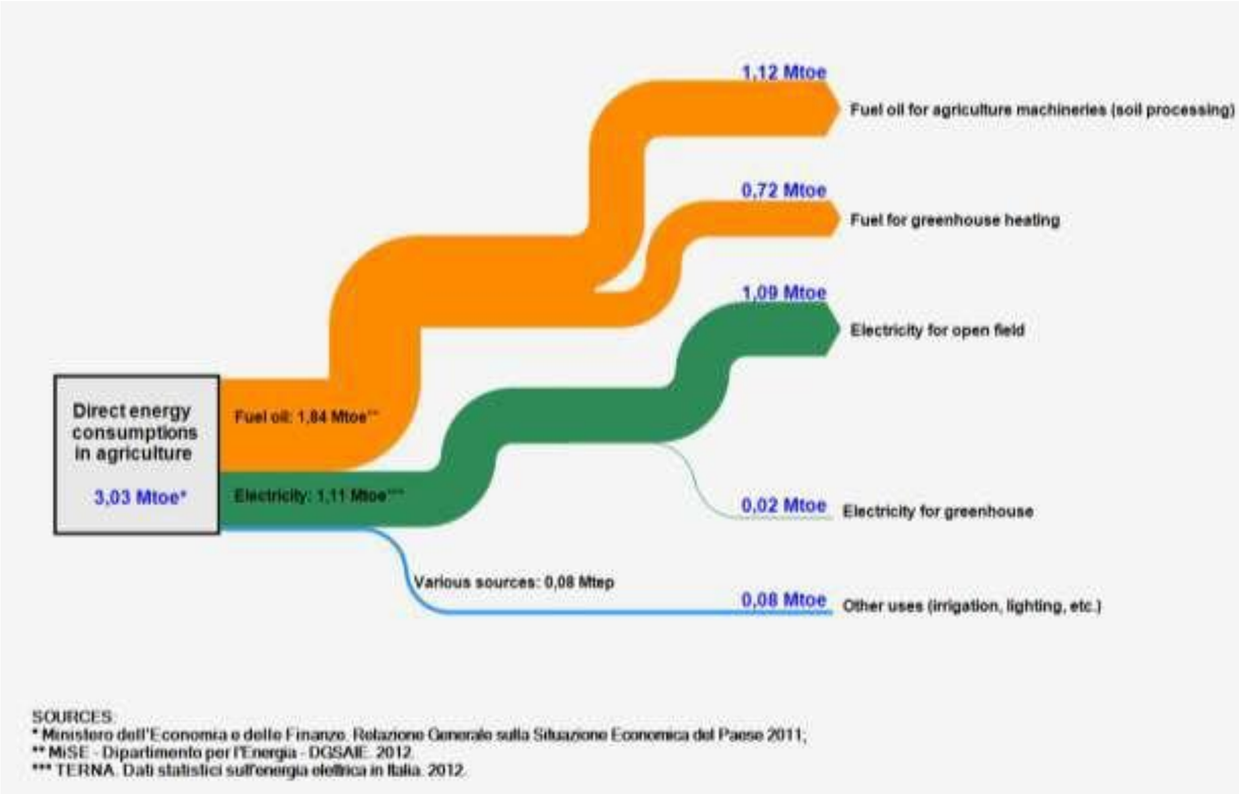

Fig. 1. Direct energy consumption in Italian agriculture .

Recently, in Italy which is one of the European countries most vulnerable to the impacts of high energy cost, the renewable energies come along as the most promising energy resource for application in greenhouse acclimatization to face the present concern on fuel costs, that has posed a serious threat to the viability of the agricultural companies in the field of greenhouses. Particularly, the photovoltaic and the solid biomass for heating and cooling purposes have attracted a lot of attention in substitution of conventional fuels, since it is general conviction that the increasing of oil energy price is a trend which doubtless will continue for the coming years in Europe, and this will increase risks and lower profit for agricultural companies and growers.

Nevertheless, biomass energy production (such as energy crops) can compete with food production for agricultural land and raw materials, as the recent experience in Italy brought to light when a large number of biogas plants were built during the last 5 years, or in early 2007 when the demand for maize increased due to ethanol production in the USA. (Mathiesen et al., 2011). However, the carbon balance should be carefully evaluated.

Besides, there is some concern over their usage in residential heating due to the emissions of various pollutants, such as polycyclic aromatic hydrocarbons, NOx, CO, SOx, and particulate matter (PM).

2. Classification of Biomass Sources

The classification of solid biofuels is based on their origin and source. The fuel production chain of fuels shall be unambiguously traceable back over the whole chain. Both EN 14961 (2010) and EN 15234 (2010) have been divided into 6 parts, where part 1 gives the general requirements, and parts 2-6 are specific for fuels to be used by relatively small-scale users and non-industrial applications. In the standards, the limit is drawn at boilers with a capacity of 500 kW. All boilers above that size are considered 'industrial', those under that limit are 'non-industrial'

The solid biofuels are divided into the following sub-categories (EN 14961-1, 2010):

- woody biomass;
- herbaceous biomass;
- fruit biomass;
- blends and mixtures.

The purpose of classification is to allow the possibility to differentiate and specify raw material based on origin with as much detail as needed.
Taking into account the energy content, table 4 shows the following Net calorific value (CV) or Lower Heating Value (LHV) (this means that the latent heat of vaporization of the water vapour created by combustion is not recovered by condensation):

Table 4. Greenhouse agriculture in Europe

Fuel	Net Calorific Value (CV) by mass	Net Calorific Value (CV) by mass	Bulk density	Energy density by volume	Energy density by volume
	GJ.tonne^{-1}	kWh.kg^{-1}	Kg.m^{-3}	MJ.m^{-3}	kWh.m^{-3}
Biomass Fuel					
Wood chips (30% MC)	12.5	3.5	250	3,100	870
Log wood (stacked - air dry: 20% MC)	14.7	4.1	350-500	5,200-7,400	1,400-2,000
Wood (solid - oven dry)	19	5.3	400-600	7,600-11,400	2,100-3,200
Wood pellets and wood briquettes	17	4.8	650	11,000	3,100
Miscanthus (bale - 25% MC)	13	3.6	140-180	1,800-2,300	500-650
Fossil Fuels					
House coal	27-31	7.5-8.6	850	23,000-26,000	6,400-7,300
Anthracite	33	9.2	1,100	36,300	10,100
Heating oil	42.5	11.8	845	36,000	10,000
Natural gas (NTP)	38.1	10.6	0.9	35.2	9.8
LPG	46.3	12.9	510	23,600	6,600

(From http://www.biomassenergycentre.org.uk)

3. Biomass heating systems

Biomass with low moisture content, provided in its raw form or processed as pellets, chips, briquettes, etc., can be converted in both heat and CO2 to a greenhouse via combustion or other thermo-chemical processes such as gasification or pyrolysis (McKendry, 2002).
Several different types of biomass boilers can be supplied with wood chips, pellets, or briquettes: their sizes range from small (10÷20 kW), to medium (50 kW and above), and to power-station (100 MW and more).
Biomass fuel is fed to the grate mechanically where it undergoes the four-stage combustion process to produce energy:

- Warming and drying Temperature T< 150 °C
- Pyrolysis 150< T<500 °C
- Gasification 500< T<800 °C
- Combustion of gases 800< T<1600 °C

The biomass boilers systems should provide a drying of the first load of fuel on the grate and then its heating towards the spontaneous ignition temperature of 400 °C, accomplished by automatic ignition systems, most notably hot air.

Warming and drying requires hot combustion chamber above and around where the fuel enters the grate. Thus, boilers contain some refractory material, and the greater this quantity of refractory walls, the less responsive the boiler to changes in heat demand, the longer the time taken to reach ignition temperature and the greater the residual heat that will need to be dissipated when the boiler is switched off.
To prevent the formation of slag on the grate, the combustible gases (mainly CO and H_2) are burned some distance away from the grate at a high temperature, while maintaining the temperature range on the grate itself.
Incomplete gasification and oxidation can occur, and black smoke can be produced, if for some reasons wet fuel is not dried sufficiently by the boiler. Moreover, the tars released during the 'Pyrolysis stage' will gradually coat the heat exchanger surfaces resulting in reduced heat exchange efficiency and the eventual failure of the boiler (Palmer et al., 2011).
Automatic feed burner main types are:
Stoker burner boilers
Stoker boiler using an underfed combustion system
Both boilers can burn wood pellets and wood chips up to 30% moisture content (MC). For wood chip with a MC of between 30% and 50%, moving grate boilers, also known as stepped grate or inclined grate boilers, have been designed.
Since the last decade, the gasification technology has been gaining a great importance when coupled with syngas combustion for heat and power, due to its high efficiency; moreover, it makes the thermo-chemical conversion of biomass cleaner and easier to control, compared to direct combustion of solid fuels (Reed and Das, 1988; Quaak et al., 1999; Whitty et al., 2008; Caputo et al., 2005; Dion et al., 2013).
Biomass boilers are not normally sized to meet the peak heat load but rather to provide a large percentage of the heat requirement, thus needing a buffer vessel: heat produced by the boiler that exceeds the immediate heat requirement of the greenhouse is stored to meet subsequent heating requirements.
Biomass consumption as fuel for greenhouse heating is related to both the greenhouse surface and the specific energy needs of crops.
Considering a thermal power of the greenhouse surface to be heated equivalent to 100 $W.m^{-2}$, a conversion yield of 85%, biomass producing 3.9 $kWh.kg^{-1}$, the annual average biomass consumption is about 45÷90 $kg.m^{-2}$ with 1,500÷3,000 running hours.
The capacity of the heat store places a limit on the amount of heat that can be stored.
The size of heat store, tipically 15÷20 x $10^{-3}.m^3$ per unit greenhouse area, depends on the control strategies and on the CO_2 enrichment in the greenhouse, if any (Chalabi et al., 2002 Nederhoff , 2004).

1. Clean CO_2 enrichment

The enrichment of greenhouse air with CO_2 leads to better plant growth, shorter cropping times, and higher quality. Therefore, low-cost CO_2 sources may result in the most profitable choice for crop growth in greenhouses, combining control of ventilation and CO_2 enrichment.
Carbon dioxide gas for enrichment can be derived either from pure gas and the combustion gases from a hydrocarbon fuel such as low sulphur paraffin, propane, butane or natural gas, or from the combustion of biomass fuel. In Canada, the fuel cost for providing heat and CO_2 represents about 28% of the operating cost of a greenhouse, and in the recent past years, a detailed economic study has been completed by Caputo et al. (2005) on utilizing wood residue for producing electricity using combustion in comparison with gasification technologies in Europe. The optimal CO_2 concentration for growth and yield seems to be 700÷900 vpm (volume parts per million). The CO_2 concentration should be kept to at least the outside level, but CO_2 enrichment is not a current practice in mild climates up to now (von Zabeltitz, 2011).
A number of studies have been carried out to determine the most economically profitable CO_2 enrichment strategy for greenhouse using CO_2 from the exhaust gases of natural gas boilers (Houter et al., 1989; Nederhoff, 1990; Rijsdijk & Houter, 1993; Ioslovich et al. 1995; Aikman et al., 1997; Stanghellini et al., 2008; Vanthoor et al., 2012). The EUPHOROS project, within the 7th Framework Programme of RTD,

dealt with the efficient use of inputs in protected horticulture, and investigated the optimum ventilation, thermal storage and CO_2 management for different climates and available sustainable energy sources, giving valuable information on costs and technologies (See Deliverable 14).
Exhaust gases from gas burners can be led directly into the greenhouse. Gas will be burned, and the CO_2 is blown with the circulating air into the greenhouse. Special control systems are necessary, and care must be taken to avoid carbon monoxide production. Thus, it seems convenient to mix the exhaust gas with fresh air (von Zabeltitz, 2011), in order to condense water vapour, dilute the concentrations of the emissions, and permit distribution in the greenhouse.
On the contrary, biomass combustion is not as clean as natural gas combustion. While it produces CO_2 and water vapour as well, it also leads to higher emissions of NO_x, SO_x, CO, Particulate Matter, and VOCs.
In terms of enrichment applications, combustion of dry and clean wood biomass can produce two times more useful CO_2 than natural gas for the same energy unit (Chau et al., 2009). Exact flue gas composition depends on furnace technology and efficiency: a comprehensive review of exhaust gas composition and toxicity, and of CO_2 recovery methods from the exhaust gas of biomass heating systems for safe enrichment in greenhouses, has been carried on by Dion et al. (2011).

Most of the pollutants mentioned previously are due to incomplete combustion. VOCs and large organic pollutants can be significantly reduced controlling residence time, temperature and turbulence (Reed and Das, 1988).
Scrubbing system with particular catalysts can transform nitrogen oxides NO_x and sulphur oxides SO_x found in exhaust gases into valuable byproducts , but the economical feasibility and the overall sustainability of developed methods should be assessed.
Cyclones, scrubbers, electrostatic precipitators (ESP) and fabric filters can typically stop PM, up to aerodynamic diameter size as large as 0.1 μm, but care should be taken to control PM concentrations, as well (Dion et al., 2011).
Membrane based CO_2 separation process seems to be the most promising technology due to its energy-saving, space-saving and ease for scale up, as reviewed by Yang et al. (2008), but currently no application to CO_2 enrichment in greenhouses have been reported.

6.Economic assessment

A techno-economic assessment, combining the technical and economical parameters which could affect the economics of a project, is highly recommended before taking the final decision (Chau et al., 2009).
From this point of view, in Italy the National Decree 28 December 2012 introduced large economic incentives, called “White Certifies”, in order to shift boilers to wood biomass types, if addressed to greenhouses heating. The technical Datasheet n. 40E - Installation of wood biomass boilers in the greenhouse industry – sets up some requirements of the whole system to be installed.
Boilers must undergo to standards EN 303-05 (2012), EN 12809 (2001), and Italian UNI 10683 (2005), dealing with technical parameters and maximum power (500 kW), and :

- efficiency not less than 85 %;
- respect of emissions as required in class 5, EN 303-05 (2012).

Biomass must fulfill the quality classes provided by EN standards , in particular:

- wood pellets: class A1/A2, EN 14961-2 (2010);
- wood briquettes: class A1/A2 and B, EN 14961-3 (2010);
- wood chips: class A1/A2 and B, EN 14961-4 (2010).

The cost of the boiler varies considerably, in relation to the technological level of the boiler itself. In Italy, the cost of a modern wood chips/pellets boiler is about 100÷250 €.kW-1, depending on its size. The cost of the boiler is to be added to other device costs that complete the system: loading system, accumulator, control system and safety, installation, etc.: in practice, the total cost (excluding building works) is more than twice the one above. In general, the specific cost can be considered in the order of 300÷400 €.kW-1 for systems of lesser power (up to approximately 80 ÷ 100 kW) and in the order of 200 ÷ 300 €.kW-1 for boilers of greater power (over 100 kW).

Despite these fact, the economic incentives called “White Certifies” cover all the above mentioned costs, thus making profitable even the conversion of the existing heating plants. In fact, incentives provided in the time span of 5 years may vary between 5 and 100 €.m-2, related to the area of the greenhouse floor surface, in relation to cladding materials and shape ratio of the greenhouse, and to 6 climatic zones as defined by the degree-day method.
As the power energy load was estimated to be between 30 W.m-2 (in southern regions) and more than 175 W.m-2 (in northern regions), the overall cost for the biomass heating system may vary between 6 and 70 €.m-2, thus
resulting in most cases lower than the incentives themselves.
In North Italy, the price for wood chips and wood pellets are 0.032 and 0.06 €.kWhth-1, respectively. Compared to heating oil price, they result in 2÷3 times lower price, making greenhouses management more profitable.

2. Conclusions

The present work deals with wood biomass systems for space heating of the greenhouses. In Italy, greenhouses heating energy load was estimated to be between 30 W.m-2 (in southern regions) and more than 175 W.m-2 (in northern regions). Besides a techno-economic analysis of wood biomass boiler systems, it is worth noting that the flue gas contains a large amount of CO_2, and that this resource can be exploited to increase the production. Since some decades ago, carbon dioxide enrichment has been established in northern Europe greenhouses, recycling the exhaust gas coming from gas heating systems, due to benefits brought to plant production: anyway it needs optimal management strategies to reduce fuel consumption.
Unfortunately, biomass boilers generate a higher volume of NO_x, SO_x, VOCs, particulate matters (PM), and ash emissions than other fossil fuels, thus making CO_2 enrichment still challenging and expensive. Recently, flue gas conditioning devices proved themselves able to reduce costs and make this process more feasible. All this standing, in relation to the economic incentives by the Italian National Decree of 28 December 2012, varying between 5 and 100 €.m-2, related to the floor area of the greenhouse, it is worth converting boilers to wood biomass boilers and even to consider the installation of some flue gas conditioning devices.

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"Simulation of the thermal behaviour of a building retrofitted with a green roof: optimization of energy efficiency with reference to italian climatic zones"

Abstract

Running a building energy simulation program (EnergyPlus), simulations were conducted on a 'public housing' building type, in order to evaluate the energy savings achieved by a green roof coupled with different configurations of external wall.

EnergyPlus enabled the investigation of the thermal behaviour variations of the building envelope, and the possible consequences, in terms of comfort, on the temperature of the internal spaces.

The variation of the energy behaviour of the building envelope type was assessed primarily through the analysis of the operative temperature T° of the elements of surface casing,

the trend of the surface heat fluxes on the faces of the elements of internal and external housing, the variation of the operating temperature inside the rooms. The energy savings achieved with a green roof varies considerably in relation to the reference performance obtained without this kind of insulating structure. The main parameters, useful to define the contribution of the green roof to the reduction of the loads of cooling plants, consist of the specific climate and the thermal isolation level of the initial coverage.

1. Introduction

In traditional building terms, roof is a top surface over an habitable area that protect inhabitants from unwanted weather elements and helps in maintaining comfortable indoor condition, protecting people and property from the sun, wind, rain and snow. In architectural terms, a roof can be sloped or flat but regardless of its configuration, both becomes extraordinarily hot in direct sun exposure, especially during the summertime. The variation in temperature of the roof surface can cover more that 70 degrees from morning till afternoon and this heat gain strongly affects the thermal comfort of the roof-space. The green roof design moved from this requirements in order to provide an efficient and sustainable solution to comfort problems as the indoor operative temperature variation during both summer and winter, the rainwater drainage and retention, and, at the urban scale, the CO2 and PM absorption, the heat island effect mitigation and a sensible contribution to biodiversity and natural landscape. A green roof is not just a decorative element on the top-floor but is a technical system performing detailed functions and fulfilling certain requirements in a building, as stated by the national standard UNI 11235 (2007).

Therefore, even if green roof design has been primarily applied starting from XVIII and XIX century, in northern Europe regions, it has been recently developed in Mediterranean regions also, as a consistent technology to improve the thermal performances of the building without increasing energy costs, especial for the summer cooling.

Determining the contribution of a green roof to the indoor comfort and to the reduction of the conditioning loads during summertime is the main aim of this research.

2. reen roof and energy savings

The potential energy savings due to the installation of a green roof vary considerably in relation to the reference performance that it refers to. A crucial parameters in defining the contribution of green roofs to reduce the HVAC loads mainly consist of the specific climate and the insulation level of the roofing type.

Most of the researches on green roof have been carried out in cold climates where green roofs primary spontaneously colonized rooftops but, in the last decade, an increasing amount of green roofs has been built especially in Mediterranean and dry climates (Werthmann, 2008).

The green roof is historically known for its ability to provide thermal insulation in cold climates, and to limit the overheating due to direct sunlight on roofing, in hot climates, as in Santamouris (2009).

More recently, many efforts have been made to quantify the contribution to energy efficiency of "green" technologies such as green roofs and green walls. Simulations based on both mathematical and real models made it possible, using quantitative parameters to calculate the thermal performance of these green envelopes and highlighting their contribution to thermal insulation and thermal inertia. These models also state and the interaction of plants with the local irradiation and mainly moisture and rainfall levels.

Therefore, with the different climatic context, the hydrological design and benefits of green roofs have to be reassessed. In regions characterized by water scarcity, innate conflicts between resource, conscious water management and green roof irrigation have to be evaluated.

3. Green Roof model in Energy Plus

As with a traditional roof, the energy balance of an green roof is dominated by radiative forcing from the sun. This solar radiation is balanced by sensible (convection) and latent (evaporative) heat flux from soil and plant surfaces combined with conduction of heat into the soil substrate.
A step forward, researches have integrate these mathematical calculation models in the most advanced building energy simulation software in order to assess the contribution of the green roof to the global performance of the building, in decreasing total heat flow and internal overheating and consequently reducing the yearly energy bill.
Currently, however, there are few design tools available to assist developers and architects in assessing the likely magnitude of energy savings associated with various implementation options.
The “Green Roof” module was introduced in EnergyPlus in 2007 and it allows user to monitor various characteristic parameters of a green roof, such as the Leaf Area Index (LAI), plant height, stomatal conductance (ability to transpire moisture), and soil moisture conditions (including irrigation).
The Green roof model simulates the heat transfer processes involved on a vegetated roof:

- long wave and short wave radiative exchange within the plant canopy,
- plant canopy effects on convective heat transfer,
- evapo-transpiration from the soil and plants, and
- heat conduction (and storage) in the soil layer

The green roof module accounts for long wave and short wave radiation incident on both soil and vegetative surfaces, evapo-transpiration effects, one dimensional conduction through and storage in the soil, and convection in the canopy-soil surface zone. It also allows for input of precipitation and irrigation schedules, tracking the resulting diurnal and seasonal variations in soil moisture.

“Performance evaluation of a solar cooling plant applied for greenhouse thermal control”

The greenhouses cultivation causes in summer season inner conditions characterized by high thermal levels such as to generate problems that can damage crops. Always more frequently for this reason it is common to provide greenhouse with air conditioning plants. In this work it will be presented an application of a solar cooling plant with absorption cooling machine for thermal control of a greenhouse and an advanced simulation model able to evaluate optimal plant configurations and controls. Solar cooling systems can be applied for greenhouse climate control in regions with high values of solar irradiation as alternative to traditional evaporative systems, allowing the reduction of primary energy consumption by exploiting the contemporaneity between the cooling requirements and the solar energy availability.
The plant consists of a single effect LiBr-H2O absorption chiller fed by evacuated-tube solar collectors; the model was developed in Matlab-Simulink and is able to simulate dynamically, with time steps up to 15 minutes, the greenhouse cooling demand and the production of the solar field.
Present study proposes a plant configuration with a distribution system in which the cooling power is not provided for the entire volume of the greenhouse, but only for the air volume surrounding the crop with a considerable saving of reduction of energy demand and an extremely efficient use of solar energy. The simulation study is based on the experimental data collected at the experimental center of the University of Bari, Southern Italy.
The aim of the work is to demonstrate that solar cooling system could provide significant energy-saving opportunities for cooling greenhouses allowing the reduction of primary energy consumption by exploiting the contemporaneity between the cooling requirements and the solar energy availability.

1. Introduction

The paper describes the implementation of a dynamic simulation model of a solar cooling plant applied for a greenhouse. The plant modeled has the purpose of maximize the solar energy use in the summer season for air conditioning of the greenhouse exploiting the coincidence between the peak demand and the period of greatest availability of solar energy. Renewable energy is an important resource for the energy and environmental retrofitting of rural buildings because heating and cooling systems powered by fossil fuels have a strong influence on the cost and environmental sustainability of agricultural production, particularly for greenhouse cultivation. The model can be used as a tool to support the design and dimensioning of the plant, they can be simulated the different behaviors of the system when the operating or control settings change, to optimize the values of the set-point in order to develop best control strategies for maximum primary energy savings.

1.1. Description of greenhouse and solar cooling plant

The greenhouses have the aim to obtain a high efficiency of production and quality of the products to be cultivated also in the case in which the external climatic conditions are not favorable. To do this it is necessary that the microclimate that influence the development of the plant is suitable for the type of crop. The climate control regulates the concentration of carbon dioxide and oxygen, the temperature, humidity, brightness and a number of other factors that must be present in balanced quantities. Very important are temperature and humidity. The first acts on the vital functions of the plant and is generally critical above 70 ° C and below 0 ° C. Outside these limits cultures die or hibernate. The amount of water vapor in the air has effects in growth, transpiration, fertilization of the flowers and in the case of high values, in the development of diseases or in the induction of physiological stress. Conversely a low value of humidity increases the transpiration impeding photosynthesis. Some values of temperature and humidity for optimal type of culture are shown in table 1:

Table 1. Temperature and humidity for optimal type of culture

Cultivation	Optimum temperature range	Optimum humidity range
Lettuce	14°C-18°C	60-80%
Peas	16°C-20°C	65-75%
Beets	18°C-22°C	60-70%
Celery	18°C-25°C	65-80%
Beans	18°C-30°C	60-75%
Tomatoes and pepperoni	20°C-25°C	50-60%
Cucumbers	20°C-25°C	70-90%
Eggplant	22°C-27°C	50-60%
Watermelon	23°C-28°C	65-75%
Melon	25°C-30°C	60-70%
Zucchini	25°C-35°C	65-80%

In the Mediterranean region it's more difficult cooling the greenhouse in summer than heating in the winter while for other climates the opposite occurs, so you have to use different techniques to achieve each time the most appropriate internal microclimates. The solar radiation induces a very high overheating of indoor air, linked to the material of which the greenhouse is made of. Such thermal overload must be eliminated by ensuring that the external temperature is lowered to the optimal values. The following figure shows the trend of the temperature inside and outside the greenhouse during daylight hours.

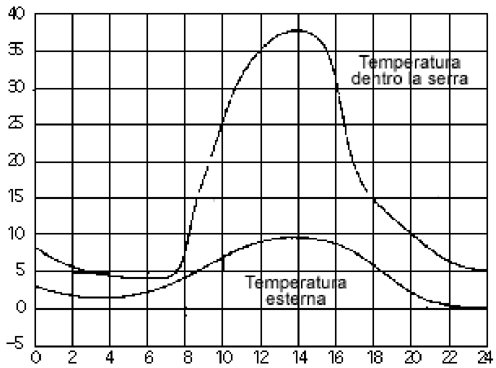

Fig. 1. Greenhouse inside and outside temperature

The experimental greenhouse is located in Valenzano (Bari, Italy) and is made of tubular galvanized steel, an arched roof type covered with plastic film, south-north oriented, having a covered area of 300 m2 (30 m in length, 10 m in width), 4.45 m high along the ridge and 2.45 m along the gutters (Fig. 2). The greenhouse covering film is an ethylene-vinyl acetate copolymer film (EVA), with a thickness of 200 µm, characterised by a solar total transmissivity coefficient of about 85-90% in the wavelength range 300–3,000 nm.
The cultivation of the plants takes place in plastic pots (1.00 m x 0.40 m x 0.40 m) with a growing substrate made of a mixture of soil and peat. The main component of the solar cooling plant are:
A solar field, placed on the ground and made of 18 evacuated tube collectors, (with a tilt angle of 30°) for a total area of 68 m²;
a hot tank with a global capacity of 1000 liters;
a single effect LiBr-H2O absorption chiller fed only by evacuated-tube solar collectors having a cooling capacity of 18 kW with a heat input of 25.1 kW, an electrical consumption of 1.45 kW, a COPthermal of 0.70;
a cooling tower with a heat rejection of 43 kW;
a cold tank with a global capacity of 500 liters;
dry cooler to dissipate the to dissipate the excess power produced by the solar field.

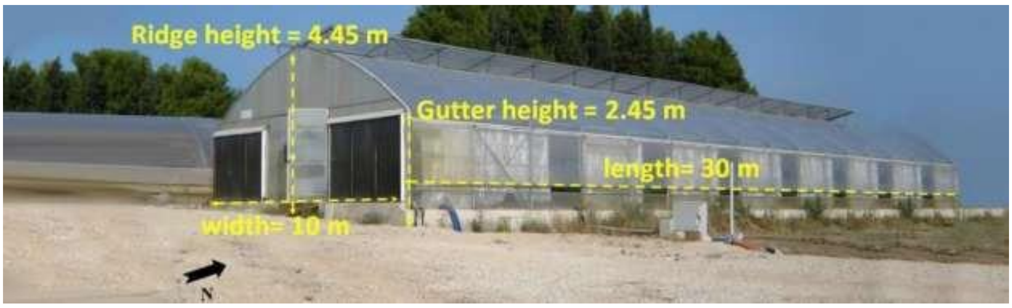

Fig. 2. Experimental green house

2. The model

The simulation model was developed in Matlab Simulink. This allows the use of various types of elements(blocks) in order to create models for simulating a dynamic system; that is, a system that can be represented by a model of differential equations or difference whose independent variable is time. Simulink interface allows to place the blocks, specify the setting parameters and interconnect multiple blocks to build models of systems more and more complex. The model processes the variables according to the sequential modular approach so that the output data of a component are used as input to the next component. To start the simulation, the user must specify a time step, a start time, a final time and an integration method. Signal values are updated during the simulation at each time step between the initial and the final step. The solar cooling model built was developed by connecting the various components (solar collectors, accumulation, absorption chiller, etc.) which in turn were created on the basis of physical equations related to their operation (Puglisi et al., 2014). Below the description of the models developed.

Solar collectors

The development of the model of the solar field started with the model configuration for the individual collector, based on the Bliss equation which expresses the efficiency of the collector as the ratio of the energy absorbed by the heat transfer fluid and the potentially exploitable from the sun; the equation was adapted to the characteristic of our plant by inserting some corrective correlations to consider: the different flow rates than those of tests defined by the relevant regulations, the number of collectors connected in series and the direction of the solar radiation not perpendicular to the surface of the solar radiation absorber (Duffie &Beckman., 2006).

Hot and cold tanks

The model was built on the hypothesis of perfect mixing with the uniform temperature in the whole tank . This temperature is variable as a function of time due to energy supplied or extracted during loading and unloading processes and to the interactions with the environment. The behavior of the tank is then described by an equation of energy balance in differential form. The control system is inserted in the model via an S-function in which the temperature of the tank, compared with that of reference and with that output temperatures of the solar circuit, is used to controls the activation of the circulation pump of the solar circuit.

2.1. Absorption chiller

The model is able to predict the cooling power delivered by the machine having as input the temperature of the inlet water to the absorber and the environmental conditions (temperature, humidity). The performance are obtained using the specifications provided by the manufacturer. Via a pair of lookup table have been implemented curves, parameterized for different water temperatures of exit from the cooling tower, these allow to obtain the thermal power input and the cooling produced, as a function of the hot water temperature supplied (Granryd et al, 2011).

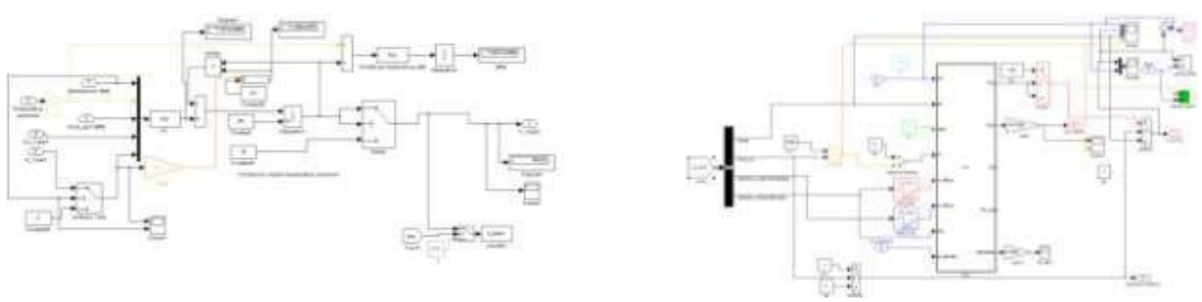

Fig. 3. Simulink model of solar collector (left) and tank (right)

3. Simulation results

Analysing the characteristics of the greenhouse, described above (Campiotti et al., 2014)the cooling power needed is about 110 kW and in the hypothesis of supplying this load with a solar cooling system, the solar collector surface required is about 350 m2.

The present study proposes a plant configuration with a distribution system in which the cooling power is not provided for the entire volume of the greenhouse, but only for the air volume surrounding the crop.
The cooling distributing system consists of various lines of pipes, positioned at the crop level, along the longest side of plastic pots, through which the cooled water circulates lowering the plant temperature. The resulted surface which must be cooled was estimated in 40 m2, with a maximum power of 18 kW. This evaluation led to determine the cooling load of the greenhouse from the data collected at the experimental centre of the University of Bari, which represent the cooling demand that the solar cooling model must supply.
Figures 5 and 6 show hourly trend of the cooling demand of the greenhouse and of the cooling power produced by the absorption chiller, given by Simulink simulation, for the period 1st April – 30th September.

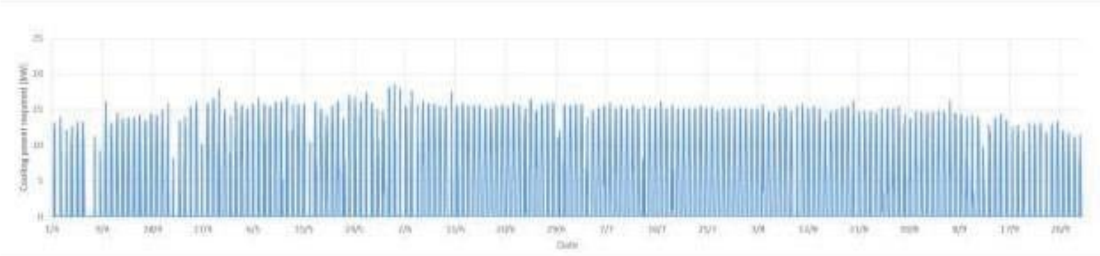

Fig. 5. Cooling power required [kW]

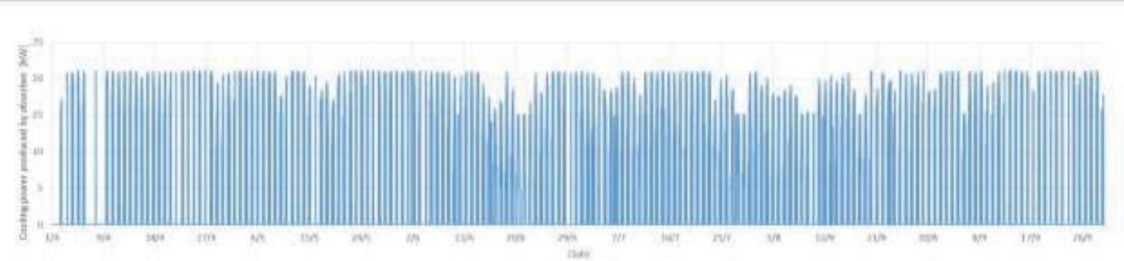

Fig. 6. Cooling power produced by absorber chiller [kW]

The figure 7 report the trend of the cold tank temperature for the period 1st April – 30th September.

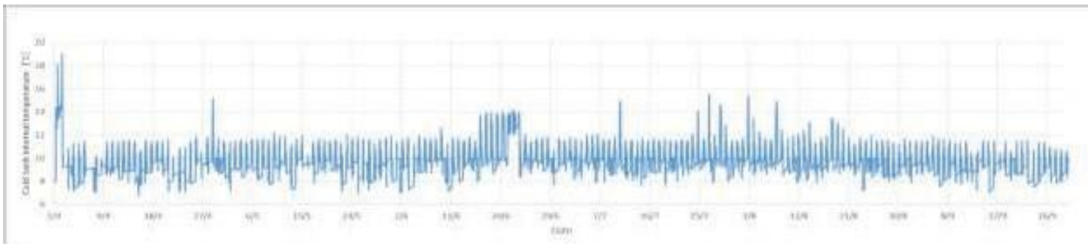

Fig. 7. Cold tank temperature trend [°C]

The three figures demonstrate that the model is able to supply the cooling demand every time step: the power generated is always higher then that demanded; furthermore the cold tank has a temperature included in a range [7- 12 °C] which guarantee that the system is well balanced from an energetic point of view because this range correspond to the work conditions of outlet water produced by absorption chiller.

4. Conclusions

The simulations performed confirm the correct design of the system and the choice of the size of the components. The model allowed to evaluate if the system was able to provide the cooling power needed, due to the delay between the onset of solar radiation and the cooling demand of the greenhouse. The dynamic model developed was therefore used as a tools for verification and confirmation of correct design and can be used as a platform to test new control and management strategies in order to minimize the consumption of primary energy.

In order to reduce primary energy consumption for cooling demand in greenhouse, a solution with a localised cooling system was analysed. The real efficiency of this method will be demonstrated experimentally in the plant described in the paper.

The solution proposed provide, as the simulation demonstrates, that solar cooling systems could provide significant energy-saving opportunities for cooling greenhouses allowing the reduction of primary energy consumption by exploiting the contemporaneity between the cooling requirements and the solar energy availability.

Acknowledgements

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"Identifying strategies for energy consumption reduction and energy efficiency improvement in fruit and vegetable producing cooperatives: a case study in the frame of TESLA project"

Abstract

TESLA (Transfering Energy Save Laid on Agroindustry) is a EU project pointing to the reduction of energy consumption and the improvement of energy efficiency in key agro-cfotoords'se cooperatives, as those processing fruit and vegetables. After a general analysis of energy consumptions during the first phase of the project, the processes responsible for the higher energy consumptions in these fruit and vegetable industries, as cold storage, have been identified. In the second phase of the project, a few case studies aimed at proposing customized solutions for reducing energy wastage and for improving energy efficiency in specific selected cooperatives have been performed. In this manuscript we report preliminary results of a case study carried out in an Italian horticulture cooperative having several production lines for fresh (1st range) and minimally processed (4th range) fruit and vegetable products. In this cooperative, an in-depth

energy audit has been performed, and additionally a process simulation software has been applied to model, evaluate and improve the operations in this processing centre and in the supply chain from the primary production sites. Such case study may be used as an example for similar cooperatives of the fruit and vegetables sector, thus contributing in making this sector more economically and energetically sustainable.

Keywords: fruit and vegetable sector; fruit and vegetable cooperatives; energy consumption; energy efficiency.

1. Introduction

In EU-28, fruit and vegetable sector represents a key sector in agriculture. Indeed, its production corresponds approximately to 17% of the total EU agricultural output value (with vegetables accounting for 10% and fruits for 7%), thus characterizing a substantial part of the agro-food consumption (European Parliament Study, 2015). A typical feature of most fruit and vegetable products that affect the whole sector (distribution in particular) is their high perishability (they represent high wasting food items); as a result, they have to be consumed soon after harvesting or have to be processed directly into a less perishable form after harvest. Evidently, for highly perishable products efficient logistics is more critical than for less perishable products (Bijman, 2012). Food safety is also an important issue in the fruit and vegetable sector, and since the consumption of fruit and vegetables is considered of crucial importance for public health, in order to prevent food safety risks, all stakeholders in the supply chain are obliged to apply either "Good Hygienic Practices" (GHP) at food primary production chain or "Hazard Analysis and Critical Control Points" (HACCP) systems at the food industry and distribution stages.

The cooperatives involved in this specific sector are implementing several innovations in order to meet customer changing needs and life habits. Besides fresh horticultural produce (1st range) – and excluding products obtained through higher energy-intensive elaboration, as for sterilized (2nd range) and frozen products (3rd range) –, several companies are marketing fresh-cut, packaged and ready-to-eat salads (4th range) that undergo minimally processing (MP) and that are becoming more and more coloured and differentiated in terms of fruit and/or vegetable ingredients. MP of fruit and vegetables allows the products to maintain their freshness without losing their nutritional quality, but at the same time these products should have a shelf-life sufficiently long to make their distribution feasible within the region of consumption (Siddiqui *et* 1*a*)*l*.., 201

Given the 2012 European Energy Efficiency Directive (EED), establishing that all EU countries are required to use energy more efficiently at all stages of the energy chain from its production to its final consumption, as well the growing cost of energy resources, several industries – including fruit and vegetable processing cooperatives – have to search for ways to minimize the consumption of energy, particularly heat energy. TESLA (Transfering Energy Save Laid on Agroindustry; www.teslaproject.org) is a 3-year lasting project (2013-2016) funded by the EU's Intelligent Energy - Europe programme (IEE/12/758/SI2.644752), which aims at reducing energy consumption and improving energy efficiency in agro-food cooperatives related to four specific agro-food sectors – namely, fruit and vegetable processing plants, olive oil mills, wineries and animal feed factories – from Spain, Italy, France and Portugal. In the frame of the TESLA project, an accurate study of typical fruit and vegetable cooperatives has been carried out in order to evaluate their energy consumptions. After a general analysis of (electrical and thermal) energy consumptions, based on literature as well as on real-life data proceeding from a number of energy audits that have been performed in some fruit and vegetable cooperatives dealing with fresh produce, the processes responsible for the higher energy consumptions in these food industries have been identified (TESLA project deliverables D.4.4 and D.6.6). In most cases, cold storage represents a key cost for cooperatives, due to the need of keeping cool a large area where fresh ingredients are stored.

Besides a more general analysis, TESLA project is performing a few case studies in specific selected cooperatives, aimed at proposing customized solutions for reducing energy wastage and for improving energy efficiency. Here we report preliminary results of a case study carried out in an Italian horticulture

cooperative having several production lines for 1st and 4th range products. In this cooperative, an in-depth energy audit has been performed, following an audit guide that has been developed during the first stage of the TESLA project (Section 3.1). The energy audit has allowed to the cooperative managers being aware of both their energy requirements and consumptions. Moreover, it has been possible to suggest specific measures aimed at reducing energy consumptions and improving energy efficiency as well as simultaneously improving operational efficiency. The tools and methodologies applied allow estimating the costs and payback times for the solution proposed.
Furthermore, the process simulation software SIMUL8 is being applied to model,

evaluate and improve the operations in the fruit and vegetable processing centre and in the supply chain from the primary production sites. In this way, more efficient solutions allowing energy savings, energy efficiency improvements and operational efficiency enhancements are being identified. This
case study will be used for proposing operations and supply chain management strategies that could be applied for improving energy efficiency and reducing excessive energy consumption in similar fruit and vegetable processing cooperatives, thus contributing also to make this sector more sustainable in both economic and environmental terms.

1. Fruit and vegetable producing cooperatives

1.1. *Description of production processes*

Fruit and vegetable producing cooperatives use to vary outstandingly in number and type of provided final products and services, depending on several factors such as the location and its climate conditions, number of employees, level of innovative technology introduced in the factory, etc… In the simplest case of fresh fruit and vegetable production (1st range) in processing cooperatives, common operating processes are: *i*) reception, *ii*) cleaning and drying, *iii*) sorting and calibration, *iv*) packaging and *v*) cooling conservation (TESLA project deliverable D.6.6). After harvesting from the primary production sites, the raw fruit and vegetable materials have to be transported as soon as possible to the storage area at the cooperative industry (pre-storage), where a preliminary check and evaluation of the sanitary state is performed during the reception phase. Next, in general, a
washing/cleaning process is carried out and then undesirable products are removed during a sorting process based on visible physical characteristics of the products. Finally, final transformed fresh products are packaged and kept in refrigerated areas before being delivered.
Minimally processed fruit and vegetables are cleaned, cut, appropriately packaged and commercialized as ready- to-eat products that have not been subjected to any thermal treatment and are preserved by relatively mild techniques. They can be maintained only for a limited time and under cold conditions (chilled storage). Additional operating processes occur in cooperatives handling with 4th range fruit and vegetables, such as: peeling or husking, slicing, chopping, blenching. In general, strict hygiene and good manufacturing practices are used and all processing occur at low temperatures. A particular attention has to be paid also to the washing water that has to have a good quality, with controlled sensory, microbiology, pH parameters and presence of mild additives for disinfection. To overcome the limitations of common sanitizing techniques, food industry is currently studying non-thermal techniques such as ozone based treatments, ultraviolet radiation, pulsed light, cold plasma, ultrasounds and novel packaging practices (*a*R*l*amos *et*., 2013).

1.2. *Energy consumption*

In the fruit and vegetable sector, the top energy-consuming processes are *a*) those requiring cooling and refrigeration by cold storage refrigerating equipment, which use to consume more than 20% of total electricity used for the obtainment of the final product, and *b*) those using thermal energy for heating, in

particular for drying horticultural products for industrial transformation and pasteurization of fruit juices, jams, canned tomatoes and other canned fruit and vegetables (not for fresh consumption), which use to consume more than 70% of total thermal energy required.
In cooperatives working with MP fruit and vegetables, the higher energy consumption is due to the maintenance of a 4°C temperature in processing areas and to the final conservation of the products after processing and before final users buy them. Furthermore, in MP production, the excessive use (and waste) of plastics, aluminum and this kind of materials used for its packaging and preserving may weight even more in terms of energy consumption when considering the indirect energy costs embedded in these materials. Research is putting a lot of efforts in proposing technology innovation using more sustainable packaging materials.

1. Case study: energy efficiency improvement in a fruit and vegetable cooperative

The “San Lidano” cooperative, located in the province of Latina (Lazio, Italy), has been considered in this case study. The cooperative was founded in 1997, but the plant installation (total surface about 1,000 m2) was completed in 2013. San Lidano has a production site specialized in the primary processing and packaging of fresh horticultural products (such as salads, chicory, carrots, spinach, tomatoes, cabbages, etc.), yielding about 3,650 tons as average annual production. Its main customer is represented by the large-scale retail chain.

Fig. 1. Schematic representation of the production processes in the San Lidano cooperative

products (such as salads, chicory, carrots, spinach, tomatoes, cabbages, etc.), yielding about 3,650 tons as average annual production. Its main customer is represented by the large-scale retail chain.
This cooperative undertakes a short and controlled production chain, as described below and represented in Figure 1.

- Production and Harvest: the cooperative is self-sufficient in terms of production, and the harvest occurs throughout the year, applying Good Agricultural Practices.
- Processing and Packaging: once raw materials arrive at the plant, their processing occurs within 24 hours using modern technologies for washing, sanitizing and packaging.
- Distribution and Commercialization: thanks to the strategic logistics of its facilities, the factory distributesand markets its products throughout Italy in the shortest possible time.

This cooperative may be considered as a “benchmark” for other fruit and vegetable producing cooperatives, and in fact it has shown to pay a lot of attention to environmental and sustainability issues. Just for example, all working areas are equipped for the collection of post-processing and washing water. This water, rich in vegetable wastes, is then conveyed to an external system for waste treatment.

Inside the cooperative installation, all processes have place in cooled warehouses, with a temperature between 5 and 15°C. Glycol at -12°C is used to cool the water pumped in the pipelines to the warehouses.

1.1. Energy audit performance

To reach the main goal of the TESLA project – that is to foster the knowledge and use of the best available practices for increasing energy efficiency and therefore energy savings –, the initial project activities have been related to the assessment of total energy consumptions by the targeted installations; indeed, 110 energy audits have been carried out in different agro-food cooperatives. Each energy audit has been performed in accordance to the methodological protocol set up at the beginning of the project, in conformity with the EN 16247:2012 standards. This is based mainly on collection of all useful information provided by cooperative managers and technical staff, and all measurements done by network analyzers and other devices (more information can be found in the Tesla project official web site: www.teslaproject.org). Each audit has been finalized in about 15 days of work, including 3- 4 visits to the cooperative installation.

In the San Lidano processing plant, the annual trend of energy consumption has been estimated, taking into account energy bills (electricity and natural gas) and reactive energy consumptions. The main energy sources used are electricity for motors and lighting (up to 92% of total energy consumption) and gasoil (LPG) for steam production in a drying tunnel (8% of total energy consumption). The whole activity in the plant has been split up in the main following production processes: raw material reception, cleaning and drying, packaging, cooling conservation, lighting, air conditioning of offices and dressing rooms for employees, compressed air production, forklifts loading and unloading, and vegetable waste recovery (see Fig. 2). For each process, electrical consumptions of the whole line and the main devices have been measured and analysed. Moreover, during the visits to the cooperative, an inventory of all characteristics of all motors has been implemented, thus gathering information about their power, cost, year of production, theoretical efficiency, and daily hours of operation.

The analysis of the data obtained from energy audit, resulted in the determination of: *i*) energy fluxes related to each different production process (Fig. 2); ii) real everage energy consumption per unit of product and per production phase; iii) assessment of real load factor and practical sizing of the motors (considering the real hours of operation and the power used); iv) assessment of the performance indicators to compare the case of study with other cooperative installations of the same agro-food sector (process-by-process through energy consumption per energy source, per process and per production line), and v) recommendation of measures for energy efficiency improvement.

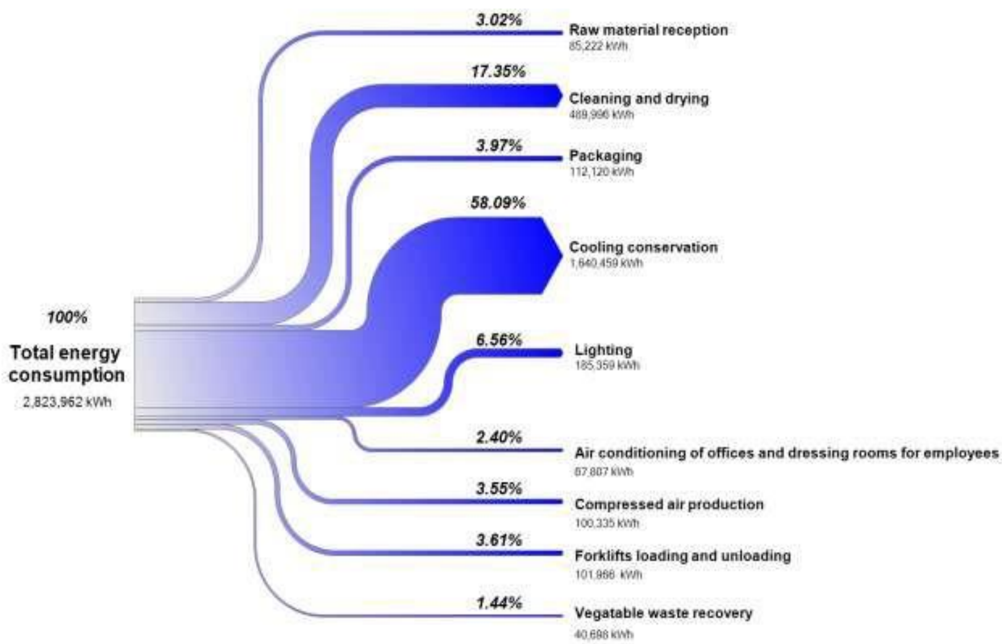

Fig. 2. Sankey diagram showing the average energy consumptions in the production processes of the audited fruit and vegetable cooperative.

The higher energy consumption is due to the cooling system, indeed the whole building is kept at low temperature given the lack of cold rooms and refrigerators. More in particular, one area is maintained at +4°C for the minimally processed products and a separated area is at +14-15°C for the raw material reception. Cooperative production is constant during all year, but the product types vary according to their seasonality. Since the cooperative already shows a high energy efficiency level, it has been necessary to recommend only few saving energy measures. In particular, the replacement of the actual lighting system made of neon lamps (low pressure gas discharge lamps) with a new lighting system based on LED could lead to an important economic saving. Anyway, considering the high investment required for the substitution all at once of the lighting system, the suggestion is to replace the lamps as they result damaged.

1.2. *Simulations for improving energy efficiency in operations and supply chain*

For identifying and assessing operational and supply management strategies aimed at achieving energy efficiency improvements, an approach based on the Lean & Green Systems Thinking has been applied. A Lean & Green Production System can be defined as a system designed for improving operational efficiency and sustainability simultaneously and continuously, in order to enhance radically the ability of either an organization or a supply chain for generating and delivering value to its customers and to the society as a whole. Continuous improvement cycles in a Lean Production System start by the understanding of the value needs of customers (and other key stakeholders) and, after this first step, the value flows

are analyzed with the objective of minimizing the eight Lean wastes. The eight Lean wastes are the following ones: *i*) overproduction; *ii*) defects; *iii*) unnecessary inventory; *iv*) transporting; v) waiting (idle people and machines); *vi*) inappropriate processing; *vii*) unnecessary motion; and *viii*) lost people potential (Zokaei *et al*., 2014).

On the other side, Green Production Systems could be defined as the result of applying a set of principles, strategies, methodologies and tools for identifying, quantifying, assessing and managing the flows of environmental wastes, which will be called Green Wastes.

It is also possible to identify eight Green Wastes: *i*) excessive energy consumption; *ii*) physical waste (solid or liquid); *iii*) excessive water usage; *iv*) air emissions (including greenhouse gases); *v*) land contamination; *vi*) discharges to water and effluent; *vii*) noise and nuisance; and *viii*) lost people potential (Zokaei *et al*., 2014).

One of the main methodologies used in the Lean & Green initiatives for the simultaneous and continuous reduction of the eight Lean Wastes and eight Green Wastes is the Sustainable Value Stream Mapping (Faulkner and Badurdeen, 2014). Because the TESLA project focuses on improving energy efficiency, the Sustainable Value Stream Mapping methodology applied is simplification of the Sus-VSM methodology proposed by Faulkner and Badurdeen (2014).

It only takes into account metrics for evaluating energy consumption, physical waste and carbon footprint as well as the usual Lean metrics for evaluating operational performance. For developing the Current Value Stream Map, the data collected in the energy audit are used. Since variation in operational data is especially high when processing fruit and vegetables, a risk environment for decision making has been assumed. For this reason, the Value Stream Maps are developed by using the simulation software SIMUL8, a simulation software of discrete events. Distributions are estimated by using experts' opinion, mainly the feedback provided by the managerial and technical staff of the cooperative and the energy efficiency auditor.

After developing the Current Value Stream Map, a visit to the cooperative was carried out for validating the developed model and identifying problems and improvement opportunities. In a meeting with the participation of the operations manager, the maintenance head, the energy auditor and researchers from UPM and ENEA, a major Lean & Green waste stream was identified. Periodically, the amount of products in process discarded by the optical selection equipment because of defective quality was excessively high. This was a waste both from a Lean perspective ("defects" and "waiting") and from a Green perspective ("physical waste", "excessive energy consumption", "excessive water usage", and higher carbon footprint of the final product). These products in process discarded by quality problems negatively affect to energy efficiency because we are using energy for processing products that cannot be delivered due to defective quality. After analyzing the whole supply chain and the primary production and manufacturing processes, it was concluded that the major causes of this Lean & Green waste were:

i) Excessive Inventory: Most of the clients of this cooperative are large retailers that frequently make orders with special features. This means that the cooperative has to be ready for processing these orders when they are received. For this reason, a variety of raw materials has to be maintained in the raw materials reception inventory as a buffer inventory. On the other hand, because of demanding quality requirements, raw materials have to be harvested in the "optimal" moment from an agronomical point of view. This fact also leads to higher inventories as well as to a decoupling between offer and demand that prevent implementing a full "pull systems" in the supply chain.

ii) Cold storage: The optimal conservation temperature of these kind products (lettuce and baby leaf) is 4 ºC. Higher temperatures lead to a faster deterioration. The storage area for raw products in this cooperative was at a temperature of 14-15 ºC.

This storage area is originally designed for short waiting periods (from truck unload until entering the process) but because of the abovementioned logistic issues, the waiting periods in this area are longer than expected and the temperature is far from the optimum. In addition, transport from the production areas (several raw materials suppliers are at distances up to 500km from the cooperative) is done at ambient temperature.

Future Stream Maps have being developed for evaluating the following operational and supply management strategies:

i) The implementation of automated quality control procedures for avoiding the entrance of defective raw materials in the processing area and the improvement of inventory management by using Communication and Information Technologies.

ii) The use of buffer inventories strategically situated in the production areas. The application of fast cooling technologies such the use of a vacuum cooling system, which is specially successful in the type of products studied (vegetables, lettuce and baby leaf), together with a cold storage at 4ºC, could allow reducing the decoupling between offer and demand. Raw materials will be send to the processing plant when needed trying to achieve a just in time delivery.

iii) Cold transport, or at least under isothermal conditions, for ensuring that the cold chain of the product is strictly maintained, from the field until the final product is delivered to the retailer.

Because these measures require an increase in energy consumption, this increase should be compensated with measures for reducing substantially energy consumption in the processing plant. A value chain perspective is needed for fulfilling the strategic goals of simultaneously reducing the energy consumption and improving the energy efficiency in the whole chain.

2. Conclusion

The fruit and vegetable sector presents peculiar features with respect to other agro-food sectors, such as the perishable nature of its products and their strong vulnerability to weather changes (abiotic and biotic challenges). The EU actively support this sector in several ways, for example by encouraging growers to join producer organizations in order to receive support for implementing operational programs. The TESLA project utilized this channel to investigate energy consumptions in several EU agro-food cooperatives and then to propose measures for improving energy efficiency and reducing energy costs in these cooperatives. Here, we have reported the case study of a modern fruit and vegetable producing cooperative, sensible to energy saving and environmental protection, in Italy. An energy audit of this cooperative has been followed by the application of Lean and Green methodological approach and interesting suggestions for improving energy efficiency and sustainability have emerged.

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"Green control of microclimate in buildings"
Abstract

In the Mediterranean area the solar heat gain in buildings needs to be controlled during the warm seasons in order to keep the internal temperature at comfortable levels and to mitigate the phenomenon of urban warming, known as Urban Heat Island. This phenomenon contributes to increase the outdoor pollutants concentration and the energy demand for air conditioning. Indoor microclimate conditions depend on several parameters related mainly to the building destination, envelope materials and orientation, its technological equipment, and to the specific region climate. The use of green shading can induce energy savings also in winter, by reducing heat losses from the external surface during mainly the night.
An experimental study was carried out at the University of Bari (Italy, 41 ° 05 'N, 16 ° 53 'E) from June 2014 to April 2015 with the aim of investigating the effective influences of this green passive system on a building vertical wall. Three vertical walls were built and equipped with a sealed structure on the backside; the walls were made with perforated bricks. The walls were covered with different evergreen climbing

plants: Pandorea jasminoides variegated for the first wall and Rhyncospermum jasminoides for the second one. A third wall was kept uncovered and used as control. A data logger and sensors were used to measure and collect the temperature of the wall, on the surface exposed to the solar radiation and on the inner surface protected by the sealed structure, the external air temperature, the wind speed and direction, the solar radiation falling on the wall. The experimental tests showed that during the daytime of warmest periods the use of the green walls allowed a reduction of the external surface temperature registered on the walls shielded by the green systems: the temperatures observed were lower than the respective temperatures of the control wall of about 3-4.5 °C. During the nighttime of coldest periods the use of the green wall allowed to keep the external surface temperature of the walls shielded by the green systems at values higher than the control wall ones: the temperatures observed were higher than the respective temperatures of the control wall of about 2-3 °C.

1. Introduction

Urban Green Infrastructures (UGI) have been recently defined as sets of man-made elements that can provide a range of environmental benefits at buildings and urban scales (Pérez et al., 2014). UGI comprise urban forests, street trees, parks, turf-grass, private gardens, green roofs and green walls. They play an important role in contributing to a range of ecosystem services such as improving aesthetically the environment to live and work, removing airborne pollutants and improving air quality, improving the habitat for invertebrates, birds, weeds and plants and promoting and increasing biodiversity, providing sound insulation and noise absorption, enhancing of storm-water management and water run-off quality (Cameron et al., 2014; Kohler and Poll, 2010; Rowe, 2011; Fernandez-CaĖero et al., 2013). Moreover, UGI contribute to the mitigation of the frequency and magnitude of the heat events due to urban heat island (UHI), to reduce the ambient temperatures, to improve human thermal comfort and to decrease energy loads on building (Pérez et al., 2014; Cameron et al., 2014; Norton et al., 2015). The UHI phenomenon induces negative outdoor comfort conditions, an increase of energy consumption for cooling, a raise of peak electricity demand, an increase in pollutants concentration and risks for human health (Karlessi et al, 2011; Jaffal et al., 2012; Kalkstein and Davis, 1989; Petralli et al., 2006).
Green roofs and green walls, as UGI, consist in the application of living vegetated horizontal and vertical layers on buildings with the main aim of reducing the energy consumption for air conditioning in summer and of increasing the thermal insulation in winter (Raji et al., 2015; Kanechi, et al., 2014; Blanusa et al., 2013; Cheng et al, 2010; Berardi et al, 2014; Fernandez-Canero et al, 2013; Santamouris, 2012; Vox et al., 2015). The design of green roofs and walls depends on factors as the building characteristics, the climatic conditions of the area and the surrounding conditions (Berardi et al, 2014; Fernandez-CaĖero et al., 2013; Santamouris, 2012; Perez at al., 2011; Perini et al., 2011; Francis and Lorimer, 2011; Jim and He, 2011; Fioretti et al., 2010; Castleton et al., 2010; Kontoleon and Eumorfopoulou, 2010; Spala et al., 2008) and their social, environmental and aesthetical positive impacts depend on the climatic conditions of the area, on the urban context, on the greening technology and on the building characteristics (Fioretti et al., 2010; Castleton et al., 2010; Wong et al., 2003; Perini et al., 2011; Wong et al., 2010; Berardi et al., 2014; Santamouris, 2012; Benvenuti, 2014; Rowe, 2011; Kohler, 2008; Francis and Lorimer, 2011; Fernandez-CaĖero et al., 2013). The use of vertical greenery in dense cities could be a promising solution to make cities more sustainable; green walls are a more appropriate solution for tall building typologies due to a high wall to roof ratio (Raji et al., 2015; Cheng et al., 2010).
The cooling effect of UGI is achieved by shading the buildings from solar radiation, by providing evapo-transpirative cooling, by reflecting the solar radiation, by thermally insulating the building with an air cavity, by influencing air speed on buildings (Hunter et al., 2014). The density of foliage and the coverage ratio highly affect the interception and the absorption of the solar radiation (shading effect) that induce a decrease of the external surface temperature (Raji et al., 2015). It has been found a linear correlation between the shading effect of a vertical greening system and the leaf area index: a denser greenery means a greater thermal insulation (Wong et al., 2009). The evapo-transpirative cooling effect leads to lower ambient environment temperatures and consequently to reduce the cooling load of the buildings (Wong et

al., 2010; Sunakorn and Yimprayoon, 2011). The air cavity between the green layer and the building wall acts as a thermal buffer able to reduce the heat losses through the building envelope (Raji et al., 2015).
Europe and North America are reported as the regions where green roofs can generate more benefits (Castleton et al., 2010; Refahi and Talkhabi, 2015) because they require low maintenance; nevertheless, in areas with lack of water and high summer temperatures, as in the Mediterranean region, some plants are unlikely to survive without intensive irrigation or without an adequate depth of the substrate (Castleton et al., 2010). More knowledge of greenery systems benefits and characteristics is needed and more research has to be undertaken into plant species suitable for the Mediterranean regions.
The main focus of this paper is to investigate the effective influences of two different climbing plants for green
vertical passive systems on a building wall. An experimental test was carried out at the University of Bari during different seasons, and surface temperatures and climatic data were evaluated in order to estimate the reduction of the wall surface temperatures equipped with the vertical greenery systems.

2. Materials and methods

The experimental test was carried out at the experimental farm of the University of Bari located in Valenzano (Bari, Italy; latitude 41° 05′ N, longitude 16° 53′ E, altitude 85 m ASL) from June 2014 to April 2015. Three vertical walls were built and equipped with a sealed structure on the backside with the aim of realizing some prototype of building vertical wall in scale. The walls were of the following dimensions: a width of 1.00 m, a height equal to 1.55 m, and a thickness of 0.20 m. They were south oriented. The walls were made with perforated bricks having 20 cm thick, 25 cm height and 25 cm length. The wall made of perforated bricks is a commonly used technology of vertical closure for residential and rural construction in the Mediterranean regions. The brick used were characterized by an average weight of the masonry work (including plaster) equal to 695 kg m-3, a thermal conductivity 3 (following UNI EN 1745:2012) equal to 0.282 W m-1 K-1 and a specific heat capacity C equal to 840 J kg-1 K-1. The sealed structure built on the backside of the walls was made of sheets of expanded polystyrene, having a thermal conductivity equal to 0.037 Wm-2K-1 and a thickness of 30 mm. A blue shading net was positioned onto the sealed structure to reduce the effect of the incident solar radiation.
Two walls were covered with different evergreen climbing plants: Pandorea jasminoides variegated, and Rhyncospermum jasminoides; a third wall was kept uncovered and used as control (Fig. 1). The plants were transplanted on June 18, 2014. The support for the climbing plants is made of an iron net placed at a distance of about 15 cm from the wall. The irrigation method used for all the plants was the drip one and the fertilization was performed with N: P: K 12:12:12.

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

A data logger (CR10X, Campbell, Logan, USA) and sensors were used to measure and collect the temperature of the walls, on the surface exposed to the solar radiation and on the inner surface protected by the sealed structure, the temperature inside the sealed volume, and the external air temperature. The data were measured with a frequency of 60 s, were averaged every 15 min and stored in the data logger. The surface temperature of the wall on the inner side, the surface temperature of the external plaster exposed to solar radiation, and the indoor temperature were measured using thermistors (Tecno.el s.r.l. Formello, Rome, Italy), placed as shown in Figure 2. The external air temperature was measured by using an Hygroclip-S3 sensor (Rotronic, Zurich, Switzerland), adequately shielded from solar radiation.

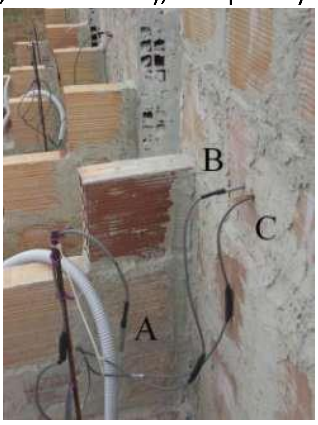


Figure 2: Location of the temperature sensors: sensor for the indoor temperature inside the volume behind each wall (A), sensor for the surface temperature of the wall on the inner side (B), sensor for the surface temperature of the external plaster exposed to the solar radiation (C).

3. Results and Discussion

The field observations showed that the plants covered sufficiently the walls from mid August 2014, even if Pandorea jasminoides variegated was more widespread than Rhyncospermum jasminoides. During summertime, the presence of vegetation mitigates the quantity of solar radiation absorbed by the walls reducing the temperature of the plaster of the external walls covered by climbing plants respect to the control wall; a difference up to 4 °C was recorded between the highest temperatures measured for the control and for the walls covered with plants (data shown in Vox et al., 2015).

Tables 1 and 2 show the average values of the maximum and minimum daily surface temperatures of the external plaster of the walls exposed to solar radiation in the cold period, from October 2014 to February 2015. In the examined period, the average values of the maximum surface temperature of the control, i.e. recorded on the wall not covered with plants, were always higher than the average values of the maximum surface temperature recorded for the vertical walls covered with Rhyncospermum jasminoides and Pandorea jasminoides variegated.
T h e differences between the highest temperatures recorded for the control and for the wall covered with plants ranged from 2.7 to 4.4 °C. The average values of the minimum surface temperature of the control wall was always lower than the temperatures recorded for the walls covered with plants. In wintertime the presence of vegetation increase the thermal insulation of the wall. The differences between the lower temperatures recorded for the control and for the wall covered with plants ranged from 2.4 to 2.8 °C (Fig. 3).

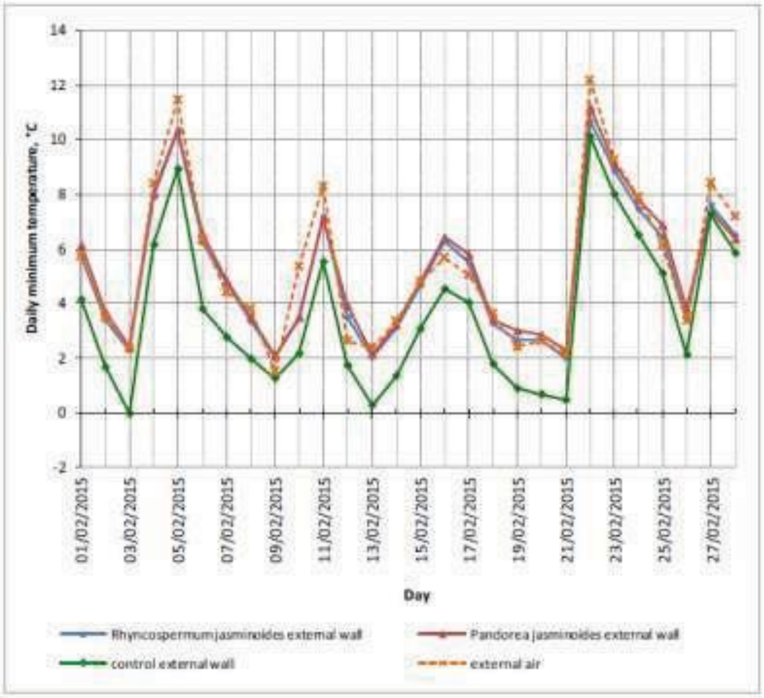
Table 1 Average values of the maximum daily external air temperature and surface temperature of the external plaster of the three walls exposed to solar radiation from October 2014 to February 2015.

Exposition period	Maximum temperatures			
	Rhyncospermum jasminoides external wall (°C)	Pandorea jasminoides variegated external wall (°C)	control external wall (°C)	external air (°C)
october 2014	24.0	22.5	25.1	23.9
november 2014	20.3	19.1	20.7	20.2
december 2014	16.2	14.6	16.4	15.1
january 2015	15.1	13.7	15.4	14.2
february 2015	13.6	12.5	14.1	14.1

Table 2: Average values of the minimum daily external air temperature and surface temperature of the external plaster of the three walls exposed to solar radiation from October 2014 to February 2015.

Exposition period	Minimum temperatures			
	Rhyncospermum jasminoides external wall (°C)	Pandorea jasminoides variegated external wall (°C)	control external wall (°C)	external air (°C)
october 2014	14.2	14.3	13.1	14.0
november 2014	12.2	12.5	10.9	12.1
december 2014	7.3	7.5	5.9	7.0
january 2015	5.4	5.3	4.0	5.4
february 2015	5.1	5.3	3.7	5.4

Figure 3: Daily minimum surface temperature of the external plaster of the three walls exposed to solar radiation and daily maximum external air temperature measured during February 2015.



4. Conclusions

The experimental test was conducted on vegetated vertical systems from August 2014 to February 2015 in South Italy taking into consideration both warm and cold periods. The application of the green walls during warm months allowed cutting the heat gain due to solar radiation by reducing the external surface temperature in daytime hours up to 4.4 °C. The use of the green walls during cold months allowed increasing the thermal insulation performance of the walls by keeping the external surface temperature in nighttime hours up to about 2.8 °C over the surface temperature of the wall not covered with plants.
Green roofs and vertical greenery popularity is growing because of their high potential to be used as sustainable solution for enhancing the thermal performance of building envelopes and for reducing energy consumption in the sector of residential and rural constructions in the Mediterranean area. Like other forms of green infrastructure, they offer many ecosystem services like the mitigation of the urban heat island effect, the creation of natural habitats for improving urban biodiversity, noise attenuation, improved air quality and aesthetical impact of constructed areas. Moreover the greening technology offers the additional benefits of reducing the energy consumption for air conditioning in summer and increasing the thermal insulation in winter

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"Environmental impact of Green roofing: the contribute of a green roof to the sustainable use of natural resources in a life cycle approach"

Abstract

Even if several studies and researches have demonstrated that green roofs significantly contribute to energy saving, indoor thermal comfort, urban heat island mitigation, rain-water management and air pollution reduction, environmental benefits of green roofs mainly depend on use of primary energy, natural resources or raw materials used in the construction.
A green roof is usually a more or less complex aggregation of different layer addressing each one to a specific characteristic and performance.
Results of previous LCA researches, based on a cold climate scenario, have demonstrated the highest influence that some specific layers have on the overall impact of the green roofs and to what extent the global impact changes when insulation and the substrate layers vary in density and quality.
Starting from results of these similar EU researches, this study aims to evaluate the variation of the overall impact in hot climates
where insulation is less strategic than heat capacity.
LCA has been applied to assess and compare the environmental impacts of four different green roof solutions compared to a standard clay pitched roof, based on the functional unit of 1m2 with the same reference service life, where layers have been selected according to local practice and market. Despite a general equivalence in environmental impacts of all the roofing elements, results have highlighted a general lack in specific life cycle inventory information that leads to a potential inaccuracy
of the assessment especially when recycled material are used in the growing medium or when disposal scenario includes recycle processes.

Nomenclature	
GWP	Global Warming Potential
AP	Acidification for soil and water
EP	Eutrophication
ODP	Ozone Depletion
POCP	Photochemical ozone creation
[ADP-element]	Depletion of abiotic resources-element
[ADP fossil fules]	Depletion of abiotic resources – fossil fuels
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
RSL	Reference Service Life
DSL	Design Service Life
FU	Functional Unit

1. Introduction

Green roofs are considered as a solution to many urban issues including urban heat island mitigation, noise and air pollution reduction, storm-water management and support of biodiversity and are quite often addressed as the best building choice to increase the environmental sustainability in an urban setting. Recent initiative at European level (CEN TC 350 WG1) also promote a benefit for those building covered by a green roof as a reduction in Land use impact.
Generally speaking, it is now quite clear that green roofs can be used to reduce or mitigate issues as urban heat island effect, water runoff, air and water quality (Liu et al., 2003; Wong et al., 2003).
Most of the reasons that stop building owners in building a green roof lay in the idea that beside the initial costs, cost form maintenance of green roof during the life cycle of the building are quite high. In fact, some studies have demonstrated that intensive or deep soil roof systems have a higher life cycle cost (LCC) than conventional practice (Wong et al., 2003), but this is not always true for extensive green roof system that might cost less than a conventional roof.
Moreover, considering that the European Regulation on Energy Efficiency 31/2010 drives to nearly zero energy building, energy and resources consumption in buildings are in a near future primarily due to the building material. More than the energy consumption in use, the environmental impact of the building materials becomes therefore an urgent performance to be evaluated in a life cycle perspective. Even environmental impacts due to energy consumption during the use phase of the building have been drastically reduced in the last 10 years, compared to data by Saiz et al. (2006), the estimation that the use represents approximately 80% to 90% of the life-cycle energy use, while 10% to 20% is consumed by the material extraction and production, and less than 1% through end-of-life treatments (Sartori at al., 2007) is still not so far from the realty, especially in Mediterranean climate where conventional building dates back to ’50es and ‘60es.

2. Case study

A single-floor social housing building, located in Pisa (Lat 43°40’ N Long. 10°23’ E) has been selected as case study. The building is E-W oriented and it has insulated brick masonry walls (U=0.32 Wm-2K-1) and a pitched clay roof.
Aims of the study were to assess the potential environmental benefits or loads, over the life cycle of the building, when the standard pitched roof is replaced by different types of green roofs. The energy performance of the building is not taken into account since the use phase B6 (operational energy in use) is not part of the assessment.
Therefore, building elements others than the roof floor, as external and internal walls and floors, have been not considered in the life cycle assessment (LCA) since they are invariant.

Table 1. Roof types used for the life cycle assessment (LCA).

Pitched roof	Extensive Green roof HD	Extensive Green roof LD	Intensive Green roof HD	Intensive Green roof RC
	Sedum	Sedum	Sedum	Grass
	Medium A 80 mm	Medium B 80 mm	Medium C 150 mm	Medium D 150 mm
Clay roof tiles	Filter layer	Filter layer	Filter layer	Filter layer
Ventilated air cavity 60 mm	Drainage/insulation EPD 80mm	Drainage/insulation EPD 80 mm	Drainage/insulation layer EPD 80 mm	Drainage/insulation layer EPD 62 mm
Thermal insulation EPS 80mm	Root barrier	Root barrier	Root barrier	Root barrier
Light concrete screed mm	Light concrete screed mm	Light concrete screed mm	Light concrete screed 40 mm	Light concrete screed mm
Clay blocks floor slab 160 mm	Clay blocks floor slab 160 mm	Clay blocks floor slab 160 mm	Clay blocks floor slab 160 mm	Clay blocks floor slab 160 mm
Plaster 15 mm	Plaster 15 mm	Plaster 15 mm	Plaster 15 mm	Plaster 15 mm

The green roofs differ because of the depth and type of medium soil, that distinguish from an extensive type and an intensive type. An extensive green roof system is characterized by its vegetation, ranging from sedums to small grasses herbs and flowering herbaceous plants (maximum high 25cm), which need little maintenance and no permanent irrigation system. The growing medium depth for an extensive green roof system is typically 3÷15cm, and is not considered as a walk area. These systems are ideal for efficient storm water management with low maintenance needs.

An intensive green roof system is characterized by its variety of vegetation ranging from herbaceous plants to small trees with professional maintenance and a regular irrigation system. A typical growing medium depth of an intensive green roof is 15÷30 cm. Intensive green roofs offer a great potential for design and biodiversity, and the plant selection, and design greatly affect the maintenance required for the upkeep of these roofs.

The quality of the medium (density, grain size, mix) strongly influences the whole the green roof performance: a green layer on a roof slab is exposed to extremely hard conditions (solar irradiation, high temperature, wind, heavy rainfalls, etc.) and a wrong medium selection could compromise a reliable and long-lasting performance, with reference to drainage, waterproofing, thermal insulation/thermal mass, quality of greenery, and maintenance costs. The medium is the layer where the plants take the nutrients from, and it is the fundamental element of the green-roof system.

That’s why this research focuses on the growing medium soil taken as the variable parameter of the system, in order to evaluate the relevance of different types of medium on the environmental impact of a green roof.

Table 2. different types of medium soil.

Medium A	**Medium B**	**Medium C**	**Medium D**
878 kg m^{-3}	500 kg m^{-3}	904 kg m^{-3}	1000 kg m^{-3}
Pumice 75%	Pumice 20%	Pumice 25%	Expanded clay 10%
Lapillum 15%	Lapillus 64%	Lapillum 60%	Recycled bricks 80%
Compost 10%	Zeolithe 0.5%	Compost 15%	Compost 10%
	Peat 14%		

The growing medium layout description refers to technical information provided by commercial companies directly, but it is mostly based on literature (Bozorg Chenani et al., 2015; Peri et al., 2012) since the original recipe of the medium is part of the company strategy and is generally confidential.

3. LCA method and inventory

The LCA methodology as stated by the recent European standard EN 15804 (2012) , Annex A1 (2013) has been used to assess the environmental impacts of different types of green roof compared to a standard pitched roof, over a Reference Service Life (RSL) of 40 years (Roofscapes, 2002).

The RSL has been defined according to the shortest life span of the materials used (primary the waterproofing membrane), assuming then that none of the green roof layers (the root barrier, the protection layer, the drainage/water retention layer, the filter layer, and the substrate) are replaced during the service life and that they fulfill their basic functional requirement all over the life span. We assumed the same for all the pitched roofs materials.
Therefore the Functional Unit FU has been defined as the vertical projection of 1 m2 of roof with a RSL of 40
years.
In order to compare the flat green roof and the pitched roof, an 1 m2equivalent unit has been calculated for the pitched roof, so to consider the tilt angle of the pitched roof (16°).
According to the modular approach introduced by the standard, the life cycle assessment has been carried out per modules and, specifically:

- Module A1-A3 Production
- Module A4 ‐ Transport to building site
- Module C2-C4 End of life

Module A1 to A3 includes all the info and LCI data related to the raw material extraction and processing, processing of secondary material input, transport to the manufacturer, manufacturing.
Module A4 describes the environmental impacts related to the transport to the building site.
Use phase from B1 to B7 have been not considered, even if phase B7 Operational water use could be relevant in assessing the resource use impact of green roofs in very hot and dry climate. In the LCA includes module B, during the use phase, extra growing medium added due to the natural run-off and the use of fertilizers shall be also considered in stage B2 Maintenance, including relative emissions from the substrate (Akiyama et al., 2000; Ciarlo et al., 2008) and potential leakage to water.
Module C2 to C4, after the demolition stage, describe transport to waste processing, waste processing for reuse, recovery and/or recycling and or final disposal.
Moreover, module D "Benefit and loads beyond the system boundaries" has been not considered due to the difficulties of defining a real scenario of reuse o recycle for most of the materials. This could lead to potentially underestimate benefit of choosing a pitched roof (clay roof tiles can be 90% recycled) but has no consequence for the green roof comparison since there are no significant differences in the four cases concerning recycle beyond the end of life stage. Even the incineration of some of the green roof layers involves an energy recovery process, there are no substantial variances in quantities that could lead to specific potential impact reduction.
The five LCA roofing scenario are described in following. The clay block slab layout is not reported in the tables even it has been considered in the LCA assessment.

Table 3. Pitched Roof - LCA scenario

Pitched roof	LCA process	Transport scenario A4	Transport scenario C3	End of life scenario
Clay roof tiles	Clay roof tile / LATERLIFE	10 km	8 km	Recycling clay roof tiles
Ventilated air cavity 60 mm	--			
Wood Frame 60 mm	Soft wood, planed, air dried	10 km	25 km	Disposal, wood untreated to municipal incineration /LATERLIFE
Waterproof barrier	Polymeric membrane HDPE / LATERLIFE	10 km	25 km	Disposal polyethylene to municipal incineration /LATERLIFE
Thermal insulation EPS 50 mm	Thermal insulation EPS LD / LATERLIFE	10 km	25 km	Disposal polystyrene to municipal incineration /LATERLIFE

Table 4. Extensive Green roof Low Density medium - LCA scenario.

Extensive Green roof LD	LCA process	Transport scenario A4	Transport scenario C3	End of life scenario
Sedum				
Medium B 80 mm	Pumice, at mine Zeolite /ETH U Peat, at mine /NORDEL U Compost, at plant/CH U	35 km	12 km	Disposal, inert material to sanitary landfill
Filter layer 1.30 mm	Polymeric membrane HDPE / LATERLIFE	35 km	25 km	Disposal polyethylene to municipal incineration
Drainage/insulation layer EPS 80 mm	Thermal insulation EPS LD / LATERLIFE	35 km	25 km	Disposal polystyrene to municipal incineration
Root barrier	Bituminous membrane / LATERLIFE	35 km	25 km	Disposal polyethylene to municipal incineration

Table 5. Extensive Green roof High Density medium - LCA scenario.

Extensive Green roof HD	LCA process	Transport scenario A4	Transport scenario C3	End of life scenario
Sedum				
Medium A 80 mm	Pumice, at mine Compost, at plant/CH U	35 km	12 km	Disposal, inert material to sanitary landfill
Filter layer 1.30 mm	Polymeric membrane HDPE / LATERLIFE	35 km	25 km	Disposal polyethylene to municipal incineration
Drainage/insulation layer EPS 80mm	Thermal insulation EPS LD / LATERLIFE	35 km	25 km	Disposal polystyrene to municipal incineration
Root barrier	Bituminous membrane / LATERLIFE	35 km	25 km	Disposal polyethylene to municipal incineration

Table 6. Intensive Green roof High Density medium - LCA scenario.

Intensive Green roof HD	LCA process	Transport scenario A4	Transport scenario C3	End of life scenario
Grass				
Medium C 30 mm	Pumice, at mine Compost, at plant/CH U	35 km	12 km	Disposal, inert material to sanitary landfill
Medium C 150 mm	Pumice, at mine Compost, at plant/CH U	35 km	12 km	Disposal, inert material to sanitary landfill
Filter layer 1.45 mm	Polymeric membrane HDPE / LATERLIFE	35 km	25 km	Disposal polyethylene to municipal incineration
Drainage/insulation layer EPS 62 mm	Thermal insulation EPS LD / LATERLIFE	35 km	25 km	Disposal polystyrene to municipal incineration
Root barrier	Bituminous membrane / LATERLIFE	35 km	25 km	Disposal polyethylene to municipal incineration

Table 7. Intensive Green roof medium with recycled materials - LCA scenario.

Intensive Green roof RC	LCA process	Transport scenario A4	Transport scenario C3	End of life scenario
Grass				
Medium C 30mm	Pumice, at mine Compost, at plant/CH U	35 km	12 km	Disposal, inert material to sanitary landfill
Medium D 150mm	Expanded Clay Recycled bricks /LATERLIFE Compost, at plant /CH U	10 km 8 km 17 km	12 km	Disposal, inert material to sanitary landfill
Filter layer 1.45mm	Polymeric membrane HDPE / LATERLIFE	35 km	25 km	Disposal polyethylene to municipal incineration
Drainage/insulation layer EPS 62mm	Thermal insulation EPS LD / LATERLIFE	35 km	25 km	Disposal polystyrene to municipal incineration
Root barrier	Bituminous membrane / LATERLIFE	35 km	25 km	Disposal polyethylene to municipal incineration

SimaPro® software has been used to calculate the life cycle impact and two databases have been used: The international Ecoinvent system processes and Industry Database 2.2 and the Italian LCA database LATERLIFE developed by the Italian National Association of Brick Industries ANDIL LCA group of the University in Florence and running under the LATERLIFE software available at www.laterizio.it. All the processes in the Ecoinvent have been revised in accordance to the standard's requirements in terms of system boundaries and allocation rules.

Production phase scenario

Several difficulties occurred in collecting the LC inventory data and mostly for the production phase A1-A3 due to the lack of both specific and generic data in the database used for the assessment. Despite the database of building materials is quite complete, especially the LATERLIFE one, no information are promptly available about the growing medium or the substrate components. Inert substrate is usually a mix of volcanic materials, mainly made by Lapillus and Pumice and organic materials as compost or peat, where NPK fertilizers are added.
Largest approximation in the assessments is due to the fact that lapillus record misses from any database. Therefore pumice has been selected to represent both volcanic materials. While compost and peat are present in Ecoinvent, specific NPK fertilizer data have been modeled starting from title information and other technical information provided by producers. In order to evaluate the impact reduction potential due to the use of recycled aggregate in the growing medium, the Medium type D has been modeled using recycled bricks. These could be modeled as scraps from the primary clay brick production or waste processed at the end of life. Since there is no LCI data in SimaPro® software, a new record has been modeled considering the energy needed for sorting and crushing bricks after the demolition stage, as well as the emission in air during these phases but excluding any other impact related to the manufacturing process, including provision of virgin material.

Transport scenario

Building materials (bricks, concrete, wooden frame, plaster, expanded clay…) are supposed to be provided by a
single supplier as well as all the green roof layers, that comes from a company retailer in the area.
As regard the transportation to disposal, several waste processing and disposal site (landfill) are located close to the town of Pisa so the end of life scenario is based on a short distance from the building site (within 25 km). A road transport by truck has been considered for both. Transport scenarios to/from the building site are described in the previous Tables.

End of Life scenario

Defining the end of life scenario is the most sensitive and crucial part of the assessment. It is a quite difficult task due to the fact that most of these materials are not classified in the Waste European Catalogue and there are no specific and consistent data available about the collection, treatment, recycle and reuse of construction materials in Tuscany.
Scenarios for end of life and waste processing have been defined according to the real market contest near Pisa and have been derived from Romani (2014). Bricks and concrete scraps, from the roof slab, are recycled and both energy use and emission in air during the sorting and crushing operations have been taken into account. Sorting and crushing waste produced during the recycling process go to landfill. Two specific processes, one for bricks one for concrete scraps have been modeled in SimaPro® software since there were no generic data available. Data have been derived from different Ecoinvent processes: Disposal, building, cement fiber slab to recycling and Disposal, building, brick to recycling. These processes present an high level of uncertainty because the operation of demolition, transport to the sorting plant, handling and sorting are combined, and the modular approach proposed by EN 15804 has been ignored. Therefore is not possible to separate, as example, emission due to demolition and
transport from emissions released during sorting. The crushing phase is missing and it has been derived from the Ecoinvent process Limestone, crushing and washing. The polymeric membrane and the thermal insulation panel are treated in a incinerator for energy recovery and waste-specific air and water emissions from incineration, auxiliary material consumption for flue gas cleaning, short-term emissions to river water and long-term emissions to ground water from slag compartment (from bottom slag) and residual material

landfill (from solidified fly ashes and scrubber sludge) as well as the process energy are considered. Light concrete screed and plaster are sorted and then disposed to landfill.
Regarding the green roof layers, there are no regulations regarding the reuse of green roof soils in agriculture. As reported by Peri et al. (2012), incineration is excluded because the large amount of inert, and the sanitary landfill is the only waste processing available due to the potential/real presence of peat; thus, the different impact of disposal for the growing mediums comes only from different quantities.

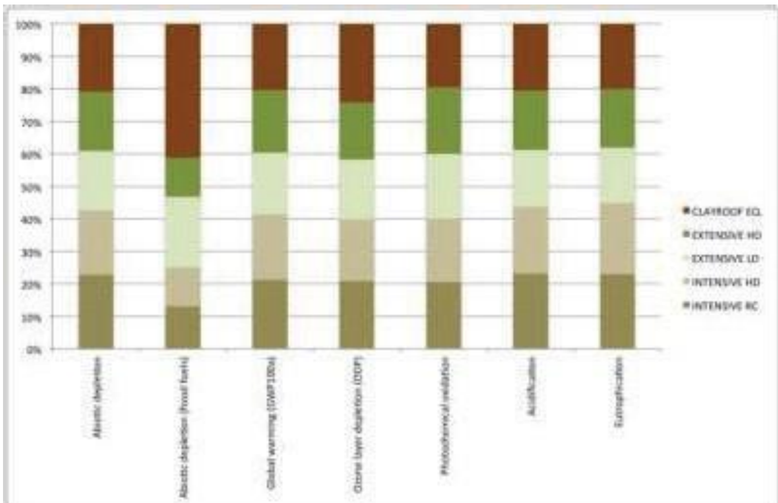
4. LCA Life Cycle Assessment

The life cycle assessment has been carried out using the CML –IA version 4.1, dated October 2012, according to EN 15804 Annex C, so to express the environmental impacts through the 7 parameters or core indicators as stated by the standard: Global Warming Potential (GWP), Ozone Depletion (ODP), Acidification for soil and water (AP), Eutrophication (EP) , Photochemical ozone creation POCP, Depletion of abiotic resources-element (ADP-element), Depletion of abiotic resources – fossil fuels (ADP_fossil fules).
Moreover, the standard introduces 10 parameters describing the resource use, based on the Life cycle Inventory LCI. In order to simplify the assessment, only two parameters Total use of non renewable primary energy resources and Total use of renewable primary energy resources have been calculated. The parameter Net use of fresh water is particularly relevant during the use phase of the life cycle of the green roof and in hot climate especially, where a regular daily irrigation is necessary to assure the vegetation survival and the thermal performance of the green roof. Since stages B1-B7 Use phase are not part of the assessment, this parameter has been not calculated.

5. Results and impacts

Comparison of the 5 different roof types shows that, despite any general comments, environmental impact of the different green roof sioonlustdon’t differ too much one from the others.
For almost all the impact categories excluded the two ones referring to the use of resources, all the indicators have the same magnitude, as shown in Fig. 1.
In general, green roofs have a lower impact compared to the clay pitched roof, especially on categories such as ADP-fossil fuels (- 20÷30%), and ODP (5-6%) while the average impact reduction amount to 5% for all the other impact categories, apart POCP (1%) and GWP (2%) (see Fig. 2).
For all the roof elements, the highest impacts come from the production phase.
For the clay tiled roof, impacts primarily comes from clay bricks and tiles and concrete because of the use of non renewable primary energy in the furnace and the use of natural resources that lead to high environmental impacts in ADP, GWP, AP and QDP.

Fig. 1.. LCA assessment. Comparison of results per roof type - LCA modules A1-A3, A4, C1-C3.



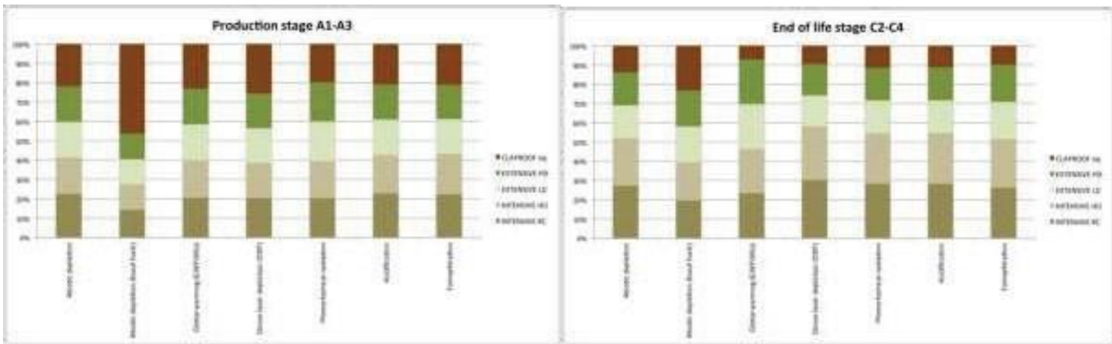


Fig. 2. LCA assessment. Comparison of results per roof type – (a) LCA modules A1-A3 Production on the left; (b) LCA modules C1-C3 End of life on the right

Table 8. LCA assessment impact indicators. Comparison of global impacts - LCA modules A1-A3, A4, C1-C3.

	Unit	INTENSIVE RC	INTENSIVE HD	EXTENSIVE LD	EXTENSIVE HD	CLAYROOF EQ.
Abiotic depletion	kg Sb eq.	2.63E-05	2.30E-05	2.10E-05	2.10E-05	2.41E-05
Abiotic depletion (fossil fuels)	MJ	1.18E+01	1.08E+01	1.96E+01	1.08E+01	3.73E+01
Global warming (GWP100y)	kg CO2 eq.	1.16E+02	1.10E+02	1.04E+02	1.05E+02	1.12E+02
Ozone layer depletion (ODP)	kg CFC-11 eq.	7.99E-06	7.21E-06	7.05E-06	6.71E-06	9.21E-06
Photochemical oxidation	kg C2H4 eq.	3.13E-02	2.96E-02	3.07E-02	3.11E-02	2.98E-02
Acidification	kg SO2 eq	3.52E-01	3.13E-01	2.66E-01	2.78E-01	3.11E-01
Eutrophication	kg PO4--- eq.	6.65E-02	6.30E-02	4.92E-02	5.26E-02	5.75E-02

For the extensive green roofs, both Low density (LD) and High density (HD) waterproofing membrane and the root barrier always count for GWP (9.5%), POD (44%) and ODP (20%), while, the growing medium B is primarily responsible for the ADP –fossil fuel in extensive green roof HD (see Fig. 3).
Growing medium B results having the lowest environmental impact for all the impact categories excluding ADP- fossil fuel and ODP. These two high impacts are caused by the Zeolithe (2.5 kg) and its sub-process related to Coal from underground mine.
For Intensive green roof, the growing medium counts for GWP (7÷15%), AP (15÷20%) and EP (20÷25%%) as also confirmed by Peri et al. (2012).

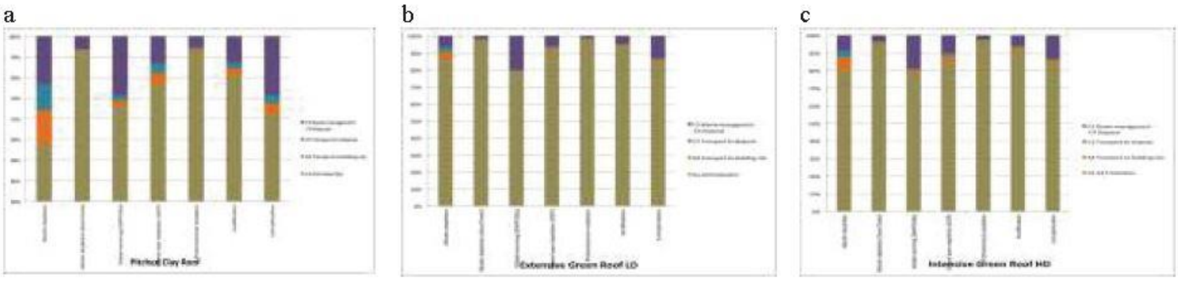


Fig. 3. A1-A3 Production stage. Comparison among three different solutions. (a) pitched roof; (b) Extensive green roof LD; (c) Intensive Green roof.

Considering that the environmental performances of the four green roof types don't differ too much one from the others, a detailed analysis of the growing medium impacts has been carried out, since this is the most consistent variation in the layout.
The use of recycled material in the sedum-base type assures a strong reduction of AP and GWP impacts due to the avoided impacts related to the use of recycled bricks instead of pumice, light clay or lapillus. In comparison to medium A, the one that has the lowest impacts for all the parameters,

medium D has a limited impact on ADP-fossil fuel, but it has a worse performance in terms of ADP-elements and all the other impact categories. These impacts are mainly due to the expanded clay production (even if it only consists in 10% of the substrate weight) and the electricity needed for crushing the bricks during the recycling process. Expanded clay is definitely a material to be carefully used in sustainable green roof, as already suggested by Borzog Chenani, et al. (2015).

6. Conclusions

This research doesn't consider the extra benefit due to the energy saving in use. Because the use phase B1-B7 has been not included in the LCA assessment.

Green roof could lead to a =10% saving in annual heating and cooling energy use (Ray et al., 2010) and

nominally 1÷2 % on the total building energy consumed (Saiz et al., 2006), but without taking into account these impacts, it seems to be still quite arbitrary to claim for a best green roof solution or to declare that green roofs are always lower impact then traditional roofing, especially in temperate mild-hot climate where such benefits are not quite significant, as reported by Fantozzi et al. (2015).

Using recycled roof tiles, that still have a large market in Italy as in other Mediterranean countries, or selecting insulation materials and waterproofing membrane made of recycled materials, the total impact of a standard roof could be significantly reduced and become closer, in terms of value, to the impact of a green roof.

Low maintenance costs of a clay roof should be also considered, because no replacement of the tiles are needed during the Design Service life of the roof, since the clay roof tiles have a 150 years life span. Replacement of insulation and waterproofing layer of a standard roof requires low energy and a very simple procedure.

Therefore, considering the benefit of a green roof in terms of comfort and energy saving but also taking into account the maintenance operations that are required to let the green roof perform in years at best, as described above (water consumption, use of fertilizers, replacement operation over 40 years, emissions to air and water), a proper design of the growing medium soil seems to be the most relevant and key element of a good green roof design.

This conclusion leads to a general request for more complete information about the growing medium available on the market since, without a detailed description of the formula, of the thermal and water retention properties, and the disposal requirements, a precise LCA or LCC assessment cannot be completed. Information about the chemical composition of the medium are brief and not specific and one of the most relevant material generally used for substrate, the lapillus, doesn't exist on the Ecoinvent database, so that any assessment is affected by a evident uncertainty due to the substitute process used instead of the proper one.

Different mix in substrate could lead to completely different impacts, so a deep study of present product is the base for the develop of new and more sustainable ones.

There is a large chance of improvement in the sustainability of green roof, especially during production and disposal phases and LCA could easily support the industries in defining lower impact solutions, in order to increase the amount of recycled materials that could be used for the growing medium and the membrane.

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"Evaluation of wall surface temperatures in green facades"

Green walls can be used to control the building microclimate as passive systems for energy saving. Three vertical walls were built at the University of Bari (Italy).
The first wall was covered with Pandorea jasminoides variegated and the second with Rhyncospermum jasminoides; the third wall was kept uncovered as a control. High-definition infrared images were recorded, and several climatic parameters concerning the walls and the ambient conditions were collected during the experimental test. The 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; the nighttime temperatures observed during cold days were higher than the respective temperatures of the control wall by up to 6·0°C. The effective thermal
resistance of the plants was calculated, using experimental data for a whole year; it ranged from 0·07 to 3·61m2 K/W.

Notation

C heat capacity, J/(kg K)
Q heat flux, W/m2
R thermal resistance, (m2 K)/W
T temperature (K)
l thermal conductivity, W/(m K)
Subscripts
bw bare wall
ext external
int internal
plant plant layer
s surface
vw vegetated wall

1. Introduction

The presence of urban green infrastructures (UGIs), such as urban forests, street trees, parks, turf grass, private gardens, green roofs and green walls, plays an important role in contributing to a broad range of ecosystem services. In cities or metropolitan areas, UGIs contribute to the mitigation of the urban heat island (UHI) effect –that is, a hotter urban area compared with the surrounding rural areas, with differences of air temperature of about 5–6°C (Berdahland Bretz, 1997; Bretz and Akbari, 1997; Bretz et al., 1998; Gentle et al., 2011; Gladis and Schumann, 2011; Jo et al., 2010; Joudi et al., 2013; Kanechi et al., 2014; Karlessi et al., 2011; Li et al., 2013, 2015;
Prado and Ferreira, 2005; Rowe, 2011; Synnefa et al., 2006; Uemoto et al., 2010; Zinzi et al., 2012). UGIs also reduce the ambient temperatures, improve human thermal comfort and decrease energy loads on buildings (Cameron et al., 2014; Campiotti et al., 2013; Fernandez-Cañero et al., 2013; Köhler and Poll, 2010; Norton et al., 2015; Pérez et al., 2014; Rowe, 2011). An UHI causes an increase in the use of air-conditioning systems and, consequently, an excessive energy consumption, a rise in air pollution and greenhouse gases' concentration in the atmosphere, poor levels of comfort outdoors and possible threats to human health (Jaffal et al., 2012; Kalkstein and Davis, 1989; Karlessi et al., 2011; Petralli et al., 2006). The main factors contributing to the UHI phenomenon are: the use of non-reflective and water-resistant materials for building external surfaces; dense urbanisation geometry characterised by wide surfaces that can absorb incident and reflected solar radiation, contributing to radiation trapping and to wind speed reduction in the emerging urban canyons; and anthropogenic heat emitted from activities such as those of industrial processes, heating and cooling systems and motorised vehicular traffic (Ryu and Baik, 2012; Santamouris, 2012; Vox et al., 2016). Green roofs and green walls, as UGIs, are living vegetated horizontal and vertical layers positioned on the external envelope of the buildings aimed at energy consumption reduction for air conditioning in summer and thermal insulation increment in

winter (Berardi et al., 2014; Fernandez-Cañero et al., 2013; Santamouris, 2012; Schettini et al., 2015, 2016).

Green vertical systems can be employed as a passive sustainable technology for mitigating the UHI effect and also for enhancing the energy efficiency of buildings, in particular in dense urban areas, where buildings with a high wall-to-roof ratio offer large surface areas available for retrofitting (Cheng et al., 2010; Raji et al 2015). The cooling effect of greenery systems is obtained by intercepting and absorbing solar radiation; the resulting reduction in the buildings' solar heat gain implies less energy consumption for air cooling in summer. The evapotranspirative effect, generated from the plants and the substrate on their surroundings, leads to a cooler ambient temperature and consequently to reduction in the cooling load of the buildings (Raji et al., 2015; Sunakorn and Yimprayoon, 2011; Wong et al., 2010). The vegetation and the substrate layer can influence the thermal performance of the buildings in winter, acting as an insulation against wind, depending on the climate of the region and on the characteristics of the greenery system used (Berardi et al., 2014; Cheng et al., 2010; Fernandez-Cañero et al., 2013; Jim and He, 2011; Köhler and Poll, 2010; Pérez et al., 2011; Perini et al., 2011; Vox et al., 2015). The Mediterranean regions, characterised by hot and dry climates, are areas where greenery systems can produce benefits, due to the shading effect and to the high evapotranspiration rate of plants (Castleton et al., 2010; Raji et al., 2015). It is important to use vegetation characterised by low irrigation requirements in order to be suitable for the exposure conditions and for the specific weather conditions. Europe and North America are reported as the regions where green roofs can be profitably applied, requiring low maintenance (Castleton et al., 2010; Refahi and Talkhabi, 2015).

In the literature, experimental results on green walls relate to investigations of not more than 2 weeks during summertime, rather than the whole year, and simulation models often were not validated with real data (Hunter et al., 2014; Pérez et al., 2014; Raji et al., 2015). Few studies report the evaluation of the effects of green wall systems on energy savings, useful to define suitable plant species and options in regions characterised by the Mediterranean climate.

When studying the potential of green facades for energy savings, one of the most relevant parameters for comparison could be the registered abatement of the temperature of the building's external wall surface during daytime as an effect generated by the green layer (Pérez et al., 2014); actually, the building's external wall surface is the most commonly evaluated parameter (Hunter et al., 2014).

The aim of this paper is to examine the effects of two different climbing evergreen plants used as green vertical passive systems on building walls during a whole year. The field test was carried out at the University of Bari (Italy) in order to overcome the lack of literature on experimental data for a longer period in the Mediterranean region. Several climatic parameters concerning the walls and the ambient conditions were analysed for estimating the variations in the walls' surface temperature equipped with the greenery systems.

The effective thermal resistance of the green layer was evaluated as a useful tool for models in order to estimate internal climate and energy fluxes.

2. Materials and methods

The field test was carried out from June 2014 to March 2016 at the experimental farm of the University of Bari in Valenzano (Bari, Italy), at a latitude of 41° 050 N and a longitude of 16° 53 E and an altitude of 85 m above sea level. Three identical walls were made as a prototype of a commonly used vertical building closure in Mediterranean civil construction. The walls facing south were built using perforated bricks joined with mortar; they were characterised by a width of 1·00 m, a height of 1·55 m and a thickness of 0·22 m. The bricks have a thickness of 0·20 m, a height of 0·25 m and a length of 0·25 m, a thermal conductivity l (Uni, 2012) equal to 0·282 W/(m K), an average density of the masonry work (including plaster) equal to 695 kg/m3 and a specific heat capacity C equal to 840 J/(kg K).

The structures including the walls were insulated on the back side, setting up a sealed structure in order to better evaluate the influence of the vegetation layer on the wall; the insulating structure was made of sheets of expanded polystyrene, having a thickness of 30mm and a thermal conductivity of 0·037 W/(m

K). In order to reduce the effect of the incident solar radiation on the sealed structure, a shading net was positioned onto the structures.
Two different evergreen climbing plants were chosen as greenery vertical systems components (Figure 1): one wall was covered with Pandorea jasminoides variegated and the second with Rhyncospermum jasminoides; a third wall was kept uncovered asa control. A plant-supporting structure made of an iron net was placed at a distance of 15 cm from the vertical wall. The plants were transplanted on 18 June 2014. The plants were irrigated withthe drip method.
The experimental data were collected by means of a meteorological station consisting of a data logger (CR10X, Campbell, Logan, UT, USA) and several sensors for measuring different climatic parameters. The data were measured at a frequency of 60 s, averaged every 15 min and stored in the data logger. The solar radiation normal to the walls was measured using a pyranometer (model 8-48, Eppley Laboratory, Newport, RI, USA) in the wavelength range of 0·3–3·0 mm. The external air temperature was measured by using a Hygroclip-S3 sensor (Rotronic, Zurich, Switzerland); it was adequately shielded from solar radiation. The temperature of the external plaster surfaces exposed to the solar radiation (Figure 2) was measured using thermistors (Tecno.El S.r.l., Rome, Italy).
Statistical analyses were carried out with the CoStat software (CoHort Software, Monterey, CA, USA). One-way analysis of variance at a 95% probability level was carried out in order to compare mean temperature values; Duncan’s test was applied at a significance level equal to 0·05.
High-definition infrared images of the walls were recorded using a thermal infrared camera (model B660, Flir Systems, Burlington, ON, Canada) in order to analyse the surface temperatures both of the plant leaves and of the walls. The measurements were carried out setting an average value of emissivity equal to 0·95 for both P. jasminoides variegated and R. jasminoides; the emissivity value was set to 0·96 for the white plaster of the uncovered wall.

The effective thermal resistance of the plant layer (Rplant) is a metric for accounting the reductions in conductive heat transfer through the wall, in terms of additional resistance, as an effect of the vegetation layer (Susorova et al., 2013). The overall thermal resistance of the vegetated wall (Rvw) is the sum of Rplant and of the thermal resistance of the bare wall (Rbw). The heat fluxes through the bare (Qbw) and green walls (Qvw) were calculated by where Text,s,bw and Tint,s,bw are the external and internal surface temperatures of the bare wall (control), respectively, Rbw is the thermal resistance of the bricks and plaster (0·73 m2 K/W), and

Text,s,vw and Tint,s,vw are the external and internal surface temperatures of the vegetated walls, respectively (Susorova et al., 2013). In the steady-state hypothesis, Rvw and Rplant were estimated using the following equations Rplant was calculated for two cases: conditioned and unconditioned spaces. The difference between the external and internal surface temperatures of the wall, in the case of conditioned space, was calculated by setting the internal air temperature at 24°C during the warm months and at 20°C during the cold months; the internal air temperature of the space was assumed equal to the internal surface temperature. In unconditioned space, the measured values were used for $T_{ext,s}$ and $T_{int,s}$. 3.

Figure 1. The experimental structures: the wall covered with R. jasminoides (right), the wall with P. jasminoides variegated (middle) and the uncovered control wall (left).

Results and discussion

Data were collected at the experimental field from April 2015 to March 2016, during which the values of the external air temperature ranged from 1•7 to 41•4°C.

The greenery systems affected the wall surface temperatures mainly in the warm period, as shown by the thermal images of the walls' surfaces and of the plants recorded in the field (Figures 3 and 4).

Figure 3 shows the temperatures measured on 1 April 2015. The temperature of the leaves was influenced by the different exposure to the solar radiation;

on the whole, the leaves recorded an average temperature of 26·1°C, and the temperature of the plaster behind the plant was 22·2°C, while the average temperature of the uncovered wall was 23·7°C. Figure 4 shows the temperatures measured on 7 July 2015. The average temperature of the plants was 26·9°C, and the temperature of the covered plaster was 26·9°C, while the average temperature of the uncovered wall was 29·0°C.

Figure 2. Sensor for the measurement of the surface temperature of the external plaster

Figure 5 shows the temperatures of the external surface of the green walls and of the control wall, the external air temperature and the solar radiation normal to the surface on a summer day of July (8 July 2015), which was characterised by a maximum external air temperature equal to 40·7°C. The selected day was part of a heat wave event (Meehl and Tebaldi, 2004); the decrease in the air temperature around noon was related to an upward variation in the north wind speed. In the daytime the presence of the vegetation layer mitigated the temperature of the external plaster of the walls, in comparison with the temperature of the control wall.

On 8 July 2015, maximum temperature decreases of 4·2 and 4·7°C were recorded for the walls protected with *R. jasminoides* and *P. jasminoides* variegated, respectively; these were due to the plant shading effect and the evapotranspiration rate (Raji *et al*., 2015).

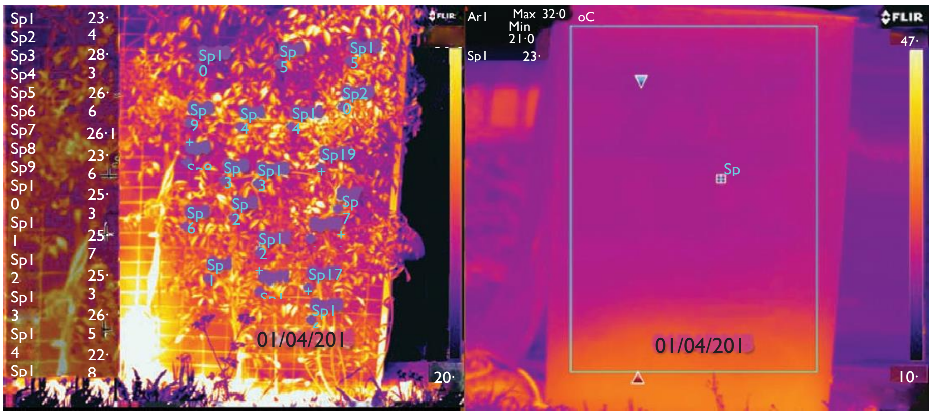

Figure 3. Thermal image of the control wall and of the green facade with *P. jasminoides* variegated, recorded on 1 April

The maximum reduction in temperature between the uncovered wall and the covered ones was equal to 9·0°C and was recorded on 31 August 2015 at 1.00 p.m. for the wall protected with *P. jasminoides* variegated. During non-heat-wave summer days, the maximum temperature decrease on the walls was about 4°C.

Pérez *et al*. (2014) reported the following reduction in the external building surface temperature: from 1·7 to 13°C in warm, temperate climate regions and from 7·9 to 16°C in snow climate regions in the case of a wall covered with traditional green facades during summertime. Susorova *et al*. (2014) reported an average decrease in the facade surface temperatures due to the presence of vegetation on the facade from 1·0 to 9·0°C during summer on the external surface. Chen *et al*. (2013) reported for a living wall system in a hot and humid climate a reduction in the exterior wall temperature by a maximum of 20·8°C and in the interior wall temperature by 7·7°C.

The mitigation of the wall surface temperature due to the plants was observed throughout the year; the monthly average values of the maximum daily temperatures shows that in the daytime the application of the greenery systems allowed the external surface temperature of the green walls to be maintained at values lower than those of the control wall; no significant difference was pointed out between the two plants (Table 1). The differences between the average values of the maximum daily temperatures recorded for the control and for the walls covered with the plants ranged between 1·6 and 5·0°C, the higher differences being recorded from July to September.

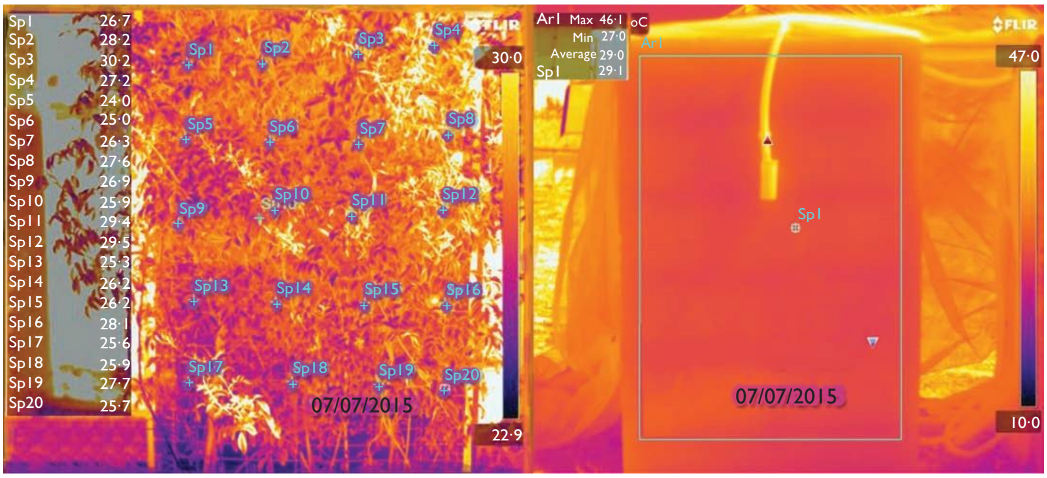

Figure 4. Thermal image of the control wall and of the green facade with *P. jasminoides*, recorded on 7 July 2015 at 9.30 a.m.

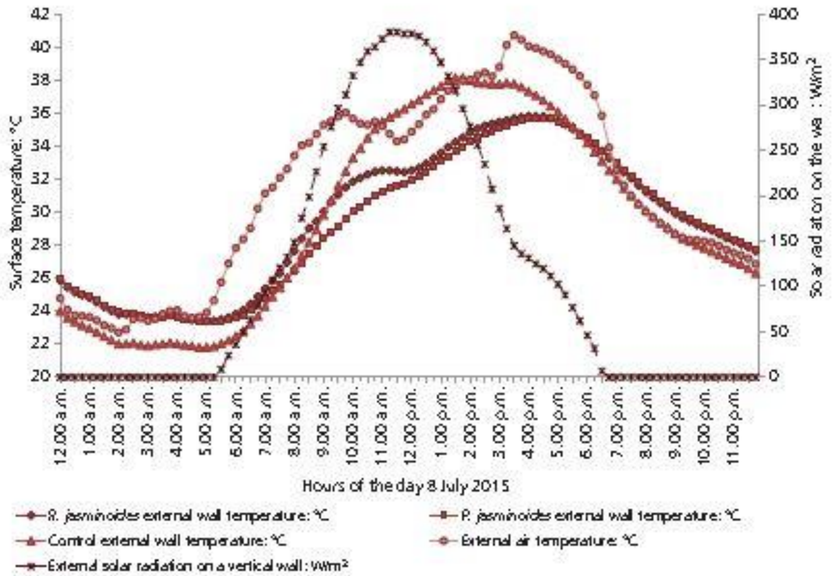

Figure 5. Surface temperatures of the external plaster exposed to solar radiation (external wall) of the three walls, external air temperature and solar radiation normal to the walls (secondary axis); data recorded on 8 July 2015

	April 2015	May 2015	June 2015	July 2015	August 2015	September 2015	October 2015	November 2015	December 2015	January 2016	February 2016	March 2016
	Average maximum daily temperature: °C											
R. jasminoides external wall	19·3^{a}	24·3^{b}	27·2^{b}	32·6^{c}	30·6^{c}	27·4^{b}	20·7^{b}	17·1^{b}	14·5^{c}	13·2^{b}	15·7^{c}	14·2^{b}
P. jasminoides variegated external wall	19·4^{a}	25·2^{b}	28·1^{b}	32·9^{c}	30·6^{c}	27·7^{b}	21·2^{b}	17·2^{b}	14·8^{bc}	13·2^{b}	16·0^{bc}	15·2^{b}
Control external wall	21·0^{a}	27·1^{a}	30·8^{a}	37·1^{a}	35·6^{a}	32·2^{a}	24·2^{a}	20·5^{a}	18·1^{a}	15·9^{a}	18·8^{a}	17·2^{a}
External air	21·3^{a}	27·7^{a}	30·5^{a}	35·8^{b}	33·8^{b}	30·6^{a}	23·6^{a}	19·1^{ab}	15·9^{b}	14·7^{ab}	17·6^{ab}	17·1^{a}
	Monthly cumulative solar radiation normal to the wall: MJ/m^2											
	330·2	291·5	269·5	304·1	343·9	356·9	320·8	320·8	331·1	289·2	298·1	275·7

Means in the same column with different superscript letters are significantly different ($P < 0·05$)

Table 1. Average values of the maximum daily external air temperature and surface temperature of the external plaster of the three walls exposed to solar radiation and cumulative solar radiation normal to the wall, April 2015–March 2016

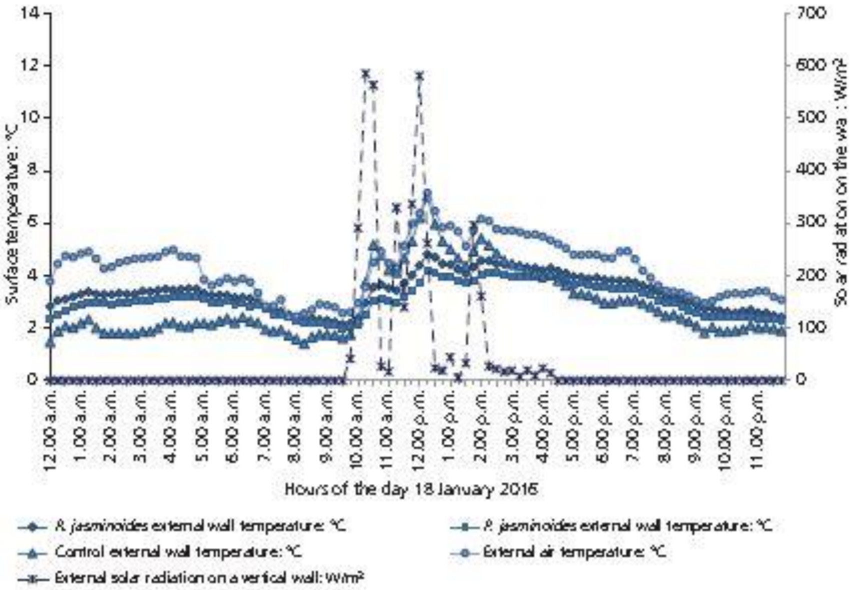

Figure 6. Surface temperatures of the external plaster exposed to solar radiation (external wall) of the three walls, external air temperature and solar radiation normal to the walls (secondary axis); data recorded on 18 January 2016

	April 2015	May 2015	June 2015	July 2015	August 2015	September 2015	October 2015	November 2015	December 2015	January 2016	February 2016	March 2016
	Average minimum daily temperature: °C											
R. jasminoides external wall	9·7^{a}	15·3^{a}	18·2^{a}	22·6^{a}	22·3^{a}	18·6^{a}	14·3^{a}	9·7^{a}	7·2^{a}	6·4^{a}	8·8^{a}	7·7^{a}
P. jasminoides variegated external wall	9·8^{a}	15·2^{a}	18·3^{a}	22·2^{a}	22·0^{ab}	18·3^{a}	14·2^{a}	9·7^{a}	7·1^{a}	6·3^{a}	8·8^{a}	7·8^{a}
Control external wall	8·4^{a}	13·8^{b}	16·8^{b}	21·1^{b}	21·1^{b}	17·4^{a}	13·1^{a}	8·2^{b}	5·6^{b}	4·8^{a}	7·3^{a}	6·5^{b}
External air	9·8^{a}	15·3^{a}	18·4^{a}	22·5^{a}	22·4^{a}	18·9^{a}	14·7^{a}	10·0^{a}	7·1^{a}	6·3^{a}	8·1^{a}	7·4^{ab}
	Monthly cumulative solar radiation normal to the wall: MJ/m^{2}											
	330·2	291·5	269·5	304·1	343·9	356·9	320·8	320·8	331·1	289·2	298·1	275·7

Means in the same column with different superscript letters are significantly different ($P < 0·05$)

Table 2. Average values of the minimum daily external air temperature and surface temperature of the external plaster of the three walls exposed to solar radiation and cumulative solar radiation normal to the wall, April 2015–March 2016

Figure 6 shows the temperatures of the wall external surface and of the external air, and the solar radiation normal to the wall on a winter's day in January (18 January 2016), which was cold and cloudy, as evidenced by the decreases in the walls' surface temperatures in the daytime, due to the presence of clouds. This day, part of a cold wave event, was characterised by a minimum external air temperature equal to 2·4°C; at nighttime the vegetation layer increased the insulation performance of the walls.

The highest increase in temperature of the external covered surface in comparison with the control, equal to

6·0°C, was recorded during a cold wave on 1 November 2015 at 4.15 a.m. for *P. jasminoides* variegated; in contrast, during non-cold-wave winter days, the maximum temperature increase on the walls was about 1·5°C.

The monthly average values of the minimum daily temperatures showed that at nighttime the application of the greenery systems kept the external surface temperature of the green walls at values higher than those of the control wall throughout the year;

No significant temperature difference was recorded between the surfaces covered with the two plants. The differences between the lowest mean temperatures recorded for the wall shielded with plants and the control ranged from 0·9 to 1·6°C (Table 2). The minimum surface temperature of the external plaster protected with the two green walls closely followed the daily minimum external air temperature.

The evaluation of the effect of the green walls in the different seasons is shown in Tables 3 and 4.

The differences between the highest temperatures recorded for the control and for the walls covered with the plants ranged between 1·9 and 4·6°C; the maximum difference was recorded in summer and the minimum in spring (Table 3).

	Average maximum daily temperature: °C			
	Spring 21/03/2015–20/06/2015	Summer 21/06/2015–20/09/2015	Autumn 21/09/2015–20/12/2015	Winter 21/12/2015–20/03/2016
R. jasminoides external wall	22·4^{b}	30·6^{c}	18·4^{c}	14·1^{b}
P. jasminoides variegated external wall	23·1^{b}	30·7^{c}	18·7^{c}	14·4^{b}
Control external wall	25·0^{a}	35·2^{a}	22·0^{a}	17·0^{a}
External air	25·3^{a}	33·8^{b}	20·7^{b}	16·0^{a}

Means in the same column with different superscript letters are significantly different ($P < 0·05$)

Table 3. Seasonal data of the average maximum values of the daily external air temperature and of the surface temperature of the walls' external plaster from spring 2015 to winter 2015–2016

The differences between the lowest temperatures recorded for the wall shielded with plants and the control varied in the range of 1·0–1·5°C; the minimum difference was recorded in summer, and the maximum difference was recorded in winter (Table 4).

	Average minimum daily temperature: °C			
	Spring 21/03/2015–20/06/2015	Summer 21/06/2015–20/09/2015	Autumn 21/09/2015–20/12/2015	Winter 21/12/2015–20/03/2016
R. jasminoides external wall	13·5^{a}	21·5^{a}	11·3^{a}	7·3^{a}
P. jasminoides variegated external wall	13·5^{a}	21·2^{a}	11·3^{a}	7·3^{a}
Control external wall	12·1^{b}	20·1^{b}	9·9^{b}	5·8^{b}
External air	13·6^{a}	21·6^{a}	11·6^{a}	7·0^{a}

Means in the same column with different superscript letters are significantly different ($P < 0·05$)

Table 4. Seasonal data of the average minimum values of the daily external air temperature and of the surface temperature of the walls' external plaster from spring 2015 to winter 2015–2016

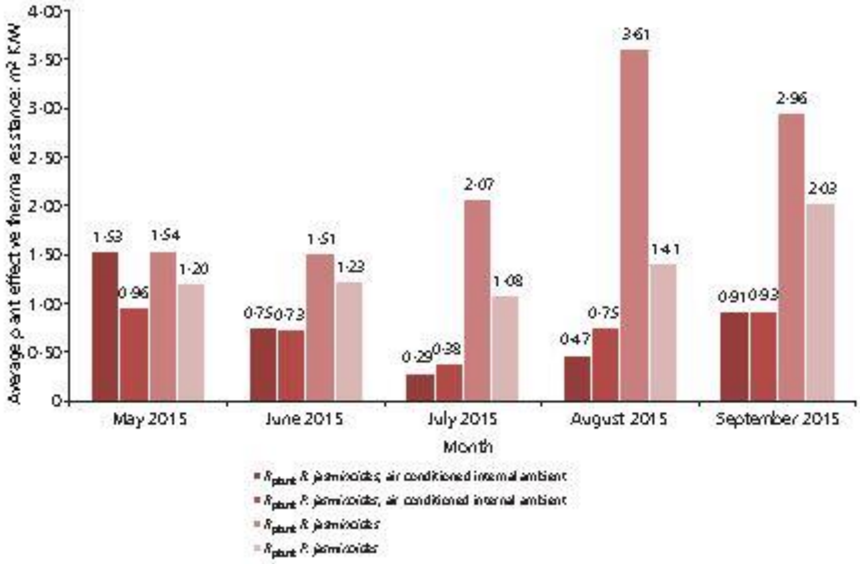

Figure 7. Average monthly effective thermal resistance of the plant layer in daytime during the warm months

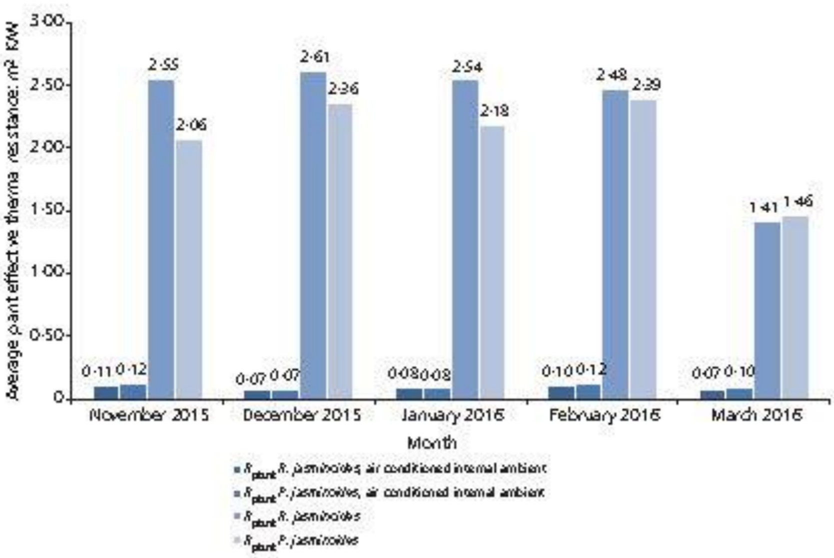

Figure 8. Average monthly effective thermal resistance of the plant layer at nighttime during the cold months

Figures 7 and 8 show the effective thermal resistance of the plant layer (R_{plant}) calculated both for the air-conditioned and for the non-air-conditioned ambient. In this study, the authors considered warm months the ones characterised by an average external air temperature higher than 20°C – that is, from May to September 2015 – and cold months those having an average external air temperature lower than 15°C – that is, from November 2015 to March 2016.

R_{plant} was not evaluated in April and October 2015 because these months were characterised by fluctuating temperatures and by heat flux direction that was not well defined.

During the daytime of the warm months (May to September), when the heat flux was from outside to inside the closed space, R_{plant} ranged from 0·29 to 1·53 m2 K/W for the conditioned space and from 1·08 to 3·61 m2 K/W for the unconditioned space (Figure 7).

In July and August, a more remarkable increase in the R_{plant} average value emerged for R. jasminoides, compared to P. jasminoides variegated, for the non-air-conditioned ambient.

The fluctuations were higher due to the lower difference in temperature recorded on the two sides of the wall, in comparison with the conditioned case.

The increase in the resistance could be attributed to the higher relative humidity and to the lower temperature of the air in the gap between plant and wall (data not shown), due to the different evapotranspiration rates of the two plants.

In the cold months (November to March) at nighttime, with the heat flux from inside to outside, R_{plant} ranged from 0·07 to 0·12 m^2 K/W for the conditioned space and from 1·41 to 2·61 m^2 K/W in case of the unconditioned space (Figure 8).

Susorova et al. (2013) found R_{plant} values ranging from 0·0 to 0·71 m^2 K/W; Kontoleon and Eumorfopoulou (2010) estimated that the thermal resistance of a 25-cm-wide plant foliage is almost 0·5 m^2 K/W.

4. Conclusions

Green walls 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 UHI and to improve the thermal energy performance of buildings.

The application of the green vertical walls to mitigate solar radiation effects on the buildings' external surfaces during warm periods led to lowering of the external surface daylight temperatures by up to 9·0°C in comparison with the wall not covered with plants. During cold periods, the green walls kept the external surface nighttime temperatures up to about 6·0°C above the surface temperature of the control wall.

Future research should be addressed to evaluate throughout the year if and to what extent the resulting decrease in the summer cooling load counterbalances the increase in the winter heating load, if present.

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

The value of the plant effective thermal resistance calculated in the present research, using experimental data for a whole year, provides a useful contribution to the scientific literature that is focused on modelling the thermal behaviour of green walls.

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“A methodology for the generation of energy consumption profiles in the residential sector”

ABSTRACT

The residential sector has been achieved in the last years more and more importance in the total energy consumption scenario by stimulating the research for solutions to promote energy efficiency and to raise awareness on energy consumption by end users.
The profile of a end-users energy consumption assumes a central role in finding solutions to reduce energy demand and increase the efficiency in the production of the same energy.
European regulations impose an obligation on Member States to provide annually data on energy consumption of households for end use and energy product. Data will be provided for Italy basing on data collected by ISTAT Survey on energy consumption in the residential sector, appropriately processed by ENEA and ISTAT.
In this paper it is presented a methodology that allowed to define a series of dwelling types, representative of the entire national sample, as a function of building, family and environmental characteristics. These dwellings, through the application of a dynamic simulation model, allowed the generation of monthly energy consumption profiles (for heating, cooling and domestic heat water) for each cluster of dwelling types and the evaluation of the energy consumption distribution of the residential sector for end use and energy product.

Keywords: energy consumption, residential sector, dwelling types, energy efficiency, end use, energy demand, energy product, dynamic simulation.

1. INTRODUCTION

The European and national policies aimed at containing the energy product consumption and at promoting the diffusion of renewable sources, have stimulated the search for ways to reduce the energy demand and to boost the efficiency in energy production. In particular, for the residential sector, the knowledge of the consumption habits of the families is of vital importance for achieving the goals set by the various European directives, as well as for raising awareness on energy consumption and for stimulating rational behaviors on energy use by end-users.

The regulation (EC) No 1099/2008 of the European Parliament and of the Council of 22 October 2008 on energy statistics, and the amending Commission Regulation (EU) No 431/2014 of 24 April 2014 on energy statistics, as regards the implementation of annual statistics on energy consumption in households, impose an obligation on Member States to provide annual data on energy consumption of households for final destination and energy source. In this framework ISTAT in collaboration with ENEA and MiSE (Italian Ministry of Economic Development) carried out the survey on households energy consumption [1,2], as part of the Italian National Statistics Plan. The survey was conducted in 2013 for the first time in Italy, on a representative sample of 20’000 households at regional level and made it possible to obtain information on characteristics, consumption habits, types of plant and energy costs of Italian households, specified by energy product (primary energy sources and energy carriers) and end-use (heating, cooling, domestic hot water, cooking, lighting and electrical equipment).

This paper describes the methodology used to estimate the energy consumption for heating and the creation of monthly load profiles for residential dwellings. For the sake of simplicity we have chosen to present the results for the Veneto Region and heating systems fueled by natural gas; the calculation method remains the same for other energy products and for the entire Italian national territory.

Furthermore, this methodology will be used in the activity ENEA-ISTAT to estimate the energy consumption of households for the years between two replications of the ISTAT survey, starting from the ISTAT 2016 survey that will be used to deliver the first data to Eurostat.

2. METHODOLOGY

The presented methodology is based on the processing of the provided statistical data from the ISTAT 2013 survey on households energy consumption, and on the identification of dwelling-type classes representative of the entire Italian residential building stock.

The information provided by the ISTAT 2013 survey and used for the methodology are mainly:

- dwelling characteristics (type of dwelling, year of build, floor surface, opaque envelope type, transparent envelope type, main exposure of the external walls);
- characteristics of heating, cooling and DHW systems (number, energy products, systems type – centralized, individual or single device-, emission and temperature control system, frequency of use and daily hours of use);
- frequency of use of the systems;
- energy cost by energy product.

The classification of the dwellings was chosen as a function of:

- period of build: before 1950, 1950-1969, 1970-1989, from 1990;
- type of dwelling: single family house, multi-family house, ground floor apartment, middle floor apartment and top floor apartment.

Table 7 summarizes the 20 identified dwelling-type classes (DTC).

Table 7 – Dwelling-type classes.

	Before 1950	1950-1969	1970-1989	From 1990
Single fam. House	DTC1	DTC6	DTC11	DTC16
Multi-fam. House	DTC2	DTC7	DTC12	DTC17
Ground fl. apt.	DTC3	DTC8	DTC13	DTC18
Middle fl. apt.	DTC4	DTC9	DTC14	DTC19
Top fl. apt.	DTC5	DTC10	DTC15	DTC20

The evaluation of the energy product consumption for heating has been carried out in different stages, as exemplified in Figure 17:

a. determination of the thermal energy demand, in continuous heating mode, of the dwelling-type [kWhy] by means of a dynamic simulation software; the simulations were performed assuming a continuous heating mode (heating system on 24 hours a day), because the survey answers do not allow to determine an hourly power profile; the simulation results also provide the time profile of the heating demand of each dwelling-type;
b. calculation of the reduction factor for intermittent heating as a function of the average number of daily hours during which the heating system is switched on, based on the answers of the survey;
c. assumption of the efficiency of the different types of plant for each dwelling-type, and estimation of the heating consumptions per floor area [kWh/m^{2}y];
d. estimation of the total annual energy product consumption for heating for each class (m^3, kg, l, etc.) for a certain energy product, obtained by multiplying the consumption per area by the total area of the dwellings, that use that specific energy product for heating, that fall in each dwelling-type class.

The decision to estimate the thermal energy demand for all the dwelling-types by means of a dynamic simulation of the dwelling, and then calculate the energy product consumption by multiplying the heating demand calculated in continuous mode by the reduction factor for intermittent heating and by the average total efficiency of the heating system was related to the information provided by survey about the type and the characteristics of the heating systems. Clearly, the information provided by the survey can’t have a detail level sufficient to estimate a management profile of the heating systems, which is instead essential to perform a dynamic simulation of the building-plant system.

Since the energy performances of buildings are strongly influenced by climatic conditions, the same dwelling-type was simulated in each climate zone. For each climatic zone in which the country is divided, the input weather data (temperature, radiation and humidity) adopted for the simulations were those of the chief town whose degree days are "barycentric" with respect to the degree days interval of the climatic zone.

3. DEFINITION OF THE DWELLING-TYPE CLASSES

Each dwelling-type class is characterized by thermo-physical and dimensional parameters, determined on the basis of the information gathered from the ISTAT survey results, appropriately processed, and of the input data required by the simulation model. Below the main properties that define each dwelling-type class are listed and described.

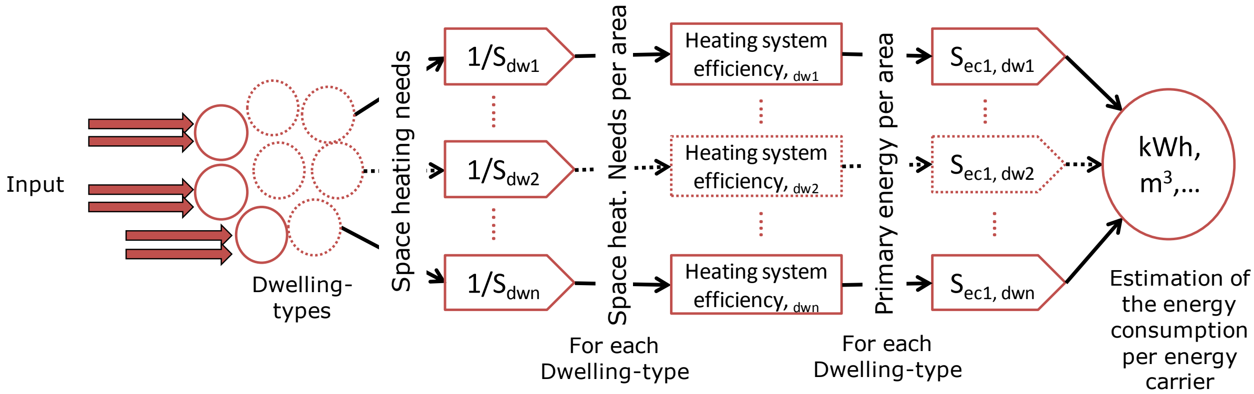

Figure 17 - Methodology scheme, for space heating and for a single energy product.

- <u>Thermal transmittance of the opaque envelope</u>: for each period of build a specific structure was deduced for the exterior walls, the floor and the ceiling, the corresponding thermal transmittance was determined, using data from the Italian standard UNI/TR 11552:2014. Table 8 summarizes the adopted values.

Table 8 – Thermal transmittance of the opaque envelope by period of build [kW/m2K].

	Before 1950	1950-1969	1970-1989	From 1990
Walls	1.093	1.065	0.675	0.456
Floor	0.781	0.781	0.850	0.442
Roof	1.376	1.376	0.777	0.441

- <u>Thermal transmittance of the transparent envelope</u>: the survey provided as possible answers two types of glass (single, double) and three types of frame (wood, metal, PVC): for these types the average transmittance values were calculated according to the Italian standard UNI/TR 11552: 2014 [3]; the equivalent transmittance of the glass and of the frame for each dwelling-type, was determined weighting the thermal transmittances corresponding to the answers of the survey on their incidence on the total number of dwellings that fall in the class; since the transparent surface is not an information inferable from the survey, a transparent surface equal to 1/8 of the floor surface was assumed to calculate the transmittance of the window. Table 9 summarizes the obtained values.

Table 9 – Thermal trasmittance of the trasparent envelope by period of build and type of dwelling [kW/m2K].

	Before 1950	1950-1969	1970-1989	From 1990
S. F. House	3.320	3.490	3.280	2.450
Multi-fam. House	3.010	3.230	2.950	2.400
Apartments	3.240	3.530	3.400	2.560

- Floor surface: since the survey answers are provided for 10 m^2 surface intervals, the floor area of the dwelling-type is calculated as the average of the central values of the surface intervals weighted on the frequency of the answers for each surface interval (Table 10).

Table 10 – Dwelling-types' heated floor surfaces [m2].

	Before 1950	1950-1969	1970-1989	From 1990
S. F. House	121.5	115.0	119.9	130.3
Multi-f. House	122.0	103.7	115.9	122.6
Gr. Fl. Apt.	86.3	92.4	82.1	83.1
Mid. Fl. Apt.	90.8	83.6	89.1	92.8
Top Fl. Apt	98.5	89.6	93.4	90.8

- Exposure: the survey provides information about two main exposures (without specifying the prevailing one) of the external walls of the dwelling. Analyzing the frequency of all possible answers and the combinations between them it was assumed that the multi-family dwellings have two possible types of exposure: two opposite sides or three adjacent sides exposed to the outside; for apartments the types of exposure are three: one single side, two opposite sides and two adjacent sides exposed to the outside; for the single family house all the 4 sides are considered exposed to the outside. Table 11 summarizes all the 34 considered types of exposure, corresponding to the simulations to be performed for each period of build. The weight of each type of exposure is proportional to the number of dwellings that fall in it; Table 12 summarizes the weight of the identified types of exposure and of their consequent simulations.

Table 11 - Dwelling walls' main exposures and consequent simulations.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
SFH	all	-	-	-	-	-	-	-	-	-
MFH	N+S	E+W	N+E+S	-	-	-	-	-	-	-
GFApt	N	E	S	W	N+S	E+W	N+E	N+W	E+S	S+W
MFApt	N	E	S	W	N+S	E+W	N+E	N+W	E+S	S+W
TFApt	N	E	S	W	N+S	E+W	N+E	N+W	E+S	S+W

Table 12 – Weight of each identified type of exposure and consequent simulation.

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
SFH	100.0%	-	-	-	-	-	-	-	-	-
MFH	44.1%	23.9%	32.0%	-	-	-	-	-	-	-
GFApt	14.2%	11.7%	12.6%	4.9%	10.5%	10.8%	7.6%	7.6%	12.4%	7.9%
MFApt	14.2%	11.7%	12.6%	4.9%	10.5%	10.8%	7.6%	7.6%	12.4%	7.9%
TFApt	14.2%	11.7%	12.6%	4.9%	10.5%	10.8%	7.6%	7.6%	12.4%	7.9%

- Heat losing surfaces: the vertical heat losing surfaces are determined in accordance with the previously identified types of exposure, considering a square shaped floor and assuming the height of the walls for each type of dwelling; the total window surface, assumed to be equal to 1/8 of the floor surface, is divided equally among the walls exposed to the outside. For both the single and the multi-family house, the floor and the ceiling are considered heat losing surfaces. As far as the apartments are concerned, the middle floor apartment has no horizontal heat losses, the ground floor has heat losses through the floor and the top floor apartment has heat losses through the ceiling.

4. THE SIMULATION MODEL

Since the aim of the work is the determination of both the energy consumption and the thermal load profiles, we chose to use a dynamic simulation model, made by the University of Catania, based on the equivalent resistance-capacitance model proposed in the european standard EN ISO 13790 [4].

Dynamic models for the evaluation of energy consumption in buildings are developed taking into account the variability of both the external climatic conditions of the internal loads. In general, the calculation of the heat load in summer is done with dynamic methods that take into account the thermal capacity and the thermal transients of the buildings

The european standard EN ISO 13790 proposes an electro-thermal dynamic model simplified with five thermal conductance and a heat capacity, called 5R1C, shown in Figure 18.

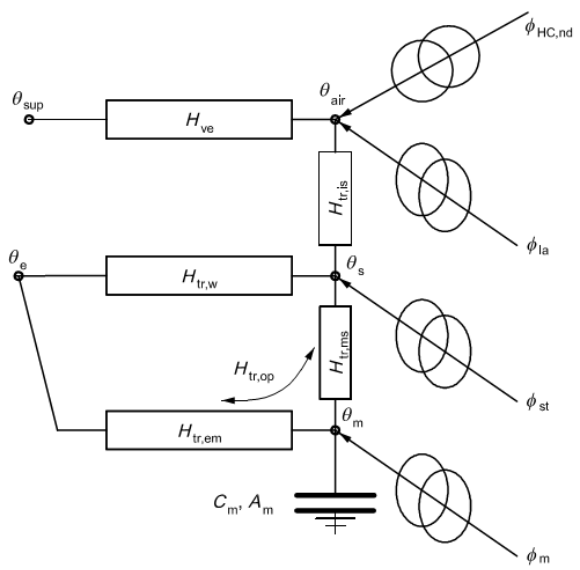

Figure 18 - 5R1C Model Scheme.

The nodes in the model scheme represent the ventilation (θ_{sup}), the outdoor air (θ_e), the envelope mass (θ_m), the envelope indoor surface (θ_s) and the indoor air (θ_{air}) temperatures. The heat transfer coefficients are: the ventilation heat transfer coefficient (H_{ve}), the transmission heat transfer coefficient for windows ($H_{tr,w}$), the emissive transmission heat transfer coefficient for the opaque envelope towards the envelope mass ($H_{tr,em}$), the conductive transmission heat transfer coefficient for the opaque envelope towards the envelope indoor surface ($H_{tr,ms}$), the coupling conductance between the envelope indoor surface and the indoor air ($H_{tr,is}$). The heat flows are: heat flow rate from internal and solar sources towards the envelope mass (Φ_m), heat flow rate from internal and solar sources towards the envelope indoor surface (Φ_{st}), heat flow rate from internal sources towards indoor air (Φ_{ia}), heating or cooling needs ($\Phi_{HC,nd}$).

The EN ISO 13790 standard defines uniquely the heat transfer coefficients and proposes a mode of solution refers to the monthly average daily conditions and monthly average daily time conditions.

The direct solution results in the calculation, set the temperature and the thermal conductance, the net flux exchanged, $\Phi_{HC,nd}$, under changing climatic conditions. This solution involves the solution of a differential equation related to the heat balance to Φ_m node:

$$C\frac{dT_m}{dt}+\left(H_{tr,em}+H_{tr,ms}-H_{tr,ms}\frac{H_{tr,ms}}{H_{tr,w}+H_{tr,ms}+H_{si}}\right)T_m=\Phi_m+H_{tr,em}T_e+H_{tr,ms}\frac{\Phi_{si}+H_{tr,w}T_e+H_{si}T_{air}}{H_{tr,w}+H_{tr,ms}+H_{si}}$$

For the net flow is we have:

$$\Phi_{HC,nd}=H_{ve}\left(T_{air}-T_{\sup}\right)+H_{si}\left(T_{air}-T_{si}\right)-\Phi_{air}$$

The recursive solution based on Heun method is:

$$T_m\left(t_{n+1}\right)=\left(1-\lambda\frac{T}{2}\right)T_m\left(t_n\right)+\frac{T}{2}\left(-\lambda T_m\left(t_n\right)+g\left(t_n\right)\right)+\frac{T}{2}g\left(t_{n+1}\right)$$

where is:

$$\lambda=\frac{H_{tr,em}+H_{tr,ms}-H_{tr,ms}\frac{H_{tr,ms}}{H_{t,w}+H_{tr,ms}+H_{si}}}{C}$$

$$g=\frac{\Phi_m+H_{tr,em}T_e+H_{tr,ms}\frac{\Phi_{si}+H_{tr,w}T_e+H_{si}T_{air}}{H_{tr,w}+H_{tr,ms}+H_{si}}}{C}$$

The calculation thus prepared is sufficient and can be quickly implemented on Excel spreadsheet.
The input data required for the model are:

- thermal transmittance of the component, W / (m².K).
- participation factor (required by UN EN 13790)
- total surface of each element m².
- solar absorption factor for opaque walls and global solar transmittance for transparent surfaces;
- shading factor (as per UNI EN 13790).
- total building height, m;
- number of air changes per hour in the absence of VMC;
- air flow temperature of ventilation in the case of controlled mechanical ventilation;
- ambient temperature that you want to have during the night attenuation.
- specific flow to the sky;
- reference temperature for plant regulation (set equal to 20° C in winter and 26° C in summer);
- total atmospheric pressure for the town considered;
- humidity of the ventilation;
- latent heat intensity for internal sources.

An important feature of the method is the ability to customize the input vectors as a function of weather data, the real profiles for plants and internal gains.

As output, the model provides for each day (representative of the month) a time profile of the latent load, the total load required, the attenuation coefficient, the indoor air temperature and the inner surface of the walls..

5. ESTIMATION of THE energy PRODUCT consumption

The consumption of primary energy from the thermal energy demand is determined according to the following parameters:

- number of hours of daily usage of the plant for each dwelling-type, calculated as the average of the answers and divided into climatic zones;
- reduction factor, $a_{H,red}$,for intermittent heating;
- average overall efficiency of the heating plant.

The $a_{H,red}$ coefficient takes into account that the plants don't run for all day, the solar and inner gains and the building time constant and is calculated according to the formula proposed in the UNI TS 11300-1 / 2014 [5]:

$$a_{H,red} = 1 - b_{H,red} \left(\tau_{H,O} / \tau \right) \gamma_H (1 - f_{H,hr})$$

The overall performance of thermal plants is calculated as the product of the efficiencies of the subsystems in which is divided, namely the generation, distribution, control and emission.

The efficiency of each subsystem is determined as a weighted average for the plant surface of each type of dwelling inferred from the survey responses, to which a value as indicated in the UNI TS 11300-2 / 2014 [6] was assigned.

The efficiency of the generation subsystem is dependent on the primary source used, while other subsystems are independent. In the case of single or portable heating systems it was assigned to each type a single overall efficiency.

The types of considered subsystems, are:

- emission: radiators, fan coils and radiant panels;
- control: on-off and thermostatic valves;
- distribution: before and after 1990 with different efficiency values for single and multi-family house, ground floor autonomous apartments, middle and top floor autonomous apartments last and centralized apartments.

For the generation subsystem supplied by natural gas, was considered the boiler for centralized and autonomous systems and stoves for those individuals.

Table 13 shows the values of the overall efficiency calculated:

Table 13 - Global efficiency of natural gas heating systems, for each dwelling-type class [-].

	Before 1950	1950-1969	1970-1989	From 1990
S. F. House	0.767	0.765	0.767	0.768
Multi-f. House	0.766	0.767	0.769	0.761
Gr. Fl. Apt.	0.794	0.788	0.792	0.771
Mid. Fl. Apt.	0.788	0.795	0.797	0.773
Top Fl. Apt	-	0.794	0.798	0.785

6. RESULTS, DISCUSSION AND FUTURE WORK

The first result, which is also the most important for the many activities in which it can be used, is the classification of the whole Italian residential housing stock in 20 classes of dwelling-types, determined as previously described.

6.1 Thermal load

For each dwelling-type, the profiles of the indoor air temperature, of the thermal energy demand (assuming a continuous heating mode) and of the thermal load (that is the dwelling energy demand with a power profile for a total number of hours equal to the maximum allowed), were obtained.

Figure 19, Figure 20 and Figure 21 show an example of the availablehourly profiles for the dwelling-type class "top floor apartment", period of build "before 1950", in the case of controlled mechanical ventilation.

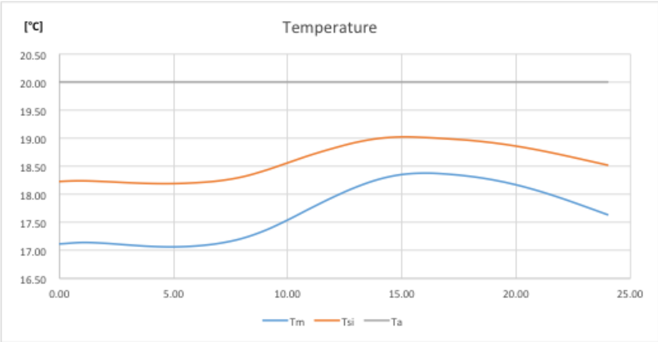

Figure 19 – Indoor temperature hourly profile, continuous heating mode [°C].

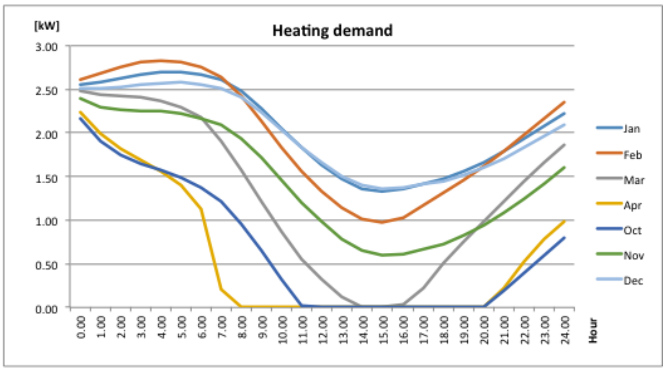

Figure 20 - Heating demand hourly profile of the average day for each month, continuous heating mode [kW].

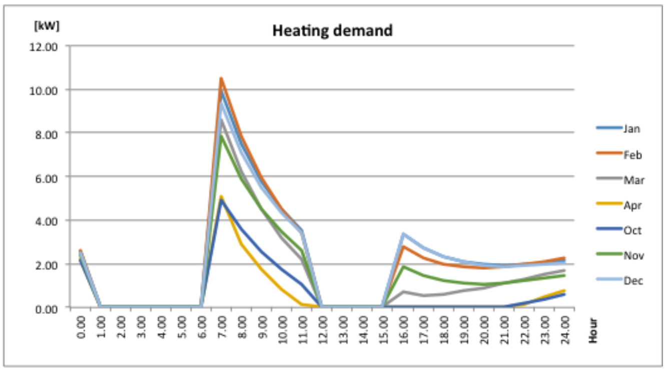

Figure 21 – Thermal load hourly profile of the average day for each month, intermittent heating mode [kW].

Figure 21 clearly shows how the presence of a power profile highlight a different distribution of the thermal output required to the heating system, providing much more detailed information and close to a real trend.

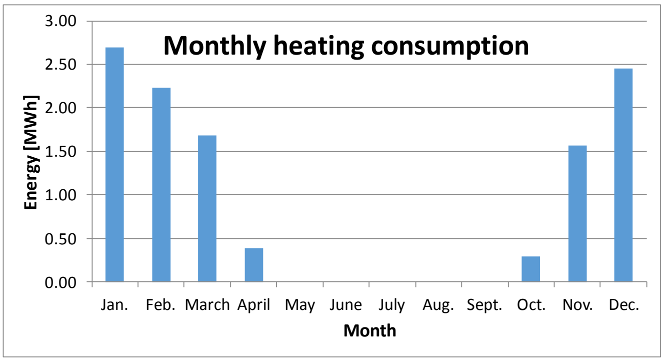

Figure 22 – Monthly heating consumption profile [MWh].

In Figure 22 an example of a monthly consumption of thermal energy for heating profile is plotted: it is referred to a single simulation run of the 34 possible for each period of build and for each climatic zone.

6.2 Energy product consumption

Starting from the results of the 34 simulations performed for each period of build (Table 11), it is possible to obtain the thermal energy consumption of each dwelling-type, as the average weighted on the table of weights (Table 12) multiplied by its corresponding reduction factor for intermittent heating, $a_{H,red}$ (Table 14).

Table 14 – Reduction factor for intermittent heating (aH,red) corresponding to each simulation, period of build "before 1950", climatic zone E [-].

	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
SFH	0.70	-	-	-	-	-	-	-	-	-
MFH	0.83	0.81	0.82	-	-	-	-	-	-	-
GFApt	0.80	0.74	0.77	0.78	0.77	0.73	0.75	0.77	0.73	0.75
MFApt	0.71	0.62	0.66	0.67	0.72	0.68	0.70	0.73	0.67	0.70
TFApt	0.73	0.64	0.68	0.69	0.70	0.66	0.68	0.71	0.66	0.69

Since four periods of build have been identified, for each climatic zone 136 simulations are performed, and their results, weighted on Table 12 and multiplied by their corresponding reduction factors for intermittent heating, allow the calculation of the thermal energy consumption of the 20 identified dwelling-types, as shown in Table 15.

Table 15 - Heating consumption for each dwelling-type, climatic zone E [kWhy].

	Before 1950	1950-1969	1970-1989	From 1990
S. F. House	19342	18232	17957	18500
Multi-f. House	24138	21245	22979	23325
Gr. Fl. Apt.	9947	11287	9802	9704
Mid. Fl. Apt.	5832	5678	5966	6018
Top Fl. Apt	11154	9669	10774	10174

Dividing the heating consumption table of the dwelling-types (Table 15) by the table of the dwelling-types' heated floor surfaces (Table 10), the heating consumption per area for each dwelling-type class, for the considered climatic zone, is obtained (Table 16).

Table 16 - Heating consumption per area for each dwelling-type class, climatic zone E [kWh/m2y].

	Before 1950	1950-1969	1970-1989	From 1990
S. F. House	159.20	158.54	149.77	141.99
Multi-f. House	197.85	204.88	198.27	190.26
Gr. Fl. Apt.	115.27	122.16	119.39	116.78
Mid. Fl. Apt.	64.24	67.93	66.96	64.86
Top Fl. Apt	113.24	107.92	115.35	112.05

The procedure described above is then applied for all climatic zones, and a table similar to Table 16 is obtained for each climatic zone.

For each dwelling-type class, is then possible to calculate the weight of each climatic zone by considering the share of floor surface of the class, falling in each zone: in the case of the Veneto Region, for instance, the single family house class is distributed between zone E (91.5% of the heated floor surface) and zone F (8.5% of the heated floor surface).

This distribution is then summarized for each climatic zone, as shown in Table 17 for the climatic zone E.

Table 17 – % of floor surfaces of the building-type classes falling in the climatic zone E [-].

	Before 1950	1950-1969	1970-1989	From 1990
S. F. House	91.5%	95.6%	94.7%	96.6%
Multi-f. House	94.6%	93.4%	95.6%	97.2%
Gr. Fl. Apt.	100.0%	97.2%	94.5%	94.3%
Mid. Fl. Apt.	96.6%	95.6%	98.6%	100.0%
Top Fl. Apt	100.0%	95.9%	76.4%	75.8%

Weighting the simulation results of each climatic zone by the percentage of floor falling in the zone itself, the heating consumption per area for each dwelling-type class is calculated. The results for the Veneto Region are summarized in Table 18.

Table 18 - Heating consumption per area for each dwelling-type class [kWh/m2y].

	Before 1950	1950-1969	1970-1989	From 1990
S. F. House	145.69	151.58	141.69	137.22
Multif. House	187.27	191.28	189.62	184.93
Gr. Fl. Apt.	115.27	118.75	112.82	110.14
Mid. Fl. Apt.	62.03	64.92	66.01	64.86
Top Fl. Apt	113.24	103.47	88.18	84.99

Multiplying the heating consumption per area by the total area of the dwellings, that use a specific energy product for heating (in the present example: natural gas), that fall in each dwelling-type class (Table 19) and dividing by the respective system's global efficiency (Table 13), it is possible to assess the total energy product consumption for heating of each dwelling-type class for the specific energy product, as shown in Table 20.

Table 19 - Total floor surface of each dwelling-type class, using Natural gas as energy product for heating [m2].

	Before 1950	1950-1969	1970-1989	From 1990
S. F. House	5135	7785	11520	5665
Multi-f. House	1915	4950	6370	7865
Gr. Fl. Apt.	3340	7330	7375	3960
Mid. Fl. Apt.	720	3135	3400	2500
Top Fl. Apt	0	225	525	690

The sum of the elements of the table of the total annual consumption of the dwelling-type classes for the considered energy product (Table 20), provides the overall annual energy product consumption for heating of the residential building stock for the considered energy product which, in the case of the Veneto Region and of natural gas, is approx. 15.014 MWh.

Table 20 - Total annual energy product consumption for heating of each dwelling-type class, natural gas [MWhy].

	Before 1950	1950-1969	1970-1989	From 1990
S. F. House	975.3	1542.9	2129.3	1011.5
Multi-f. House	468.3	1234.0	1570.6	1910.9
Gr. Fl. Apt.	484.9	1105.2	1050.0	565.4
Mid. Fl. Apt.	56.7	255.9	281.5	209.8
Top Fl. Apt	0.00	29.31	58.03	74.69

The project activity is still in progress. The present step, in progress, is the comparison between the consumption data calculated with the presented methodology and those estimated by the ISTAT survey, the final results of the comparison will be published later.

7. CONCLUSIONS

The above presented methodology has enabled, by means of processing the data on energy consumption of Italian families provided by the ISTAT survey and with the aid of a dynamic simulation model, the realization of a tool able to estimate the energy consumption and to create the thermal load profiles of the representative dwellings of the Italian residential sector.

In particular the methodology allowed to group the entire national sample in 20 cluster of type dwellings, as a function of building (dimensions, equipment, energy characteristics, etc.), family (number of occupants, consumption habits, etc.) and environmental (region, climatic zone, etc.) characteristics.

The methodology is able to estimate energy consumptions distinguished for end use (heating, cooling and domestic hot water) and energy product.

The aim of the work is to increase knowledge of consumer habits of end users to outline a real scenery of the buildings consumption useful to address the choice of the most efficient technological solutions and to provide guidance on the policy actions of support for the dissemination of the most promising technologies.

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Energia, Ambiente e innovazione: "I meccanismi di incentivazione per l'efficienza energetica"

l potenziale di risparmio energetico non sfruttato è ancora ampio, ma le misure recentemente adottate, insieme ai meccanismi di incentivazione già in forza, saranno in grado di stimolare investimenti, con importanti ricadute positive anche in termini di creazione di posti di lavoro e crescita economica stabile di lungo periodo.
tracciata dalla Strategia Energetica Nazionale nel 2013, l'Italia ha adottato due provvedimenti chiave nel 2014, delineando in tal modo il percorso verso gli impegnativi obiettivi di risparmio energetico posti al 2020.
Sia il recepimento della Direttiva sull'Efficienza Energetica (Decreto legislativo n. 102/2014) sia il Piano d'Azione per l'Efficienza Energetica del 2014 hanno fornito, rispettiva- mente dal punto di vista normativo e strategico, un quadro ampio ed esaustivo, che mira alla rimozione delle barriere che ritardano la diffusione dell'efficienza energetica, sia a livello nazionale sia locale.
Come in molti altri Paesi membri dell'Unione Europea, il potenziale di risparmio energetico non sfruttato è ancora ampio, ma vi è fiducia che le misure recentemente adottate, insieme ai meccanismi di incentivazione già in forza, saranno in grado di stimolare investimenti cost-effective, con importanti ricadute positive anche in termini di creazione di posti di lavoro e crescita economica stabile di lungo periodo. Il Decreto Legislativo 102/20141 ha recepito in Italia la Direttiva 2012/27/UE (Energy Efficiency Directive – EED), stabilendo un quadro di misure per la promozione e il miglioramento dell'efficienza tese ad una riduzione dei consumi di energia primaria di 20 milioni di tonnellate equivalenti di petrolio (Mtep) al 2020, pari a 15,5 Mtep di energia finale. Parte di tale
ammontare di risparmi energetici costituisce un obiettivo vincolante, stabilito in ottemperanza all'articolo 7 della EED per il periodo 2014-2020.
In particolare, dal regime obbligatorio dei Certificati Bianchi si attende un risparmio di circa 4,3 Mtep/anno in termini di energia finale; ad esso si abbinano le due misure alternative delle Detra- zioni fiscali (0,98 Mtep/anno di risparmio) e del Conto Termico (1,47 Mtep/anno). La Figura 1 riporta il risparmio cumulato annuale atteso dai meccanismi proposti.

Fig. 1 Quadro di sintesi del conseguimento dei risparmi (Mtep/anno di energia finale), anni 2014-2020 Fonte: Ministero dello Sviluppo Economic

Il periodo 2013-2014 è stato caratterizzato da rilevanti evoluzioni normative, volte all'aggiornamento degli attuali meccanismi di incentivazione all'efficienza energetica, al fine di assicurare il raggiungimento degli ambiziosi obiettivi di risparmio di energia finale previsti dalla EED. La gestione dei meccanismi ha puntato all'ottimizzazione e semplificazione dei processi, nell'intento di ridurre gli oneri amministrativi a carico degli operatori, in uno scenario di grandi e rilevanti novità introdotte dal Decreto Legislativo 102/2014, che ha aggiornato i meccanismi del Conto Termico e dei Certificati Bianchi, allo scopo di potenziarne l'efficacia.
Di seguito verranno sinteticamente i principali risultati conseguiti dagli strumenti citati in precedenza.
Titoli di Efficienza Energetica o Certificati Bianchi
Come noto, il meccanismo dei Certificati Bianchi consiste nella creazione di un mercato di certificati attestanti la riduzione dei consumi di energia primaria derivanti da misure e interventi di efficienza energetica negli usi finali. In particola- re, i distributori di gas ed elettricità con più di 50.000 clienti finali sono considerati soggetti obbligati al raggiungimento di obiettivi prefissati: è previsto un contributo tariffario in loro favore a parziale copertura degli oneri sostenuti per il raggiungimento di tali obiettivi. Al tempo stesso, soggetti volontari quali distributori con meno di 50.000 clienti, società di servizi energetici, soggetti con obbligo di nomina di energy manager, soggetti con energy manager volontario, soggetti che hanno implementato un sistema di gestione dell'energia conforme alla ISO 50001, possono agire negli usi finali implementando misure che producano ti- toli di efficienza.
Nell'ambito del suddetto D.Lgs. 102/2014, è previsto l'aggiornamento delle Linee Guida attualmente vigenti: il Ministero dello Sviluppo Economico, in collaborazione con ENEA, RSE e GSE, ha predisposto un documento che illustra le principali linee di indirizzo per il potenzia- mento e la qualifica del meccanismo dei Certificati Bianchi e, in data 31 luglio 2015, ha avviato una consultazione pubblica con l'obiettivo di raccogliere le osservazioni e le pro- poste degli stakeholder. La revisione delle Linee Guida e la definizione dei nuovi obiettivi di risparmio in capo ai soggetti obbligati, definiranno un nuovo *framework* allo scopo di rendere ancora più efficace il meccanismo come strumento di supporto e promozione per la realizzazione di nuovi investimenti nel settore dell'efficienza energetica.
Nel corso dell'anno 2015 sono state presentate 10.763 Richieste di Veri- fica e Certificazioni (RVC), relative sia a prime rendicontazioni che a rendicontazioni successive, e 999 Proposta di Progetto e di Programma di Misura (PPPM), per un valore complessivo pari a 11.762 richieste. In termini di risparmi energetici certificati, il GSE ha riconosciuto circa 5 milioni di Titoli di efficienza Energetica (TEE), cui corrispondono risparmi di energia primaria pari a 1,7 Mtep (Tabella 1).
La maggioranza dei TEE è stato con- seguito mediante progetti realizzati nel settore industriale, generando circa il 64% dei TEE complessiva- mente riconosciuti nel 2015, con particolare riferimento ai progetti di efficienza energetica relativi all'ottimizzazione dei processi produttivi nei settori più energivori. Il settore civile rappresenta circa il 31% dei TEE riconosciuti nel 2015, riguardando prevalentemente progetti relativi agli impianti per la climatizzazione e la produzione di acqua calda sanitaria. I progetti relativi all'illuminazione hanno generato oltre il 4% dei TEE riconosciuti nell'anno di riferimento.

	RVC-C	RVC-A	RVC-S	PPPM	Grandi Progetti	Totale
Richieste presentate	2.170	4.103	4.490	999		11.763
Titoli di Efficienza Energetica riconosciuti	3.123.642	179.327	1.597.855		128.240	5.029.064
Risparmi energia primaria [tep]	1.009.743	63.716	631.981		28.000	1.733.440

Tab. 1 Progetti, Titoli di Efficienza Energetica riconosciuti e risparmi certificati con i Certificati Bianchi (tep energia primaria), anno 2015 *Fonte: GSE - Gestore Servizi Energetici SpA*

Al 31 dicembre 2015 risultano 4.693 operatori accreditati, costituiti per circa l'80% da società di servizi energetici, le quali si confermano come l'operatore maggiormente attivo in termini di numerosità di progetti presentati, con oltre 11.000 richieste presentate nel 2015.

Detrazioni fiscali

Le detrazioni fiscali per la riqualificazione energetica del patrimonio edilizio esistente mirano alla riduzione del fabbisogno energetico per il riscaldamento dell'intero edificio, attraverso il miglioramento delle prestazioni termiche dell'involucro dell'edificio (coibentazione di solai, pareti o la sostituzione di serramenti o parti di essi o l'installazione di schermature solai) e la sostituzione degli impianti di climatizzazione invernale.

Altra novità importante è la possibilità per gli interventi realizzati su parti comuni dei condomini di cedere la detrazione alle aziende che eseguo- no i lavori, in cambio di uno sconto. In questo modo sarà possibile anche agli inquilini incapienti di sfruttare le detrazioni. Infine, la possibilità di usufruire delle detrazioni viene estesa anche agli Istituti autonomi per le case popolari, per le spese sostenute dal 1º gennaio al 31 dicembre 2016, per interventi realizzati su immobili di loro proprietà adibiti ad edilizia residenziale pubblica.

Il riconoscimento delle detrazioni fiscali ha giocato un ruolo fonda- mentale nello sviluppo dell'efficienza energetica nel settore residenziale. Basti pensare che dall'avvio nel 2007 a novembre 2014, nel corso di circa otto anni sono state trasmesse più di due milioni di richieste di detrazione all'ENEA, ente responsabile della gestione del meccanismo. Gli utenti sono stati assistiti nell'accesso al meccanismo da ENEA, la quale ha risposto a 80.000 quesiti di carattere tecnico, e da FormezPA, attraverso il servizio Linea Amica di "prima informazione"attivo dal 2012.

Poiché fino a settembre 2016 è ancora possibile la trasmissione dei dati relativi ad interventi realizzati nel 2015, gli risultati consolidati sono quelli relativi al 2014, anno in cui sono stati realizzati circa 300.000 interventi. La Tabella 2 ne riporta il dettaglio per tipologia, per un totale di oltre 3,2 miliardi di euro di investimenti attivati, a fronte dei quali è stato conseguito un risparmio complessivo di circa 0,117 Mtep/anno di energia primaria, equivalenti a poco più di 0,112 Mtep di energia finale.

Escludendo dal conteggio gli interventi relativi alle fonti rinnovabili, il risparmio conseguito nel 2014 da interventi di efficientamento è di 0,108 Mtep/anno di energia prima- ria e finale.

Sulla base delle prime risultanze relative ai dati 2015 il numero di richieste ricevute è in linea con quello dello scorso anno. Sebbene per il 2015 vadano ad aggiungersi alla lista degli interventi

incentivati anche quelli relativi alle schermature solari, da una prima analisi preliminare dei dati il numero di tali interventi non è elevato, pertanto si ipotizza anche per il 2015 la stessa distribuzione di interventi di efficientamento osservata per il 2014, peraltro del tutto simile anche a quella degli anni precedenti. Sulla base di tali informazioni ed ipotesi, in via conservativa e al netto del contributo apportato da interventi relativi alle fonti energetiche rinnovabili, il risparmio energetico conseguito nel 2015 è stimato in poco più di 0,108 Mtep/anno di energia primaria e finale, pari a quello del 2014.

Tipologia di intervento	Numero di interventi	Spesa	Risparmio energetico conseguito [Mtep/
Strutture opache verticali	3.239	160.691.293	0,0054
Strutture opache orizzontali	3.700	187.444.188	0,0080
Infissi	209.924	1.806.553.44	0,0487
Solare termico	17.420	120.697.898	0,0036
Caldaie a condensazione	54.320	743.882.061	0,0388
Pompe di calore	9.081	153.311.438	0,0065
Impianti geotermici	148	5.048.997	0,0002
Caldaie a biomasse	473	12.576.689	0,0007

Scaldacqua a pompa di	1.490	20.312.166	0,0006
Totale	299.795	3.210.518.17	0,1125

Tab. 2 Interventi realizzati, spesa sostenuta e risparmio conseguito tramite le detrazioni fiscali, anno 2014 *Fonte: ENEA*

La detrazione fiscale per gli interventi di recupero del patrimonio edilizio è stata introdotta dall'articolo 1, commi 5 e 6, della legge n. 449 del 27 dicembre 1997. I principali interventi di recupero sono relativi all'impiantistica, comprese le caldaie a condensazione incentivate anche tramite le detrazioni fiscali per la riqualificazione energetica. Si osserva tuttavia che il numero di caldaie a condensazione incentivate attraverso quest'ultimo canale è di gran lunga inferiore rispetto al numero venduto sul mercato. Ciò poiché molte caldaie a condensazione destinate alla sostituzione del vecchio impianto sono state incentivate attraverso le detrazioni fiscali per il recupero edilizio.
Adottando il risparmio energetico unitario deducibile dalle detrazioni fiscali per la riqualificazione energetica, il risparmio complessivo conseguito nel 2014 attraverso le caldaie a condensazione incentivate con le detrazioni fiscali per il recupero edilizio è pari a 0,12 Mtep/anno.
Non essendo ancora disponibili dati per il 2015, considerando il trend linea- re delle vendite, in via preliminare si adotta anche per il 2015 tale valore di risparmio energetico.
Conto Termico
Il Conto Termico, superata la fase di start-up del primo anno di funzionamento, sta registrando un sempre maggiore interesse da parte dei soggetti privati e delle Pubbliche Amministrazioni.
Nel 2016 è stato varato il Conto Termico 2.0, che entrerà in vigore dal 31 maggio 2016. La seconda release del Conto termico potenzia e semplifica il meccanismo di sostegno già introdotto dal decreto 28/12/2012, che incentiva interventi per l'incremento dell'efficienza energetica e la produzione di energia termica da fonti rinnovabili. I beneficiari rimangono le Pubbliche Amministrazioni, imprese e privati che potranno accedere a fondi per 900 milioni di euro annui, di cui 200 destinati alla PA. Oltre ad un ampliamento delle modalità di accesso e dei soggetti ammessi (sono ricomprese oggi anche le società in house e le cooperative di abitanti), sono stati introdotti nuovi interventi di efficienza energetica, inclusi quelli che prevedono la trasformazione di edifici esistenti in Edifici a energia quasi zero (NZEB).
Le variazioni più significative riguardano anche la dimensione de- gli impianti ammissibili, che è stata aumentata, mentre è stata snellita la procedura di accesso diretto per gli apparecchi ricompresi in uno specifico catalogo.
Altre novità riguardano gli incentivi stessi: sono infatti previsti sia l'innalzamento del limite per la loro erogazione in un'unica rata (dai prece- denti 600 agli attuali 5.000 euro), sia la riduzione dei tempi di pagamento che, nel nuovo meccanismo, passano da 6 a 2 mesi.

Tab. 3

Tipologia soggetto ammesso	Richieste con contratto attivato	Incentivi totali [M€]
Soggetti privati	7.598	24,73
Pubblica Amministrazione	244	6,85
Totale	7.842	31,58

Richieste con contratto attivato ed incentivi erogati attraverso il Conto Termico, anno 2015
Fonte: GSE - Gestore Servizi Energetici SpA

Soggetti beneficiari	Tipologia di intervento	Interventi realizzati	Energia primaria risparmiata [Mtep/anno]
	1.A - Involucro opaco	64	0,00026
	1.B - Chiusure trasparenti	69	0,00014

Pubblica Amministrazione	1.C - Generatori a condensazione	121	0,000366
	1.D - Schermature	3	n.d.
	Totale	257	0,000773

Tab. 4 Risparmio energetico conseguito attraverso interventi incentivati con il Conto Termico, anno 2015
Fonte: GSE - Gestore Servizi Energetici SpA

Misura	Risparmi conseguiti nel 2014 da interventi del 2014	Risparmi conseguiti nel 2015 da interventi del 2014	Risparmi conseguiti nel 2015 da interventi del 2015	Risparmi cumulati 2014-2015
Certificati	1,004	0,435	0,366	1,805
Detrazioni fiscali	0,228	0,228	0,228*	0,684
Conto Termico	0,000005	0,000005	0,000773	0,000783
Totale	1,232	0,663	0,595	2,490

Tab. 5 Risparmi energetici annuali conseguiti per misura nel 2014 e 2015 (Mtep/anno energia finale)
Fonte: elaborazione ENEA su dati GSE ed ENEA

Nel corso del 2015 sono state tra- smesse al GSE - Gestore Servizi Energetici SpA (organismo respon- sabile dell'attuazione e della gestione del meccanismo) 8.263 richieste di concessione degli incentivi (RCI), di cui 283 pervenute da parte di Amministrazioni pubbliche (3,4% del totale), le quali possono accedere ad interventi di efficientamento energetico. Le richieste con contratto attivato dal 1 gennaio 2015 al 31 dicembre 2015 sono state in totale 7.842, di cui 244 da parte di Amministrazioni pubbliche (3,1% del totale).

Gli incentivi totali riconosciuti, relativi alle richieste con contratto attivato, ammontano ad un totale di circa 31,58 milioni di Euro, di cui circa 6,85 milioni di Euro per le Amministrazioni pubbliche.

La Tabella 3 riporta i dati sintetici relativi ai risultati consolidati della procedura di Accesso Diretto, suddivisi per tipologia di Soggetto Ammesso. Gli interventi realizzati, riferiti alle richieste con contratto attivato, sono 8.055: tale numero è superiore al numero delle richieste con contratto attivato (7.842) per la presenza di richieste cosiddette "multi-intervento", con più interventi realizzati con- testualmente.

La Tabella 4 riporta il risparmio energetico annuale conseguito nel 2015 per le sole categorie di inter- vento relative all'efficienza energetica. I risparmi complessivi conseguiti attraverso i soli interventi di efficienza energetica realizzati nel 2015 nell'ambito del Conto ammontano a circa 0,0008 Mtep di energia prima- ria e finale.

Sintesi dei risultati conseguiti nel 2014 e 2015 per l'adempimento dell'articolo 7 della Direttiva

La Tabella 5 riporta i dati consolida- ti del 2014 e le stime dei risparmi di energia finale conseguiti nel 2015: il risparmio cumulato conseguito nel biennio 2014-2015 è pari a circa 2,5 Mtep/anno.

Conclusioni

L'analisi svolta mostra come le misure ad oggi poste in essere hanno consentito al nostro Paese di adotta- re un trend di risparmio energetico in linea con gli obiettivi comunitari. In un contesto di crisi economica come quello attuale, i meccanismi di incentivazione vigenti hanno mostrato buoni risultati in termini di risparmio conseguito ma anche di volano per la crescita economica. Il regime dei Certificati Bianchi ha dimostrato il suo ruolo fondamentale per la realizzazione degli interventi, in particolare nel settore industriale.

Parallelamente, in un periodo in cui si conferma ancora una volta la crisi del mercato delle nuove edificazioni, il recupero e la riqualificazione energetica del patrimonio esistente costituiscono la parte preponderante del fatturato del settore.

Infine, considerando sia le novità dal punto di vista normativo sia le risorse a disposizione, sussiste un importante margine per la realizzazione di nuovi interventi e per il potenzia- mento dello strumento incentivante del Conto Termico.

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L'energia rappresenta un fattore di crescita economica, benessere e progresso tecnologico e sociale. L'utilizzo di energia primaria, cresciuto a livello mondiale del 40% tra il 1980 e il 2010, ha una tendenza destinata a confermarsi anche nel ventennio che ci porterà al 2030 (secondo le stime della International Energy Agency).

"Efficienza energetica" è ormai un termine di uso comune, sia negli ambiti a lui più propri (scientifico, tecnologico, economico), sia in quelli, solo apparentemente, più estranei.

La dicotomia tra la natura immateriale dell'energia e il suo intreccio con la vita quotidiana rende difficile il rapporto tra il necessario rigore scientifico e la traduzione in messaggi semplici ed efficaci, in grado di intercettare anche platee non esperte. Solo la conoscenza sviluppa scelte concrete che ciascuno di noi è chiamato a fare, nella consapevolezza delle opportunità e dei rischi che l'insieme dei nostri comportamenti individuali può innescare su scala globale.

Emerge sempre più, quindi, la necessità di divulgazione culturale del tema dell'efficienza energetica, coinvolgendo non solo gli addetti ai lavori, ma l'intera opinione pubblica. Le risorse immateriali della comunicazione appaiono elementi imprescindibili per far funzionare al meglio la risorsa materiale dell'energia, per metterla al servizio del bene comune.

Un notevole vantaggio, inoltre, è che l'efficienza energetica non suscita opposizioni, in quanto evocativa di molteplici vantaggi, sebbene la cultura specifica in materia sia scarsa e confusa.

Le misure di efficienza energetica sono sempre più riconosciute come un mezzo per ridurre le emissioni dei gas serra, migliorare la sicurezza dell'approvvigionamento e ridurre i costi delle importazioni. Non ultimo, garantisce un sistema energetico meno esposto ai rischi e alla volatilità che la crescita economica globale inevitabilmente determina, promuovendo inoltre la competitività delle economie europee.

La leadership dell'Europa nella transizione verso un'economia a basse emissioni di carbonio deve continuare dopo la Conferenza di Parigi, sia attraverso l'attuazione degli obiettivi in materia di clima ed energia per il 2030 che con una diplomazia in materia di clima ed energia coerente, affinché venga garantito che tutti i Paesi diano seguito ai loro impegni. Questa transizione offre grandi opportunità! L'Italia da questo punto di vista è un Paese che si è particolarmente distinto per i risultati raggiunti. Infatti, nella classifica stilata dall'American Council for an Energy Efficient Economy (ACEEE) si piazza al secondo posto delle economie mondiali più avanzate in tema di efficienza energetica. Si tratta del risultato di un'analisi condotta sui Paesi con le 16 economie più grandi del mondo e tiene conto sia delle politiche adottate, sia dei risultati raggiunti.

Le energie rinnovabili e l'efficienza energetica creano posti di lavoro in Europa e richiedono nuove competenze e nuovi investimenti. Molti dei cambiamenti legati a questa transizione avranno luogo nelle città, grandi e piccole; diventando "più intelligenti", le città saranno gli elementi determinanti delle politiche dell'UE in materia di energia sostenibile.

Fare efficienza energetica significa, per un Paese povero di materie prime come l'Italia:

- ridurre la dipendenza energetica;
- stimolare la diffusione delle risorse rinnovabili;
- stimolare l'industria a rendere più prestazionali i sistemi di generazione;
- scegliere configurazioni impiantistiche che prevedano l'uso di sistemi di trasformazione delle fonti fossili più efficienti.

Rimanendo in ambito nazionale, gli strumenti legislativi che ratificano le direttive hanno imposto una serie di obblighi e introdotto dei meccanismi di sostegno per la diffusione di sistemi e soluzioni efficienti (sia dal punto di vista energetico, sia da quello ambientale) da rendere l'efficienza energetica fattore in grado di influenzare, più o meno consapevolmente, alcune nostre azioni.

Per fare qualche esempio, oggi nessuno comprerebbe un elettrodomestico di classe C, piuttosto che una lampadina ad incandescenza e, cosa ancor più importante, nella scelta di tali oggetti la classe energetica, ovvero il consumo, sono diventati fattore discriminante per la scelta. Ma molto c'è ancora da fare. La consapevolezza dell'uso razionale dell'energia non ha raggiunto un livello di maturità sufficiente nei

comportamenti quotidiani. Basta un esempio per rendersene conto. Se mi trovo in una stanza con le luci artificiali accese e l'illuminazione naturale è intensa, correttamente spengo le luci. Ma se in una giornata invernale i riscaldamenti rendono la casa particolarmente calda, non agisco sulle valvole del mio termosifone per regolarlo ma … apro la finestra! Perché questo doppio comportamento? Perché se spengo la luce, l'effetto è immediato, mentre se spengo il termosifone prima di percepire l'abbassamento della temperatura della stanza è necessario un certo periodo di tempo (decine di minuti). L'aspetto psicologico gioca un ruolo determinante e sottolinea quanto sia fondamentale l'informazione degli utenti finali, ma anche degli operatori, per aumentare la consapevolezza sull'uso razionale delle risorse energetiche.
Il numero monografico EFFICIENZA ENERGETICA E VANTAGGI PER LO SVILUPPO, curato da Maria Laura Padovani, Giovanni Puglisi, Roberta Roberto e Paola Batistoni, nasce con l'intento di fornire elementi utili a comprendere, delineare prospettive e individuare strumenti per l'immediato futuro.
Il numero si apre con una intervista al direttore esecutivo dell'International Energy Agency (IEA) per poi continuare, nella sezione *focus*, con articoli tecnici che iniziano illustrando i meccanismi di incentivazione attualmente esistenti in Italia e continuano affrontando tematiche più specifiche: la contabilizzazione dell'energia termica negli edifici, le diagnosi energetiche, la mobilità urbana, il sistema agricolo-alimentare, le energie rinnovabili per i data center, un esempio di analisi costi-efficacia. Completano la sezione tre articoli che esulano dall'ambito tecnologico e affrontano il tema dell'efficienza energetica da un punto di vista più generale, il primo esaminandone termini e concetti, un altro le problematiche della comunicazione e un terzo l'interazione fra tecnologia e comportamento umano.
Il *quadrointernazionale* è dedicato alla tematica del contenimento del fabbisogno energetico degli edifici, che rappresentano per il nostro paese il settore che assorbe la percentuale più alta dell'energia destinata agli usi finali (circa il 39%).
Nel *punto e contropunto* abbiamo messo a confronto Rosa Filippini e Chicco Testa, sulla consapevolezza dei cittadini, sul grado di preparazione dell'industria italiana e sulla gestione del processo relativo all'efficienza, risparmio e uso razionale dell'energia.

Energia, Ambiente e innovazione: "La contabilizzazione accurata e trasparente dell'energia"

L'introduzione di sistemi di misurazione e fatturazione del consumo individuale degli appartamenti e degli edifici multi-purpose può generare una sensibile riduzione della domanda di riscaldamento/ raffreddamento. Esiste però una significativa differenza tra sistemi di misura diretta ed indiretta, sia in termini di prestazioni che di tutela del consumatore.
La contabilizzazione accurata e trasparente dell'energia nelle singole unità abitative è certamente un tema centrale nelle politiche nazionali ed europee. Per consentire a tutti i consumatori di energia dell'UE di partecipare pienamente alla transizione energetica, sia gestendo i loro consumi in modo ottimale sia utilizzando soluzioni tecnologiche ad alta efficienza energetica, la Commissione Europea ha recentemente sviluppato il cosiddetto "New Deal for Energy Consumers" (SWD, 2015). Questa strategia si basa sui seguenti tre pilastri:
denominati contatori di energia termica o contatori di calore (heat meter, HM), effettuano una misura puntuale dell'energia termica fornita in un circuito di scambio termico. I secondi sono invece ascrivibili a tre differenti tipologie:

1. i ripartitori di calore (heat cost allocator, HCA);
2. i sistemi di contabilizzazione del calore basati sui tempi di inserzione compensati con la temperatura media del fluido termovettore (insertion time counter, ITC-TC);
3. i sistemi di contabilizzazione del calore basati sui tempi di inserzione compensati con i gradi giorno effettivi dell'unità immobiliare (insertion time counter, ITC-DDC).

La Tabella 1 mostra l'applicabilità di detti sistemi rispettiva- mente in impianti termici a distribuzione verticale ed orizzontale.

impianti a distribuzione verticale (a colonne montanti)

Tipo terminale di emissione	Diretta		Indiretta		
	Contatore Di energia		Ripartitori di calore	Totalizzatori dei tempi di	
Radiatore	non ottimale a)		Ottimale	Ottimale	
Termoconvettore	non ottimale a)		Buona	Ottimale	
Ventilconvettore	non ottimale a)		non realizzabile	non ottimale	
Pannello radiante a pavimento	non ottimale a) b)		non realizzabile	non ottimale b)	
Pannello radiante a parete o	non ottimale a) b)		non realizzabile	non ottimale	
Bocchetta aria calda	ottimale		non realizzabile	non realizzabile	
Impianti a distribuzione orizzontale					
Tipo terminale di emissione	Diretta		Indiretta		
	Contatore di energia		Ripartitori di calore	Totalizzatori dei tempi di inserzione	
Radiatore	Ottimale c)	non ott.	buona	Buona	
Termoconvettore	Ottimale c)	non ott.	buona	Buona	
Ventilconvettore	Ottimale c)	non ott.	non realizzabile	non ottimale	
Pannello radiante a pavimento	Ottimale c)	non ott.	non realizzabile	buona c)	non ott. d)
Pannello radiante a parete o	non ottimale		non realizzabile	buona c)	non ott. d)
Bocchetta d'aria calda	Ottimale		non realizzabile	non realizzabile	

a) condizione antieconomica; b) possibile se il fluido è intercettabile;
c) nel caso le tubazioni di mandata e ritorno siano contenute in appositi moduli; d) nel caso le tubazioni di mandata e ritorno siano sotto traccia

Tab. 1 Compatibilità del sistema di contabilizzazioni

	Metodi diretti	Metodi indiretti		
Strumenti di contabilizzazione	HM	HCA	ITC-TC	ITC-DDC
Norma applicabile	MID (EN 1434)	EN 834	UNI 11388	UNI 9019
Sistema di controllo	Appartamento	Ambiente riscaldato	Zona termoregolata	Zona termoregolata
Accuratezza	Elevata	Media	Media	Medio-bassa
Unità di misura	Dimensionale (energia)	Adimensionale		
Conformità	Marcatura metrologica MID Verifica prima (MID) Verifiche periodiche (DM 155/2013)	Marcatura CE (non metrologica) Nessun Obbligo Verifica Prima Nessun Obbligo Verifiche Periodica		
Costi acquisto e installazione	Medio-alti (installazione complessa)	Economici (Sempliceinstallazion)		

Tab. 2 Caratteristiche dei sistemi di contabilizzazione

I sistemi di contabilizzazione diretta sono attualmente gli unici strumenti regolati al punto di vista metrico legale dalla Direttiva MID, pertanto essi risultano utilizzabili sia per la misura dell'energia termica al punto di fornitura che nella successiva ripartizione dei consumi condominiali. Tuttavia, come si evince dalle Tabelle 1 e 2, tali dispositivi spesso non risultano tecnicamente applicabili o risultano comunque non convenienti dal punto di vista economico. Questo accade, ad esempio, in interventi di retrofit su edifici esistenti sia a causa della configura- zione distributiva degli impianti di riscaldamento (e.g. impianti centralizzati con distribuzione a colonne montanti verticali), sia a causa di vincoli architettonici e economici. Viceversa, i dispositivi di contabilizzazione indiretta sono nella gran parte dei casi pienamente applicabili in edifici esistenti, ma risultano carenti dal punto di vista normativo e regolatorio, ovvero sotto il profilo metrico-legale a garanzia della transazione energetica ed a tutela della fede pubblica.
I sistemi di contabilizzazione indi- retta ad oggi disponibili, ed utilizzabili per la ripartizione delle spese di riscaldamento sono basati su dispositivi e metodologie conformi alla UNI EN 834 (i.e. i ripartitori di calore elettronici), alla UNI 11388 o alla UNI 9019 (i.e. i totalizzatori dei tempi di inserzione).

Configurazione dei sistemi di contabilizzazione

In Figura 1 sono riportate le configurazioni tipiche dei sistemi di contabilizzazione e ripartizione dell'energia termica in ambito condominiale. In particolare si possono individuare tre differenti configurazioni:
a) l'energia consumata dal- le singole unità immobiliari viene misurata mediante HM diretti;
b) la ripartizione dell'energia termica avviene mediante i conteggi degli HCA;
c) la ripartizione avviene mediante ITC (compensati della temperatura del fluido o dei gradi giorno).
In tutte le soluzioni indicate il calcolo dell'energia totale immessa nella rete di distribuzione (sia essa fornita da una caldaia che da un altro sistema di produzione o da una sotto-stazione di teleriscaldamento) deve essere effettuato, coerentemente alla norma UNI 10200, sulla base di misure effettuate con uno o più contatori di calore posti a valle dei sistemi di generazione (come indicato in Figura 1) o in base alle prestazioni dei generatori di calore e al consumo di combustibile o energia elettrica.

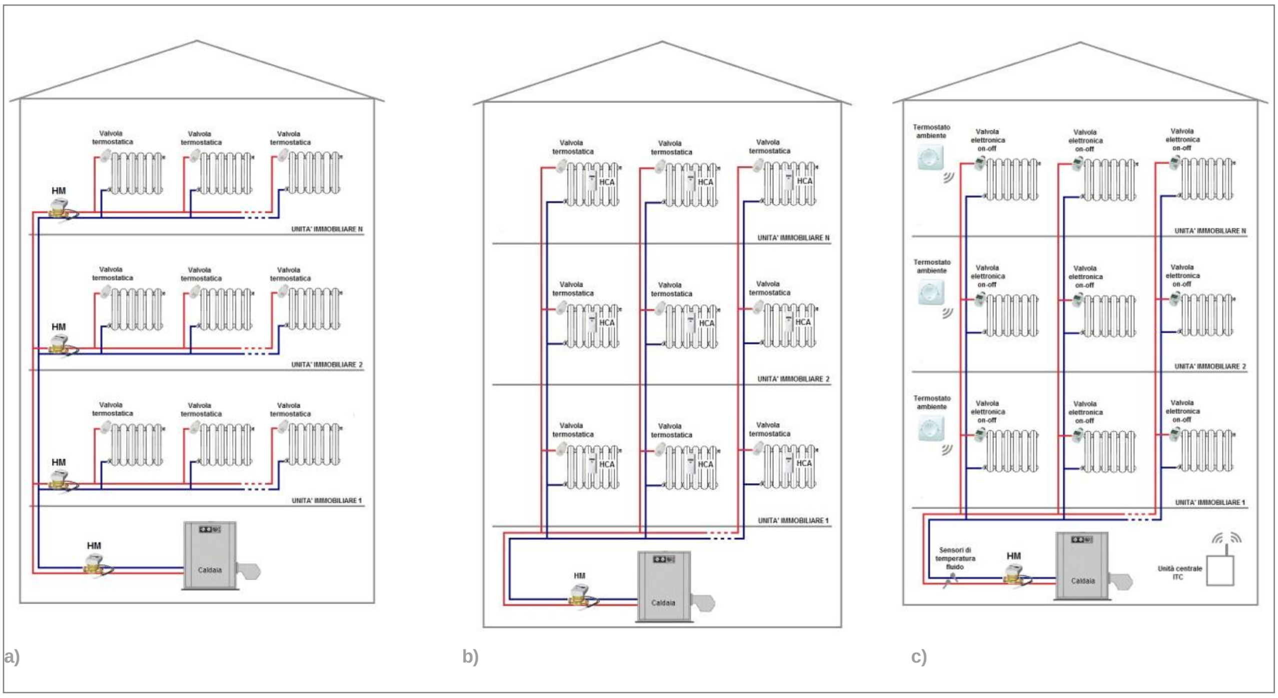
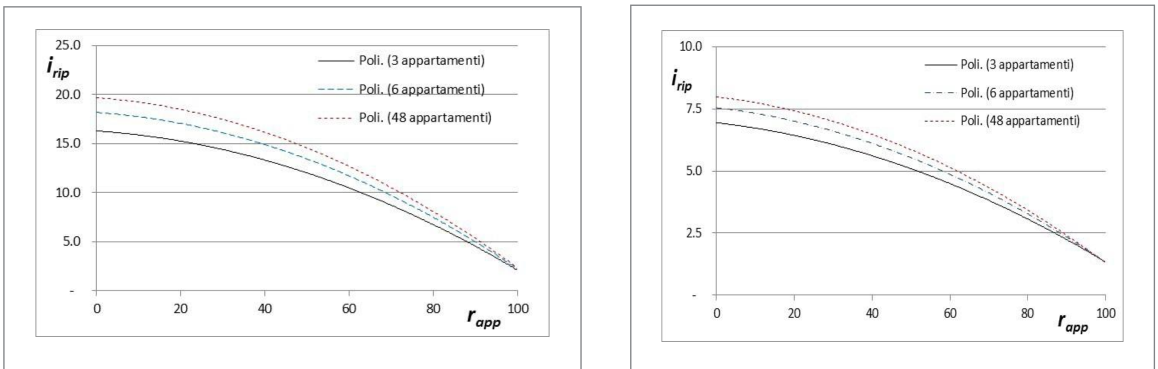


Fig. 1 Configurazione dei sistemi di contabilizzazione e ripartizione del calore, a) ripartizione con HM; b) ripartizione con HCA, c) ripartizione con ITC.

La configurazione "a" garantisce la correttezza delle misure effettuate entro i limiti ammessi dalla Metrologia Legale (Direttiva MID).
Tuttavia, in numerose applicazioni su edifici esistenti essa risulta non applicabile ed è necessario ricorrere a sistemi di contabilizzazione di tipo indiretto.
La configurazione "b" prevede l'utilizzo su ciascun corpo scaldante dell'edifico di un ripartitore di calore (HCA). Il valore di conteggio restituito dall'HCA è dato dall'integrale nel tempo della differenza tra la temperatura superficiale del corpo scaldante e quella dell'aria ambiente moltiplicato per un fattore di valutazione totale, K.
La ripartizione dei consumi di energia volontari viene valutata come rapporto tra le unità di ripartizione in un singolo appartamento e quelle dell'intero edificio (UNI 10200, 2015).
Gli HCA sono utilizzabili unicamente su unità terminali tipo radiatori o convettori. I ripartitori elettronici disponibili sul mercato sono generalmente dotati di un'interfaccia ottica di programmazione e lettura e/o di un sistema di trasmissione wireless che consente le letture dei dati a distanza.
Sia nella configurazione "a" che nella "b" deve essere prevista l'installazione di un sistema di termo regolazione costituito da valvole termostatiche o, in alternativa, valvole on-off controllate da uno o più termostati ambiente.
La configurazione "c" invece prevede l'utilizzo di contatori dei tempi di inserzione (ITC) compensati della temperatura di mandata del fluido termovettore o dei gradi giorno. In questo caso, i termostati, installati in ogni unità immobiliare o zona termica, attivano/disattivano valvole on-off di zona o di corpo scaldante insieme al contatore dei tempi di inserzione. Tutti i componenti del sistema dialogano con una unità centrale in grado di elaborare i dati e fornire i conteggi utilizzabili ai fini della ripartizione dei consumi volontari.
Questi sistemi possono essere applicati ad impianti a distribuzione verticale ed orizzontale (con radiatori, termoconvettori, ventil-convettori, pannelli radianti) in cui il fluido termovettore è intercettabile o su ciascun corpo scaldante, o a li- vello di zona o, almeno, a livello della singola unità immobiliare.



caldanti e installazioni simili (r_{cs}=90%)

b) Corpi scaldanti e installazioni diversi tra loro

Fig. 2 Incertezza di misura al variare della correlazione e del numero di appartamenti

Accuratezza della ripartizione

La trasparenza del dato di consumo energetico e l'accuratezza della misura sono, come detto, due aspetti fondanti del cosiddetto "New Deal" e devono, quindi, rappresentare per il progettista della rete condominiale un obiettivo inderogabile. Purtroppo la complessità dei sistemi di misura e la molteplicità delle caratteristiche impiantistiche rende spesso arduo tale compito. Per tale motivo la sperimentazione messa in atto presso l'Università di Cassino mira a testare in campo da un lato la capacità degli utenti di acquisire e comprendere le misure e di adeguare di conseguenza i propri consumi, dall'altro di valida- re un modello per la stima "a priori" dell'incertezza di misura.
Mentre le incertezze estese dei singoli dispositivi di misura e contabilizzazione diretti (derivanti soprattutto dalle incertezze sulla misura delle portate volumetriche e delle tempera- ture) ed indiretti (derivanti soprattutto dalle incertezze sulle potenze termiche effettive dei corpi scaldanti e delle temperature effettive misurate), riportate in Tabella 3, sono facilmente calcolabili applicando il modello ISO, più complessa è la valutazione della accuratezza della ripartizione nella ripartizione dei consumi dell'intero edificio. A tale scopo è opportuno sottolineare che:

1. il contributo delle incertezze accidentali sulle unità di ripartizione di ciascun appartamento si riduce al crescere del numero di corpi scaldanti installati nel singolo appartamento;
2. il contributo delle incertezze accidentali sulle unità di ripartizione conteggiate sull'intero edificio si riduce al crescere del numero di appartamenti e pertanto può ritenersi trascurabile nei grandi con- domini;
3. gli effetti correlativi tra ripartitori o totalizzatori installati nel singolo appartamento contribuiscono ad aumentare le incertezze sistemati- che di ripartizione;
4. gli effetti correlativi tra appartamento ed edificio contribuiscono a ridurre le incertezze sistematiche di ripartizione.

Tutto ciò determina un'incertezza complessiva del sistema di contabilizzazione inferiore a quella del singolo dispositivo (ripartitore/totalizzatore) installato su ciascun corpo scaldante.

Per stimare l'incertezza è però fondamentale valutare i coefficienti di correlazione sia tra corpi scaldanti del medesimo appartamento, che tra quelli di diversi apparta- menti. Ciò è possibile valutando il numero di corpi scaldanti simili per tipologia, per modalità di installazione e di esercizio. In Figura 2 viene riportato l'andamento dell'incertezza nella ripartizione del calore in funzione del coefficiente di correlazione rcs (tra la tipologia dei corpi scaldanti
installati nel medesimo edificio) e al
variare di rapp (tra tipologie di corpi scaldanti nell'appartamento in esame e i restanti tipologie di corpi scaldanti installate negli altri appartamenti) nelle seguenti ipotesi semplificative:

1. incertezza accidentale, iA=3%;
2. incertezza sistematica, iB=15%;
3. 10 corpi scaldanti per appartamento. Dall'analisi dei risultati emerge che l'incertezza di ripartizione aumenta notevolmente al decrescere della correlazione rapp (dovuto ad esempio ad una ristrutturazione parziale di un solo appartamento). L'incertezza di ripartizione presenta comunque una migliore compensazione nel caso di corpi scaldanti e relative installazioni dei sistemi di misura molto diversi tra loro (Figura 2b).

Inoltre l'effetto della compensazione degli errori è più rilevante nei piccoli condomini, laddove cioè la percentuale dei consumi del singolo appartamento è più rilevante.
La sperimentazione in corso consentirà sia di validare il modello di stima dell'incertezza nella ripartizione, sia di progettare ex ante in modo ottimale il sistema di misura. I risultati di una prima sperimentazione condotta su una villa bifamiliare in una stagione di riscaldamento sembrano confermare il modello proposto.
Conclusioni
Nel presente lavoro gli autori, a valle di una breve disamina dei sistemi di contabilizzazione e ripartizione del calore, presentano l'architettura dei sistemi di contabilizzazione diretti ed indiretti in ambito

residenziale.
Vengono inoltre presentati i primi risultati relativi al modello di stima dell'incertezza di ripartizione dei sistemi indiretti.
L'analisi dei diversi sistemi di contabilizzazione e misura in ambio residenziale mostra che:
esiste una profonda differenza tra sistemi di misura diretti ed indiretti, sia in termini di prestazioni che di tutela del consumatore;

	Incertezza	
	minim	massim
Contatori di calore HM	2%*	9%
Ripartitori HCA	3%	24%
Totalizzatori ITC-	6%	30%
Totalizzatori ITC-	15%	30%

* stimato per un HM in classe 1
** relativo ai totalizzatori conformi alla UNI 11388:2015
Tab. 3 Incertezze estese dei singoli dispositivi di misura e contabilizzazione

malgrado la semplicità dei sistemi di ripartizione indiretti, non sempre le prestazioni metrologiche in campo sono congruenti con le specifiche di prodotto, a causa della difficoltà nella stima dei fattori di valutazione (ovvero delle potenze termiche effettive dei corpi scaldanti su cui gli stessi sono installati e delle temperature effettive misurate); le condizioni di installazione ed operative possono influenzare significativamente le prestazioni metrologiche sia dei sistemi diretti che di quelli indiretti; in particolare gli aspetti più critici rilevati sono la misura su ridotte differenze di temperatura e gli effetti fluidodinamici che si determinano in condizioni di installazione non standard.

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Energia, Ambiente e innovazione: "Efficienza energetica: la strada per innovare il sistema agricolo-alimentare"

In Italia, il settore agricolo-alimentare, che include i comparti agricoltura, industria di trasformazione, distribuzione e servizi, ha un consumo finale di energia di 13,30 Mtep. Esaminati i costi di energia diretta e

indiretta del comparto agro-alimentare, vengono sottolineate le misure e le innovazioni tecnologiche disponibili per migliorare l'efficienza energetica e la sostenibilità ambientale del sistema agroalimentare.
I beni alimentari rappresentano il settore più importante dell'industria manifatturiera nell'Unione Europea (UE), con una presenza di piccole e medie imprese di oltre il 90% distribuite soprattutto nel Sud dell'Europa. Soltanto l'1% delle aziende del settore, tuttavia, può essere catalogato come "grande impresa". Nei 28 Paesi dell'Unione Europea, il sistema agricolo-alimentare (produzione primaria, trasformazione e distribuzione) ha raggiunto nel 2012 un fatturato complessivo che supera i 1.000 miliardi di € (RAEE - Rapporto Annuale Efficienza Energetica, 2015). Sotto il profilo energetico, in Europa, il settore dei beni alimentari contribuisce per il 26% ai consumi finali di energia. A livello globale, la FAO stima una quota superiore al 30%, basandosi però su dati spesso incerti e provenienti da fonti diverse.

Sistema agricolo-alimentare	% del consumo totale di energia	Consumo energia finale	Fonte
Mondo	32%	95 EJ/anno *	FAO, Issue paper 2011 "Energy-smart food for People and climate"
Europa-27	26%	285 Mtep	Elaborazione ENEA da JRC, Science and Policy, Report 2015
Italia	11,18%	13,30 Mtep	ENEA-UTEE, RAEE 2016

* 1 exajoule (EJ) = 1018 Joules

Energia per i prodotti refrigerati: 50-60 kWh/anno/m3

Tab. 1 Stime sui consumi di energia del sistema agricolo-alimentare

Infine, in Italia, i consumi di energia del sistema agricolo-alimentare rappresentano circa il 11,18% dei consumi totali (Tabella 1).
Sotto l'aspetto delle emissioni di CO_2, nel 2010, la Commissione Europea stima per la filiera agroalimentare in Europa (produzione, trasformazione, distribuzione, ristorazione, consumo domestico) circa 1.000 milioni di tCO_2eq (EC, Preparatory study on food waste across EU 27. October(33), 2010).
Nel sistema agricolo- alimentare, i consumi diretti di energia, che includono i combustibili per le serre e i trasporti, risultano pari a 4,95 Mtep, mentre i consumi indiretti, tra i quali il consumo di fitosanitari, fertilizzanti e materiali plastici, raggiungono i 8,35 Mtep, per un to-tale di 13,30 Mtep. Diversamente, il comparto agroindustria richiede in- genti quantità di energia, soprattutto calore ed energia elettrica per i processi di produzione, trasformazione, conservazione dei prodotti di origine animale e vegetale, funzionamento delle macchine e climatizzazione degli ambienti produttivi e di lavoro (RAEE, 2016).

Tab. 2 Consumi di energia della Grande Distribuzione Organizzata in Europa Fonte: AICARR 2015; RAEE 2015

50-60% dei consumi per energia elettrica	
Energia per i prodotti refrigerati: 50-60 kWh/anno/m3	
Energia per i prodotti congelati: 60-70 kWh/anno/m3	
Consumo di energia: 500-1000 kWh/anno/m2	
50-60% per refrigerazione	Media: 290 kWh/anno/m2
25% per luce	Nota: In Italia, dove sono state censite aree commerciali per la Grande Distribuzione Organizzata per 3.100 ha nel 2013, questo settore riporta un consumo annuale di energia elettrica pari a 4,5 Mtep
20% per condizionamento	
5% per altri usi	

Nell'ultimo decennio, la Grande Distribuzione Organizzata (GDO) si è affermata giocando un ruolo fondamentale nell'attuale modello di agroindustria *energy intensive*, sostenendo sia la diffusione dei beni alimentari che il miglioramento della sicurezza alimentare. Tuttavia, la GDO ha anche contribuito ad aumentare i costi energetici associati al settore primario e all'industria alimentare. La Tabella 2 riporta una stima dei costi energetici relativi al comparto della GDO in Europa.
Particolare attenzione si pone per la filiera dei prodotti di IVa (prodotti che non hanno subito trattamenti di trasformazione con impieghi di calore o freddo, ma sono puliti, taglia- ti, confezionati in vaschette e pronti al consumo) e di Va gamma (pro- dotti semilavorati che hanno subito un trattamento termico di cottura, successivamente confezionati sotto- vuoto o in atmosfera controllata), in quanto si collocano tra le filiere più energivore.

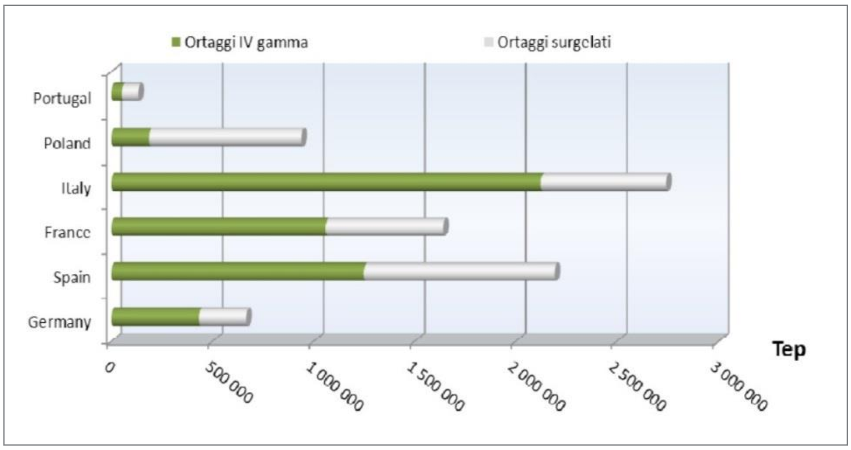

Fig. 1 Consumi energetici della IVa gamma e dei surgelati in Europa

Fonte: ENEA su dati EUROSTAT 2013

La Figura 1 riporta i dati cumulati sulla diffusione e sui consumi energetici che caratterizzano l'industria europea della IVa gamma e degli ortaggi surgelati in Europa. Una misura dell'efficienza energetica nelle filiere agroalimentari è rappresentata dal rapporto tra la quantità di energia ottenuta (ad esempio l'energia contenuta nel prodotto vegetale) e l'energia in ingresso (ossia la quantità di energia che viene utilizzata per il processo di coltivazione e/o il processo di produzione industriale). A tal proposito, la Tabella 3 mostra la forte sproporzione tra l'energia contenuta nei prodotti e l'energia utilizzata nel processo produttivo dei comparti della carne, delle produzioni vegetali, degli ortaggi di IVa gamma e dei surgelati. Particolarmente significativi sono i rapporti elevati nei comparti della carne (5:1) e delle produzioni in serra (20:1), soprattutto se confrontati con la coltivazione dei vegetali in campo che presentano un rapporto quasi pari a 1.
Un ulteriore elemento di riflessione, da non sottovalutare nella prospettiva di favorire un uso più razionale dell'energia nel sistema agricolo- alimentare, è il fenomeno dello spreco di cibo. La FAO nel 2011 riportava per i Paesi industrializzati uno spreco medio di 95÷115 kg/ anno/persona, soprattutto a livello di rivenditore e di consumatore, e uno spreco di 6÷11 kg/anno/persona per i Paesi in via di sviluppo, in particolare nelle fasi dopo raccolto e della lavorazione, data la scarsità di mezzi e tecnologie. Oltre che nelle filiere agroalimentari, gli sprechi caratterizzano anche il settore della pesca, dove l'UE ha calcolato che il 40÷60% di tutto il pescato sia ributtato in mare, mentre l'*Environment Programme* delle Nazioni Unite ha riportato che gli scarti totali annuali di pesce a livello mondiale ammontano a 30 milioni di tonnellate e che mediamente solo metà del pescato viene consumato (Tristram Stuard, 2009). Una tecnologia che di recente ha trovato una significativa considerazione da parte degli operatori delle imprese agroalimentari è la digestione anaerobica per la produzione di biogas attraverso l'impiego degli scarti agroalimentari. Studi della Regione Emilia-Romagna riporta- no che dagli scarti della lavorazione industriale provenienti delle produzioni agricole regionali (soprattutto mais, pomodoro, patate e leguminose) è associata una

potenzialità di produzione di 11 milioni di m3 di biometano che equivalgono a circa 9 kWh/m3 (Segré, 2013).

Efficienza energetica per il settore agricoltura e l'industria agroalimentare

L'introduzione nei processi agroindustriali di tecnologie capaci di migliorare l'efficienza energetica del sistema agricolo-alimentare costituisce ormai una priorità rispetto alla necessità di aumentare la sostenibilità energetica ed ambientale del settore primario e dell'industria alimentare.

Prodotti alimentari (consumi considerati)	Energia consumata (kcal/kg)	Energia per kg di prodotto (kcal/kg)
Carne fresca (stalla, macellazione)	4.712	1.100,6
Carne surgelata (stalla, macellazione, refrigerazione)	7.007,8	1.100,6
Vegetali freschi in campo (fitosanitari, lavorazione terreno)[a]	187	206,3
Vegetali freschi in serra riscaldata (fitosanitari, combustibile)[b]	5.245,1	206,3
Ortaggi IV[a] gamma[c] (produzione, lavorazione, trasformazione)	4.213,3	189,1
Ortaggi surgelati (produzione, lavorazione, trasformazione, refrigerazione)[c]	5.847	189,1

[a] I valori dell'energia consumata sono stati riferiti a 15 kg/m²/anno. Il trasporto non è incluso

[b] I valori dell'energia consumata sono stati riferiti a 25 kg/m²/anno. Il valore energetico medio è stato riferito a: lattuga, pomodoro, peperone, cetriolo, fragola. Il trasporto non è incluso

[c] Valore energetico medio di: lattuga, pomodoro, peperone, cetriolo. Il trasporto non è incluso

I valori energetici sono stati tratti dalle tabelle composizioni alimenti dell'INRAN (Istituto Nazionale di Ricerca per gli Alimenti e la Nutrizione)

Tab. 3 Energia del prodotto ed energia immessa
Fonte: ENEA su dati ISTAT, 2013

Attraverso la partecipazione al progetto TESLA (*Transfering Energy Save Laid on Agroindustry*; www.teslaproject.org), l'ENEA ha individuato e proposto una serie di metodi e tecnologie innovative utili per migliorare l'efficienza energetica e diminuire gli impatti ambientali (Tabelle 4 e 5). La Tabella 4 riporta alcune proposte ENEA per migliora- re l'efficienza energetica del sistema agricolo-alimentare.

Inoltre, occorre sottolineare che l'energia indiretta, in termini di fitosanitari e fertilizzanti per i processi agricoli, rappresenta una quota significativa dei consumi energetici per le filiere agroindustriali (la produzione di una tonnellata di azoto richiede in media il consumo di una tonnellata e mezzo di petrolio). Diversamente, per i fitosanitari (dati Istat stimano al 2014 un consumo di circa 30.000 t), si riportano in media intensità energetiche comprese tra i 18 e i 100 kWh/kg (Pagani e Vittua- ri, 2013). A questo proposito, appare sempre più importante l'impiego dei metodi e delle tecniche dell'agricol- tura biologica che, oltre a favorire il risparmio di energia indiretta dovuta ai fitosanitari e ai fertilizzanti (il consumo di energia dell'agricoltura biologica è mediamente inferiore di un terzo rispetto all'agricoltura convenzionale), consente anche una maggiore qualità delle produzioni in termini di sicurezza alimentare e di sostenibilità ambientale (le aziende biologiche limitano fortemente l'uso di fitosanitari e fertilizzanti). A tal proposito, nel Rapporto 2013, l'EFSA (*European Food and Safety Authority*) ha riportato che nell'1,6% dei prodotti ortofrutticoli analizzati sono risultate concentrazioni superiori ai livelli consentiti per alcuni determinati pesticidi.

L'ISPRA, nel Rapporto nazionale pesticidi nel- le acque del 2014 (dati 2011-2012), ha stimato che nelle acque superficiali sono stati trovati residui di pesticidi nel 55,5% dei 1.469 punti di prelievo. Ai fini del miglioramento dell'efficienza energetica nel sistema agricolo-alimentare si configurano di particolare importanza sia l'implementazione della norma ISO 50001:2011, che rappresenta il nuovo standard internazionale per la gestione dell'energia, sia l'applicazione di sistemi di gestione ambientale o certificazione EMAS, come sottolineato dal recente Decreto Legislativo 102/14, che ha recepito la Direttiva europea sull'efficienza energetica 27/ EU/2014. Il decreto definisce le rego- le per migliorare l'efficienza energetica delle imprese e per implementare la norma ISO 50001 che ha sostituito la precedente EN 16001:2009.

Tecnologia utilizzata	Aspersione con rotolone gigante	Batterie di ventilatori ad accensione sequen- ziale e restringimento meccanico della portata
Fattori che condizionano il consumo di energia	Alta pressione di esercizio (10-12 bar) e rendi- mento irriguo alla pianta superiore del 65%	Velocità di funzionamento costante
Innovazione	Aspersione con pivot e ala piovana con pressio- ne di esercizio di 2-3 bar; irrigazione a goccia	Regolatore di frequenza (inverter) e gestione automatica dell'impianto
Risparmio energetico	*25%*	*40-70%*
Costo investimento	*medio*	*Medio-alto*
Pay-back period (anni)	*5*	*7*

Tab. 4 Innovazione tecnologica per migliorare l'efficienza energetica

Applicazione	**Tecnologie alternative**
Recupero flussi di calore	Scambiatori di calore per acque di scarico cicli di lavaggio e scarico Scambiatori di calore per gas di scarico di essiccatori e caldaie a vapore Recupero calore dalle condense del vapore Recupero calore dell'aria degli ambienti di lavoro
Uso più razionale delle macchine di processo e di servizio	Utilizzo motori elettrici più efficienti Utilizzo trasformatori elettrici più efficienti Installazione inverter per motori elettrici Controllo automatico/centralizzato delle utenze
Interventi sugli impianti (tecnologie sostenibili) e sulla struttura (contenimento termico)	Solar *cooling* per la climatizzazione Tecnologie fotovoltaiche per la produzione di energia Utilizzo di caldaie a biomassa per la climatizzazione Coibentazione degli ambienti di stoccaggio e dell'impianto di distribuzione del calore Miglioramento delle prestazioni energetiche dell'involucro edilizio Installazione di *energy* management software negli ambienti di lavorazione, trasformazione e stoccaggio

Tab. 5 Proposte per migliorare l'efficienza energetica nella filiera agroalimentare

Conclusioni

Il sistema agricolo-alimentare mo- derno, basato su un'organizzazione industriale del lavoro e sul modo di produrre e consumare il cibo, se da un lato ha contribuito al miglio- ramento delle condizioni socio-economiche e all'aumento della qualità e della sicurezza alimen- tare dei prodotti, da un altro lato, tuttavia, ha troppo spesso trascu- rato i costi energetici e gli impatti ambientali che risultano associati alla produzione e al mercato degli stessi beni alimentari.

La Direttiva europea sull'efficienza energeti- ca 27/EU/2014 responsabilizza le imprese e stimola i cittadini a una maggiore consapevolezza dei con- sumi di energia. Una maggiore at- tenzione per l'agricoltura biologica ai fini della diminuzione dei costi energetici e degli impatti ambien- tali e l'introduzione di innovazione tecnologica si pongono ormai come strategie prioritarie per il sistema agricolo-alimentare. L'ENEA con- tribuisce allo sviluppo dell'efficienza energetica fornendo un sostegno al meccanismo dei Certificati Bianchi e soprattutto con i controlli di confor- mità delle diagnosi energetiche di al- meno il 3% sul totale (o 100% in caso di auditor interno all'azienda). La più ampia collaborazione tra istituzioni, agenzie, mondo scientifico e consu- matori è fondamentale per rendere il sistema agricolo-alimentare meno *energy intensive* e più responsabile verso le risorse naturali di energia, aria, acqua e suolo.

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2) *Efficienza Energetica per la competitività delle imprese agricole, agroalimentari e forestali*". ENEA Sede, 14 giugno 2016.

Scopo e tematiche affrontate:

scopo dell'evento, organizzato presso la sede ENEA di Roma il prossimo 14 giugno, è quello di affrontare i temi della riqualificazione tecnologica e della competitività del sistema agricolo-alimentare in linea con i programmi europei e nazionali sull’efficienza energetica, sulla green economy e sullo sviluppo economico sostenibile.
I consumi totali di energia finale del sistema agricolo-alimentare rappresentano il 32% su scala mondiale, il 26% nell’Unione Europea e circa il 13% nel 2013 a livello nazionale. Le filiere agricole e agroalimentari richiedono energia fossile in termini diretti per i macchinari, la trasformazione, il condizionamento climatico e la commercializzazione, in termini indiretti per i fitosanitari, i fertilizzanti e i materiali plastici. Secondo la UE, il sistema agricolo-alimentare in Europa (produzione, trasformazione, distribuzione, ristorazione, consumo domestico) è responsabile dell’emissione annuale di 1000 milioni di $tCO2_{eq}$.
L’ENEA sulla base del decreto 102/14, che ha recepito la direttiva 2012/27/UE sull’Efficienza Energetica, svolge l’attività di controllo sulla conformità delle diagnosi energetiche delle imprese e contribuisce al raggiungimento degli obiettivi del “Quadro 2030 per le politiche dell’energia e del clima”. Inoltre, collabora con il MIPAAF, sulla base di un Protocollo d’Intesa triennale, per promuovere l’efficienza energetica e l’uso delle fonti rinnovabili di energia nei settori produttivi agricoli, agroindustriali e forestal