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Economic and Technical Feasibility of Metering and Sub-metering Systems for Heat Accounting

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ABSTRACT

The energy efficiency directive 2012/27/EU (EED) requires that final users in multi-apartment buildings supplied by common central heating source should be provided by 31 December 2016 with accounting systems, as long as technical feasibility and reasonable costs in relation to the potential energy savings can be demonstrated. Such systems would reflect users actual thermal energy consumption. The typical configuration of Italian multi-apartment buildings implies quite expensive installation costs and sometimes even prevents the installation for technical reasons. Coherently with EED, in such cases alternative cost-efficient methods for heat accounting should be adopted, such as indirect methods. This study assesses the economic and technical feasibility of the most common heat accounting systems. In this paper, after a brief analysis of the different approaches adopted in EU member states, the authors present a cost/benefit analysis that considers the main capital and running costs of individual heat accounting systems with respect to the potential energy savings achievable.

Keywords: Energy Efficiency, Heat Accounting, Cost Efficiency
JEL Classifications: O31, O33

1. INTRODUCTION

The European directive 2012/27/EU (European Parliament, 2012) on energy efficiency directive (EED) considers individual metering of heat consumption a remarkable potential driver of energy efficiency. According to the article 9.3 of EED, multi-apartment buildings supplied by a district heating network or by a common central heating/cooling source should be provided by 31 December 2016 with individual meters capable to effectively measure the consumption of heat or cooling or hot water for each unit where technically feasible and cost-efficient. According to the EED, individual direct heat meters (HMs) should be preferentially installed. Nevertheless, under certain circumstances, the use of individual HMs might be technically complicated and costly in relation to the potential energy savings. In such cases, alternative cost-efficient methods for heat accounting should be adopted, such as indirect methods. The modest diffusion of allocation services (especially in countries with moderate climate) avoided the development of studies regarding costs and benefits associable to real individual consumptions.

In Italy, almost 5.5 million apartments are potentially subject to the requirements of EED, of which only 2% are already equipped with direct HMs or indirect heat cost allocators (HCAs) (Felsmann et al., 2015). However, such estimation is quite approximate, as in a subset of them both direct and indirect heat metering might result technically or economically unfeasible. Table 1 shows the characteristics of Italian residential buildings (ISTAT, 2011).

Unfortunately, the typical configuration of heating plants in Italian multi-apartment buildings rarely allows an easy installation of direct HMs and such installation is often quite expensive or even technically unfeasible (e.g., in historical buildings). When HMs are not economically or technically feasible, the EED allows the installation of indirect systems, such as HCAs, which are particularly useful in buildings with architectural or structural constraints (Authors, 2015a). Noticeably, indirect systems do not carry out a direct and accurate measurement of thermal energy consumptions, since they give back a dimensionless estimation of heat consumption through some parameters strongly correlated with it. Such estimation can be therefore used to share heating/cooling costs of the entire building among single users, incentivizing tenants to reduce their own energy consumption also through operational rating energy diagnosis instead of asset rating one (Authors, 2015b).

In Italy, Decree 102/14 implemented the EED and confirmed the mandatory installation of heat accounting systems by 31 December 2016. The Decree identified suitable existing standards and technical recommendations to accomplish the goal and delegated the authority for electricity, gas, and water to set appropriate regulations for service, quality and safety of district heating and of individual heat accounting. In this respect, the national standard UNI 10200:2015 provides specific information about the design and management of heat accounting systems, expressly quoting both direct and indirect meters.

EU member states are implementing the EED quite differently one from another. In some countries, such as Germany and Austria, almost every building is obliged to install individual metering and sub-metering systems, with few specific exceptions. In other countries, such as Great Britain, a technical and economical assessment is to be performed for each building. Finally, in other countries, such as France and Sweden, the commitment to introduce individual heat accounting systems is quite limited, as their economic efficiency is still considered unsatisfactory.

EU commission is oriented to suggest the member states to implement specific actions for individual heat accounting and informative billing in order to maximize energy savings in the residential sector. Such actions should be considered in view of the building characteristics and of their economic efficiency.

Buildings can be classified according to the following three types:
- Viable buildings, whose characteristics suggest that technical and economic feasibility is likely to be satisfactory in most cases;
- Exempted buildings, whose characteristics suggest that technical and economic feasibility is likely to be not efficient in most cases;
- An open class of buildings which cannot be classified neither as viable nor exempted, which need an individual assessment of technical and economic feasibility.

The assessment of the economic efficiency of individual heat accounting systems requires an in-depth estimation of the related capital and running costs and of expected benefits in terms of energy savings potentially achievable from the installation of individual metering and sub-metering systems. To this aim, Table 2 shows capital and running costs of direct HMs and indirect HCAs and of the needed thermostatic valves available for the German (Felsmann and Schmidt, 2013) and UK (Olloqui and Duckworth, 2014) markets. Noticeably, available costs of German market do not include costs for thermostatic valves, whereas for UK market such information is available.

To date, several studies provided estimations of energy savings in different building typologies across several European countries (Table 3). Nevertheless, such estimations are extremely variable and range from 8% to 40%, due to different experimental contexts, which include different automation levels of temperature control, the usage of home displays, the frequency of consumption readings, the type of user and of building. Furthermore, existing studies are in most cases referred to central Europe climate, which is very different from the Mediterranean one. In Italy, only a few systematic analyses have been conducted to estimate the expected benefits and, to the best of our knowledge, none of them has been described in literature.

In this paper, after a brief analysis of the main features of direct and indirect heat metering and sub-metering systems, a cost-benefit

Table 1: Residential buildings in Italy (Source: ISTAT)

Construction date	Total (millions)	Social housing (millions)	Single-family buildings (millions)	Total multi-apartment buildings (millions)	Type of heating source (%)		
					None	Individual	Central
<1945	6.60	0.12	2.39	4.21	35	40	15
1945-1955	4.33	0.11	0.99	3.34	25	40	35
1956-1965	5.71	0.17	1.09	4.62	10	40	50
1966-1975	5.14	0.22	1.15	3.99	10	60	30
1976-1985	3.32	0.18	0.80	2.53	10	80	10
1986-2001	2.16	0.12	0.80	1.37	5	90	5
>2001	1.20	0.09	0.42	0.78	5	90	5
Total	28.47	1.03	7.64	20.83	19	55	26

Table 2: Capital and running costs of different direct HMs and indirect HCAs in Germany and UK in case of individual heat measurement and informative accounting

Description	Capital (one-off) cost			Running cost per year		
	Cost per heating element	Cost per apartment	Cost per building	Cost per radiator	Cost per apartment	Cost per building
Germany						
HM	-	€314.00	€21.00	-	€23.80	€67.50
HCA	€39.00	-	€126.00	€5.20	-	€75.10
UK						
HM	-	€257.83	-	-	-	-
HM installation	-	€77.35	€837.95[2]	-	€90.24	-
HCA[1]	€51.57	-	€837.95[2]	-	€90.24	-
Thermostatic valve[1]	€64.46	-	-	-	-	-

[1]Installation costs not included, [2]for N_{APT} ≤8; €1,031.33 for 9< N_{APT}<32; €1,224.70 for 33< N_{APT}<64; €2,578.32 for N_{APT} >65. HM: Heat meters, HCA: Heat cost allocators

analysis of the economic efficiency of such systems is presented and discussed. For the reader's convenience, an Appendix Table 1 including all the acronyms used in this article is available at the end of the paper.

2. DIRECT AND INDIRECT SYSTEMS FOR HEAT ACCOUNTING

As discussed above, thermal energy consumptions can be estimated through direct or indirect devices. Direct thermal energy meters, also known as HMs allow a "true" direct thermal energy measurement and enable accurate measurements of actual consumptions. HMs are regulated by the European Directive on measuring instruments MID (European Parliament, 2004), which guarantees the conformity in both a metrological and legal perspective and recognizes the importance of the technical standard EN 1434 (CEN, 2007a) and of the technical recommendation OIML R75 (2002). Three typologies of indirect measuring devices are available, as summarized in Table 4:

- HCA, regulated by EN 834 (CEN, 2013) and EN 835 (CEN, 1994);
- Insertion time counters compensated with the average temperature of the heat transfer fluid (ITC-TC), regulated by UNI 11388 (UNI, 2015a);
- Insertion time counters compensated with the actual degree-days of the building unit (ITC-DDC), regulated by UNI 9019 (UNI, 2013).

Table 5 shows the technical feasibility of direct HMs and indirect HCAs and ITCs accounting systems in buildings in which a central heating system with vertical or horizontal configuration is available, coherently with the technical standard UNI 10200 (UNI, 2015b). It turns out that heat accounting with direct HMs is not always technically feasible and rarely results cost-efficient. This mainly

Table 3: Average, minimum and maximum expected benefits in some European countries

Reference	Member state	EB (%) Average	Min	Max
(Felsmann et al., 2015; Oschatz, 2004)	Germany	20.2	9	30
(Routledge and Williams, 2012)	UK	20	15-17	30
(Siggelsten and Hansson, 2010)	Sweden	n.a.	10	40
(Gullev and Poulsen, 2006)	Denmark	n.a.	15	17
(Gorzycki, 2014)	Poland	15	8	33
(Biron, 2015)	France	20	19.8	n.a.
(European Commission, 2013)	EU	n.a.	n.a.	30

EB: Expected benefit

Table 4: Technical characteristics of direct and indirect devices for heat accounting

Characteristics	Direct system	Indirect systems		
	HM	HCA	ITC-TC	ITC-DDC
Technical standard	MID+EN 1434	EN 834	UNI 11388	UNI 9019
Control volume for the thermal balance	Heating plant of the apartment	Heated zone[1]	Regulated zone[2]	Regulated zone[3]
Accuracy	High	Medium	Medium	Medium
Costs	Medium-high	Medium	Medium-high	Medium-high
Unit	kWh	Allocation unit (dimensionless)		
Metrological	"CE" + "M" metrology marking (MID)	"CE" marking		
Conformity	Initial verification by manufacturer (MID)	No duty of initial verification		
	Subsequent verification (DM 155/2013)	No duty of subsequent verification		

[1]Heating elements not included, [2]Heating elements and heating plant included, [3]Heating elements, heating plant and perimeter walls included. HM: Heat meters, HCA: Heat cost allocators

Table 5: Technical feasibility of direct and indirect devices for heat accounting

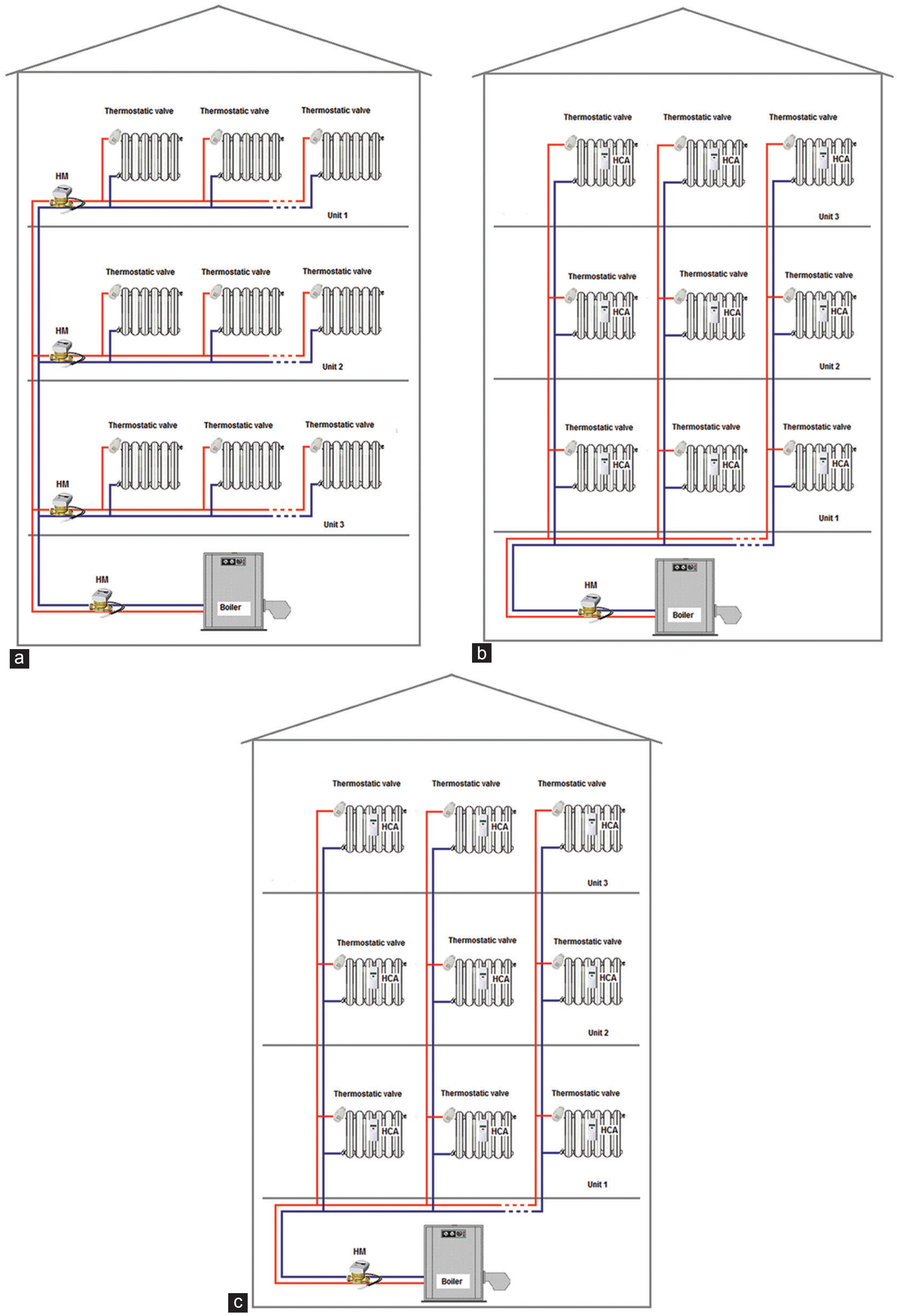
Heating element	Central heating plant with vertical mains				
	Direct systems		Indirect systems		
	HM		HCA	ITC	
Radiator	Poor[1]		Optimal	Optimal	
Convector	Poor[1]		Good	Optimal	
Fan coil	Poor[1]		Not feasible	Poor	
Underfloor heating panel	Poor[1,2]		Not feasible	Poor[2]	
Wall or ceiling heating panel	Poor[1,2]		Not feasible	Poor	
Hot air nozzle	Optimal		Not feasible	Not feasible	
Heating element	**Central heating plant with horizontal pipes (ring)**				
	Direct systems		**Indirect systems**		
	HM		**HCA**	**HM**	
Radiator	Optimal[3]	Poor[4]	Good	Good	
Convector	Optimal[3]	Poor[4]	Good	Good	
Fan coil	Optimal[3]	Poor[4]	Not feasible	Poor	
Underfloor heating panel	Optimal[3]	Poor[4]	Not feasible	Good[3]	Poor[4]
Wall or ceiling heating panel	Poor		Not feasible	Not feasible	Poor[4]
Hot air nozzle	Optimal		Not feasible	Not feasible	

[1]Uneconomicalm, [2]Feasible if the fluid can be intercepted, [3]When flow and return pipes are available in specific modules, [4]When flow and return pipes are embedded in walls. HM: Heat meters, HCA: Heat cost allocators

happens in the case of retrofit interventions on existing building, due to the configuration of the central heating plant (e.g., in the presence of vertical mains) or in the case of architectural constraints (e.g., in historical buildings). Conversely, indirect devices can be installed in most existing buildings but are lacking in a metrological and legal perspective, which are crucial for the fairness of economic transactions and for consumer's protection.

On the whole, heat metering and sub-metering systems in multi-apartment buildings can be classified according to three configurations of the central heating plant (Figure 1): (a) With horizontal pipes (ring configuration) equipped with individual HMs; (b) with vertical mains equipped with HCAs; (c) with vertical mains equipped with ITC-TC or ITC-DDC.

Figure 1: Typical configurations of heat accounting systems with heat meters (a), heat cost allocators (b), and insertion time counters (c)



3. COST-BENEFIT ANALYSIS OF HEAT METERING AND SUB-METERING SYSTEMS

The European standard EN 15459 (CEN, 2007b) is explicitly quoted in the EU Guidance note on EED (European Commission, 2013) and in article 9, par. 5 recital (b) and (c) of Decree 102/2014 as an applicable methodology for the economic assessment of the efficiency of individual metering and sub-metering systems in buildings. In fact, the above-mentioned standard can be used, even partially, for the evaluation of the economic feasibility of energy saving choices in buildings and for the comparison of different options of energy saving in buildings (i.e., system type, fuel type).

EN 15459 (CEN, 2007b) resorts to the following parameters: (i) The real interest rate R_R, i.e., the market interest rate compensated with the inflation rate R_i; (ii) the discount rate $R_d(p)$; (iii) the present value factor $f_{pv}(n)$, that is the multiplicative coefficient of costs/revenues in order to obtain the corresponding value referred to the initial year. The above described parameters are calculated by means of Equations (1), (2) and (3), respectively:

$$R_R = \frac{R - R_i}{1 + R_i / 100} \tag{1}$$

$$R_d(p) = \left(\frac{1}{1 + R_R / 100}\right)^p \tag{2}$$

$$f_{pv}(n) = \frac{1 - (1 + \frac{R_R}{100})^{-n}}{R_R / 100} \tag{3}$$

The economic efficiency of the investment can be therefore assessed from the calculation of the global cost of the investment $C_G(\tau)$ corresponding to calculation period τ (4) or, as an alternative, from the evaluation of the yearly cost (5):

$$C_G(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} \left(C_{a,i}(j) \bullet R_d(i) \right) - V_{f,\tau}(j) \right] \tag{4}$$

$$a(n) = \frac{1}{f_{pv}(n)} \tag{5}$$

Where: R_i is the annual inflation rate (which can depend from the i-th year); p is the number of years; τ is the calculation period in years; C_I is the initial investment cost; $C_{a,i}(j)$ is the annual costs for component or j-th system of the i-th year (nominal value), including the management costs and the costs occurred for replacements; $R_d(i)$ is the discount rate for the i-th year; $V_{f,\tau}(j)$ is the final value of the j-th component or system j-th at the end of the calculation period τ.

Here below, a sensitivity analysis of cost-efficiency of both direct (HMs) and indirect (only HCAs) heat metering and sub-metering systems is presented, taking into account capital expenditure (CAPEX) and operational expenditure (OPEX) costs for the UK market as listed in Table 6. In such analysis the following assumptions are invoked:

- Investment and operational costs as in Table 2 for the UK market;
- An average sized apartment of 80 m²;
- A mean number of radiators for each apartment N_{CS}=5;
- Calculation period τ=10 years;
- Expected benefit EB ranging 10-40% of the energy costs;
- Real interest rate (inflation rate included) R_R=4%;
- Energy rate T_e (€/kWh) of heating, obtained from the gas mean rate T_{gas}=0.80 €/Sm³ and considering the conventional gross heat value of natural gas GHV=38.52 MJ/Sm³ (AEEGSI, 2016).

Furthermore, costs consequential to the installation of individual accounting devices (e.g., supply and installation of circulating pumps and inverters, of thermostatic valves and so on) and to the necessary adjustment of the heating plant itself have been neglected.

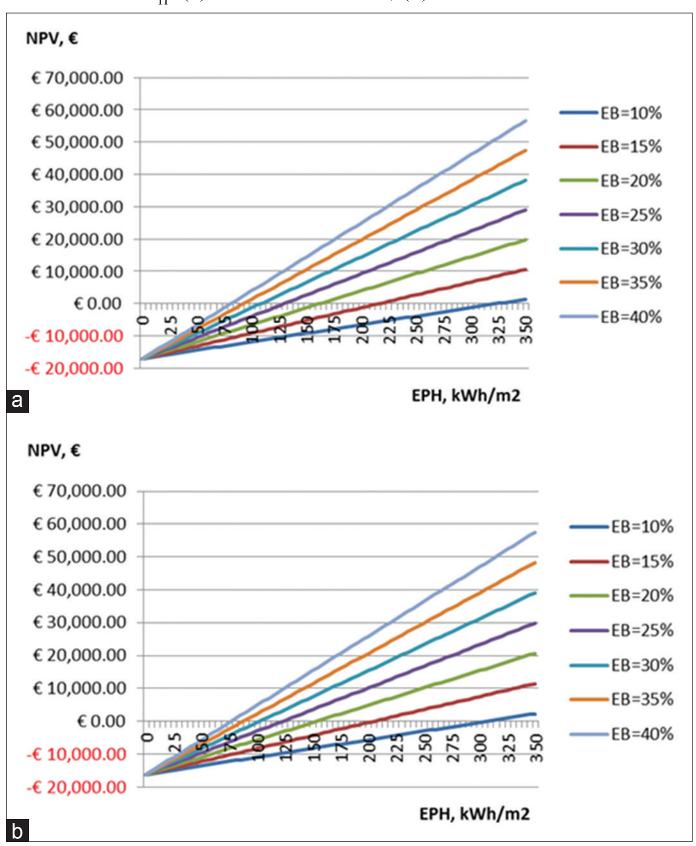
In Figure 2, the net present value (NPV) trend along 10 years is depicted as a function of the primary energy need EP_H at typical

Table 6: CAPEX and OPEX of the direct (HMs) and indirect (HCAs) accounting systems in the UK (for a typical building of 12 apartments each with average heated surface of 80 m², 5 heating elements for each apartment)

Device	CAPEX	OPEX
HM individual	€8,920.97	€1,082.89
HCA	€7,992.78	€1,082.89

CAPEX: Capital expenditure, OPEX: Operational expenditure, HM: Heat meters, HCA: Heat cost allocators

Figure 2: Net present value with calculation period τ=10 years as a function of EP_H: (a) Direct heat meters, (b) direct heat cost allocators



conditions at different expected benefit EB ranging 10-40% for a building of 12 apartments. It is evident that when the expected benefit decreases (both for HMs and for HCAs) also the EP_H at which the investment turns cost-efficient decreases. Such value ranges 85-325 kWh/m^2 for HMs and 80-315 kWh/m^2 for HCAs when EB=10% and EB=40%, respectively.

Similarly, in Figure 3, the NPV trend along 10 years as a function of the pay-back period (PBP) is depicted for different EP_H at fixed EB=25% (surely optimistic) for a building of 12 apartments. From Figure 3 it is possible to find out that as EP_H decreases also NPV decreases. Thus, the investment always results not cost-efficient when EP_H < 100 kWh/m^2. Moreover, PBP is lower than 10 years only for EP_H>120 kWh/m^2.

Figure 3: Pay-back period as a function of EP_H: (a) Direct heat meters, (b) indirect heat cost allocators

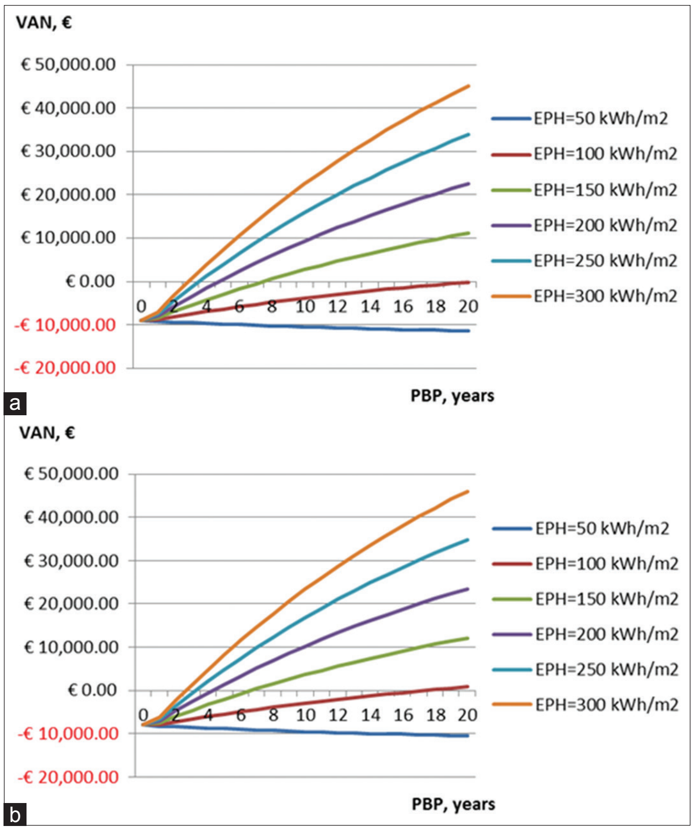
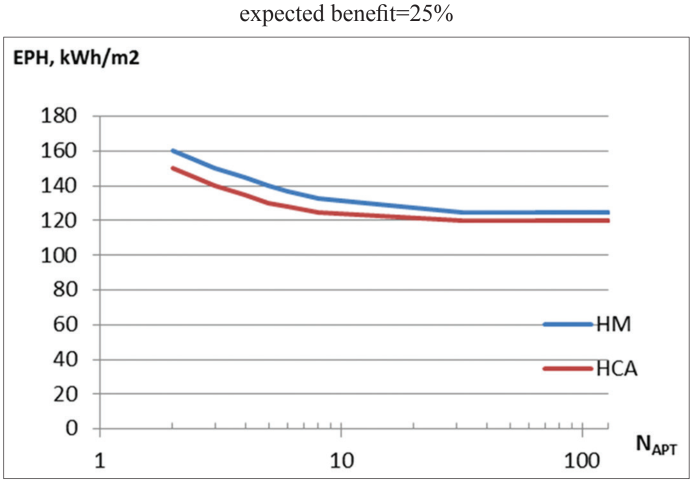


Figure 4: Energy needs lower limit for a variable number of flats and expected benefit=25%



Finally, in Figure 4 the trend of the EP_H value at which the investment turns cost-efficient after 10 years is shown when the number of apartments in the building varies. From the Figure 4 it is evident that such value is strongly affected by the number of apartments only for small buildings (i.e. two-family houses and N_{APT} < 8).

4. CONCLUSIONS

The cost benefit analysis of heat metering and sub-metering systems underlines some critical aspects of the implementation of the directive 2012/27/EU for energy efficiency. The sensitivity analysis, in fact, shows a significant dependence of the economic efficiency of such systems on the energy performance of the building (i.e., its primary energy needs) and on its dimensions, besides on capital and running costs and on the expected benefits.

When a data acquisition system capable to continuously read individual heat consumption in real time is available, the following results applies for both HM and HCA:

- When EB decreases, the primary energy need EP_H of the building at which the investment turns cost-efficient decreases;
- Similarly, when the EP_H decreases, the economic efficiency of the investment decreases as well (always resulting not cost-efficient when EP_H<100 kWh/m^2) and PBP is lower than 10 years only when EP_H>120 kWh/m^2;
- The limit of EP_H, beyond which heat metering and sub-metering systems are cost-efficient, depends on the number of apartments, especially in small buildings.

Noticeably, authors' evaluations are based on earlier studies that carried out similar evaluations in different markets of European countries and at different climatic conditions. Thus, future researches should carry out a precise survey of the capital and operational costs, and an experimental characterization of the expected benefits in different European markets and at different conditions, especially at Mediterranean climate ones.

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APPENDIX

Table 1: Acronyms

Acronym	Definition
AEEGSI	Italian regulatory authority for electricity gas and water (Autorità per l'energia elettrica il gas e il sistema idrico)
CAPEX	Capital expenditure
CEN	European committee for standardization (Comité européen de normalisation)
$C_G(\tau)$	Cost of the investment corresponding to calculation period τ
EB	Expected benefit
EED	European directive 2012/27/EU on energy efficiency
EP_H	Primary energy need
$f_{pv}(n)$	Present value factor
HMs	Heat meters
HCAs	Heat cost allocators
ISTAT	Italian national institute of statistics (Istituto nazionale di statistica)
ITC-DDC	Insertion time counters compensated with the actual degree-days of the building unit
ITC-TC	Insertion time counters compensated with the average temperature of the heat transfer fluid
MID	European directive 2004/22/EU on measuring instruments
N_{CS}	Mean number of radiators for each apartment
NPV	Net present value
OIML	International organization of legal metrology (Organisation Internationale de Métrologie Légale)
OPEX	Operating expenditure
PBP	Pay-back period
$R_d(p)$	The discount rate
R_i	Inflation rate
$V_{f,\tau}(j)$	Is the final value of the j-th component or system j-th at the end of the calculation period
UNI	Italian committee for the unification (Ente Nazionale Italiano di Unificazione)