PRELIMINARY ANALYSIS OF THE POTENTIAL BENEFIT OF THERMOREGULATION SYSTEMS AND INDIVIDUAL METERING OF HEAT CONSUMPTIONS IN THE ITALIAN RESIDENTIAL BUILDING STOCK

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Abstract

Individual metering in residential buildings has been identified by the European Union (EU) as one of the main drivers to reduce energy consumption in the residential sector.
The European Directive 2012/27/EU on energy efficiency requires the introduction of consumption-based cost allocation of heating, cooling and hot water in multi-apartment buildings supplied by a central heating source. The purpose is to ensure that users of each apartment have enough information to adopt energy-efficient practices.
To this aim, the Italian Decree nr. 102/2012 and subsequent modifications set the obligation for apartment and multi-apartment buildings supplied by a common central heating source or by a district heating/cooling network, to install, by June, the 30th, 2017, sub-metering systems to allow a fair cost allocation through the tenants.
In buildings where the use of heat meters is not technically feasible or not cost-efficient, individual heat cost allocators shall be used for measuring heat consumptions at each radiator, unless it would be demonstrated that the installation is not cost-efficient according to UNI EN 15459.
In several studies conducted in different EU Member States a very wide range (8-40%) of the expected benefit of individual metering of heat consumptions has been found. Unfortunately, specific studies regarding the Italian territory and the Mediterranean climatic conditions are still lacking.
In the present study, after a brief analysis of energetic benefit of such systems installed in some real multi-apartment buildings, the authors evaluate the potential benefit of thermoregulation and individual heat metering in the Italian residential building stock.
To this end, the Italian residential building stock has been analysed through both the ISTAT census 2011 and a recent statistical analysis performed by ENEA based on ISTAT data.

1. Introduction

In 2012, the European Union placed particular emphasis on greater knowledge of the energy consumption of end users by issuing the Energy Efficiency Directive 2012/27/EU [1]. In particular, Article 9 provides that consumers should be encouraged to better manage their consumption through individual accounting and informative billing.

In particular, article 9 set the obligation for multi-apartment buildings supplied by a common central heating source or by a district heating/cooling network, to install, by December the 31st 2016, sub-metering systems to allow a fair cost allocation through the tenants. The obligation applies as long as the installation of such systems is considered to be efficient in terms of cost/benefit ratio.

Italy applied article 9 without any substantial changes with Legislative Decree n. 102/2014 and Legislative Decree n. 141/2016 , making the obligation effective from 31st

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December 2016 (actually the obligation has recently been extended to June 30th 2017 with "Milleproroghe" Decree).

As regards multi-purpose buildings supplied from a district heating or a common source, owners are obliged to install individual heat meter for heating/cooling and DHW for each apartment or unit.

In multi-purpose buildings where the use of heat meters is not technically feasible or not cost-efficient, individual heat cost allocators (HCA) and thermoregulation systems shall be used for measuring heat consumptions at each radiator, unless it would be demonstrated that the installation is not cost-efficient according to UNI EN 15459.

To date, the potential impact of the application of this policy strategy on the Italian Country system is not completely clear, as the scientific literature lacks of studies regarding the effects of the installation of individual metering and thermoregulation systems in non-continental climates.

With respect to the mentioned regulatory obligation, Member States (MS) adopted different policy approaches [2]: in Germany and Austria, for example, the installation of heat accounting systems is compulsory for almost the majority of the buildings supplied by a common central heating source, whereas Sweden and Finland exempt nearly all the buildings virtually subject to the obligation, as it has not yet been clarified the existence of a real advantageous cost/benefit ratio at the actual operating conditions.

With regard to the expected benefits resulting from the installation of individual accounting systems in terms of energy savings, the interpretative note of Directive 2012/27/EU estimates that these can reach up to 30% [3].

In scientific literature there are not many studies on the evaluation of expected benefits for European countries. These studies describe energy savings ranging from a minimum of 8% to a maximum of 40% [4].

In particular, a recent bibliographic summary of the last 85 years [5] examines the results of 32 studies on individual accounting and billing of actual consumption in continental climates (Poland, Germany, Austria, Austria, Switzerland, Russia, etc...), based on the measurement of consumption before and after installation of measurement systems.

Among the studies concerning this matter, only few are based on the actual measurement of the energy saving carried out after the experimental observation of the buildings before and after the installation of the heat accounting and thermoregulation systems and, as previously mentioned, the vast majority is conducted in MS with continental climate (Poland, Germany, Austria, Switzerland, Russia etc.). The study estimates average savings in Europe of around 20%.

Among these, Cholewa et al. (2015) [6] analysed the energy consumption of 40 apartments in a multifamily building located in Poland for over 17 heating seasons. For the study, half of the investigated apartments have been equipped with heat cost allocators (HCA) on each radiator, half did continue to pay the heating costs basing on the square meter of the floor surface area. All the investigated apartments were equipped with thermostatic radiator valves (TRV) after 2 heating seasons from the beginning of the observation. The results have shown a clear difference between the energy consumption of the apartments equipped with both TRV and HCA and the ones of the flats without

HCA (-26.6% on average at the second year from TRV installation). The difference became greater when a more extensive retrofit intervention on the building envelope was carried out, allowing a better regulation of the internal temperature by the tenants.

It is underlined that, to the authors' best knowledge, no long-term experimental campaign for an empirical assessment of the benefit expected from the installation of heat accounting and thermoregulation systems was performed in Mediterranean climates. Indeed, it is difficult to extend the abovementioned results to buildings located in warm climates, such as the Italian one, also due to the different constructive characteristics of the national building stock.

2. Analysis of potentially benefits and influencing factors

The benefit obtainable by individual metering and thermoregulation, as well as energy consumption, is variable depending on several factors such as, family income, type of feedback and level of user information (a more frequent and detailed information on consumption can increase the total savings up to about 4% [7]), time between the installation of individual heat meters and the observation (in general, the expected benefit is fully realized from the second year since the installation of thermal meters) [8].

In order to assess the potential expected benefits, a preliminary study was conducted on 15 multi-apartment buildings supplied by a central heating source. The investigated buildings are located in two regions (Piemonte and Lazio).

The building consumption for space heating has been investigated during two heating seasons: one year before the installation of individual metering systems and one year after the installation of such systems.

Table 5 shows the results normalized respect to actual degree day (DD) of the zone. Although some of the buildings have increased their consumption, an average saving of around 8% was observed during the frist year after the installation of thermoregulation and individual heat metering systems.

The first results show a high variability of benefit for different buildings probably due to the diversity of climatic conditions and the numerous mentioned variables.

To allow for a better estimate of the benefit under the different conditions, it is necessary to extend the study to a higher number of multi- apartment building as envisaged by the current ENEA-UNICAS project.

City	Gas consumption before installation [m^3/DD]	Gas consumption frist year after installation [m^3/DD]	energy saving at 1st year [%]
TO	28.95	30.21	4.40%
TO	14.94	15.12	1.20%
TO	10.36	7.88	-24.00%
TO	6.48	5.37	-17.20%
TO	6.43	5.31	-17.40%
TO	8.48	7.30	-13.90%
TO	11.31	13.17	16.50%
TO	11.95	13.21	10.50%
TO	8.91	8.13	-8.80%
TO	5.76	6.67	15.80%
TO	22.83	20.19	-11.60%
RM	26.40	22.47	-14.90%
RM	10.75	8.63	-19.70%
RM	14.57	12.04	-17.40%
RM	25.57	20.91	-18.20%
Total	**213.69**	**196.58**	**-8.00%**

Table 5: Benefit from normalised thermoregulation with respect to climatic data

3. Characterization of the regional building stock

The aim of the study is to estimate the potential effect of the obligation introduced by Italian Legislative Decree 141/2016 on the Italian country, in terms of tons of oil equivalent potentially savable per year.

To this end, the Italian residential building stock has been analyzed through both the ISTAT census 2011 and a recent statistical analysis performed by ENEA based on ISTAT data.

In particular, the ISTAT 2011 census surveyed 31,138,278 dwellings. About 22% of the Italian dwellings is inhabited, while only 0.001% of the Italian dwellings is occupied exclusively by non-resident people, the latter is considered negligible for the purposes of the present analysis. ISTAT divides the surveyed dwellings in 6 dimensional categories and 9 constructive ages (between 1918 and 2006).

Referring only to dwellings occupied by residents, about 64% of Italian dwellings is part of a multifamily building (i.e. a building with 3 or more housing units), while the remaining share is equally distributed between the single/two-family building categories. For the scope of the present analysis, it is useful to observe that about 70% of the Italian dwellings was built before 1980, i.e. before any legislative requirement for energy efficiency of buildings (Law 373 of 1976) was issued. Of these, approximately 45% are multifamily buildings (see table 2).

Building category	housing units	buildings [n]	before 1980	1981 - 2000	Post 2001	All ages
single family house	1	4688972	14.27%	3.82%	1.39%	19.48%
two-family building	2	3995081	12.32%	3.32%	0.96%	16.60%
multy family house	3 - 4 5 - 8 9 -15 16 and more	3518114 3443130 3044095 5375902	44.85%	13.28%	5.79%	63.92%
Total		24065294	71.44%	20.43%	8.13%	100.00%

Table 6: Italian dwellings for different categories and construction ages (data processing by ISTAT census)

In order to take into account the variability of building typological and constructive features, the ISTAT database was analyzed on a regional basis, thus identifying: i) useful floor area, ii) number of floors and apartments per building, iii) heating systems features (i.e. central or independent heating system).

Figure 4 shows regional distribution of the 6 dimensional categories of building basing on the latest (2011) ISTAT census.

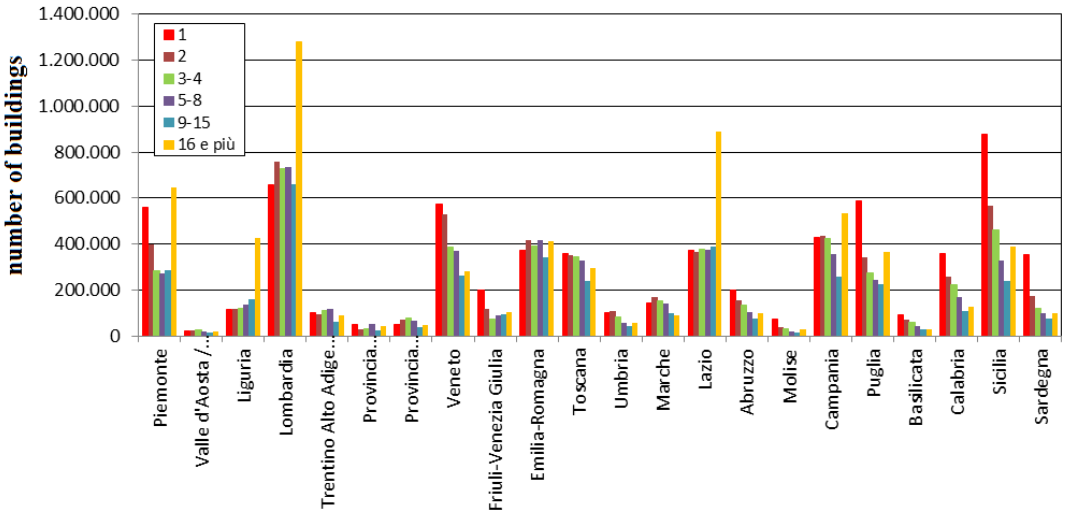

Figure 4: regional distribution of the 6 dimensional building categories (ISTAT census, data processed by UNICAS)

Finally, according ISTAT census, centralized heating plant is about 18.75% of the total heating systems in building/ dwelling occupied by residents in Italy as shown in Table 3.

Type of thermal plant	mumber of plants	percentage of plants
centralized heat plant	4,871,072	18.75%
Autonomous system for single dwellings	15,717,341	60.51%
Single fixed devices for the whole house	2,137,636	8.23%
Fixed individual appliances for some parts of the house	3,246,891	12.50%
TOT.	25,972,940	100%

Table 7: Dwellings occupied by residents: number and type of heating installation

According to the regional distribution, it can be noticed that) about 55% of total central heating plants is located in three regions (Piemonte, Lombardia e Lazio).

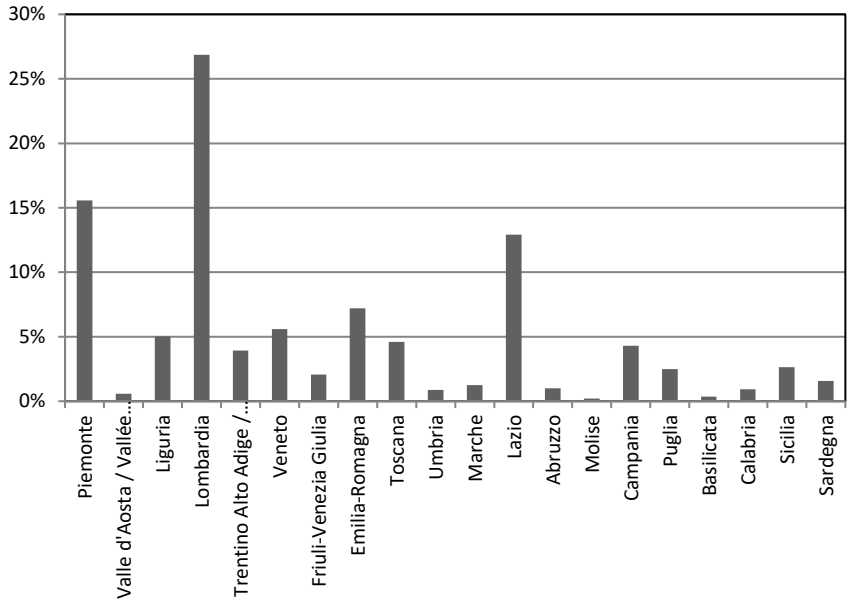

Figure 5: Regional distribution of dwellings with centralized heat plant

3.1 Evaluation of regional energy demand for space heating

In order to allow the assessment of the overall energy benefit of individual metering and thermoregulation systems, the energy consumption for space heating of the Italian residential building stock has been estimated.

According to statistical analysis, the classification of buildings was carried out in 54 classes (6 categories of occupation and 9 constructive periods between 1918 and 2006) associated to each region with the following simplified assumptions:

i) Average number of floors per occupational category, determined by weighted average: number of floors / number of building;

ii) floor height, obtained from the characterization of the national office building stock published by ENEA [9].

iii) Average useful floor area of dwellings: determined by total dwellings and total useful surface provided by ISTAT census

iv) External surface assuming: (i) cubic form of heated volume ; ii) ratio of window surfaces / useful floor area equal to the current legal limit (1/8) for all typologies and constructive times;

v) 10% thermal bridge increase for all building categories;

vi) thermal transmittance of envelope components varying as a function of the construction age (Figure 3), based on data from TABULA project [10] which identifies the national construction types and the relevant period of greater diffusion for the climatic zone E. For the purpose of this study, such constructive typologies have been considered representative throughout the national territory.

In order to take into account both building envelope retrofit throughout the national territory and the variability of the constructive features of regional building stock, the average thermal transmittance of buildings prior to 1990 have been reduced in percentage according to degree day of climatic zone.

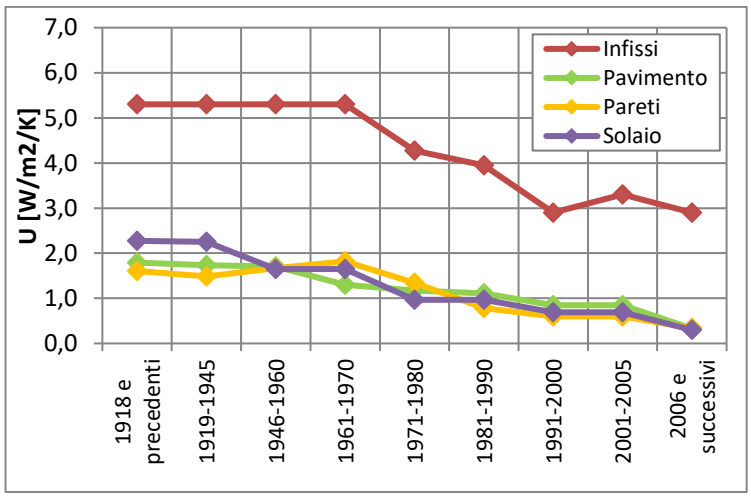

Figure 6: Estimated thermal transmittance of national building stock (UNICAS processing of TABULA data)

The primary energy need for space heating has been estimated according to asset rating method as described by Ministerial Decree 26/06/2009 with the following simplified assumptions: i) solar heat gain evaluated for a real reference building, located in different latitudes ii) boiler efficiency evaluated according to data available by TABULA project for different ages iii) no unheated spaces in the building iv) efficiency of distribution and regulation system equal to 0.95 v) free gain utilization factor equal to 0.95. Primary energy demand for space heating has been evaluated in operational rating condition using the intermittent coefficients previously estimated by ENEA following a sampling analysis involving 20,000 buildings of the Italian territory. The intermittent coefficients are available for six representative provinces of the respective climatic zones and for different dwelling typologies (single family house, multi-family house, apartment close-up, top floor apartment, intermediate floor apartment)

4. Benefit of thermoregulation systems and individual metering

The primary energy need for space heating of residential Italian building stock amount to about 20.4 Mtep, as calculated by the authors. In order to validate the calculation model, the result has been compared with the data provided by Regional Energy and Environmental Plans (PEARs) [11], and National Energy Balances (BEN) provided by the Ministry of Economic Development [12]. However, these data are provided in aggregate form under "Residential macro area" including energy consumption from heating and cooling, lighting and household electrical appliances, cooking and domestic hot water. To overcome this problem, the share for space heating has been evaluated comparing Italian residential sector consumption evaluated by EUROSTAT from 1990 to 2015 with national energy demand for space heating evaluated by ENEA from 2000 to 2013 as shown in table 4.

Year	Italian residential sector consumption (EUROSTAT) [Mtep]	Space heating (ENEA) [Mtep]	Share for space heating [%]
1990	26.06		
1995	26.32		
2000	27.59	16.7	60.42%
2001		17.1	
2002		17.2	
2003		19.7	
2004		19.2	
2005	33.92	21.7	63.88%
2006		21.1	
2007		20	
2008		22.8	
2009		23.3	
2010	35.39	23.9	67.50%
2011	32.38	20	61.77%
2012	34.35	22.2	64.69%
2013	34.23	22.2	64.91%
2014	29.55		
2015	32.49		
Media			**64.02%**
Incremento % annuo (2000-2013)			**2.56%**
Incremento % annuo (2003-2013)			**1.15%**

Table 8: Residential consumption (BEN) and share for air conditioning

Furthermore, the Regional Energy and Environmental Plans (PEARs) have been issued in different years, starting from 1998 (Liguria region) to 2013 (Molise region). In order to allow a comparison, all data have been discounted compared to the reference year 2017, considering a percentage increase in space heating energy consumption by 1% per year, as shown in table 5.

	space heating (evaluated by authors) [Mtep]	space heating (PEAR data and average share factor 0.64) [Mtep]	Percentage error [%]
Sardegna	0.283	0.335	-15.52%
Sicilia	0.599	0.552	8.54%
Calabria	0.267	0.241	10.81%
Basilicata	0.14	0.133	5.35%
Puglia	0.815	0.83	-1.88%
Campania	0.777	0.791	-1.79%
Molise	0.119	0.121	-2.03%
Abruzzo	0.259	0.245	5.49%
Lazio	1.593	1.851	-13.97%
Marche	0.525	0.491	6.85%
Umbria	0.225	0.224	0.63%
Toscana	1.324	1.335	-0.82%
Emilia	1.672	1.485	12.57%
Friuli-Ven.	0.424	0.392	8.28%
Veneto	3.799	3.995	-4.90%
Trentino	0.552	0.529	4.41%
Lombardia	3.805	3.651	4.20%
Liguria	0.685	0.729	-6.05%
Valle d'Ao.	0.101	0.087	16.17%
Piemonte	2.407	2.254	6.77%
Italy	20.37	21.212	-3.97%

Table 9: Comparison between calculated heating consumption and actualized PEAR data. (UNICAS processing of EUROSTAT data [20] and ENEA data [25])

The average error of estimated energy demand for space heating (Table 5) is within 4% compared with to national data and within 20% compared with regional data of PEARs; This one is consistent but acceptable; indeed, regional data comparison is altered by lack of current data as well as data about actual energy demand for space heating.

The potential benefit of thermoregulation systems and individual metering of heat consumptions has been calculated by "filtering" regional consumption shown in table 5 compared to: (i) the percentage of regional centralized heat plan, ii) categories of

occupation (excluding single-family house), iii) cost / benefit ratio of the installation according to UNI EN 15459.

The cost / benefit ratio is strictly dependent on energy consumption for space heating before systems installation.

According to Celenza et al. [2], the economic efficiency of thermoregulation systems and individual metering is not demonstrated below a threshold of primary energy consumption for space heating (asset rating).

According to results of technical-economic analysis shown in the document of the Authority for Electricity, Gas and Water Systems, AEEGSI, (DCO 252/2016), installation of individual heat meters is not cost efficient in case of primary energy need for space heating (EP) is less than 80 kWh / (m2* year); indeed individual heat meters in multi-family building is cost efficient in case of EP is greater than 155 kWh / (m2 *year) evaluated by Energy Performance Certificates (EPC).

In the same document, AEEGSI identifies a minimum level (10%) and maximum level (20%) of expected benefit of individual metering in the multi-family building.

In this study two scenarios have been analyzed combining the minimum benefit (10%) to buildings with a primary energy consumption more than 155kWh/(m2*year) and maximum benefit to buildings with primary energy consumption more than 80 kWh(/m2*year).

As shown in Table 6, if all the potentially obliged buildings (EP>80 kWh/m^2, EP>155 kWh/m^2) would install thermoregulation systems and individual heat metering ,the expected energy saving would be between 0.247 and 0.839 Mtoe / year.

	Apartments with centralized thermal plant [%]	Centralized heat plant - Energy Cunsumption [Mtoe]	Centralized heat plant - Energy Cunsumption (Ep>155 kWh/m^2) [Mtoe]	centralized heat plant - Energy Cunsumption (Ep>80 kWh/m^2) [Mtoe]	Total Energy saving (benefit 10%) [Mtoe]	Total Energy Saving (benefit 20%) [Mtoe]
Sardegna	11.61%	0.0329	0.0098	0.0226	0.001	0.0045
Sicilia	6.63%	0.0397	0	0.0231	0	0.0046
Calabria	5.91%	0.0158	0	0.0097	0	0.0019
Basilicata	7.43%	0.0104	0.0045	0.0083	0.0004	0.0017
Puglia	8.04%	0.0655	0.0184	0.0446	0.0018	0.0089
Campania	10.34%	0.0804	0.004	0.0484	0.0004	0.0097
Molise	8.39%	0.01	0.0058	0.0087	0.0006	0.0017
Abruzzo	9.53%	0.0246	0	0.0161	0	0.0032
Lazio	27.61%	0.4398	0.1923	0.3998	0.0192	0.08
Marche	9.97%	0.0523	0.0347	0.0476	0.0035	0.0095
Umbria	11.96%	0.0269	0.0082	0.0215	0.0008	0.0043
Toscana	14.68%	0.1944	0.1179	0.1798	0.0118	0.036
Emilia	18.82%	0.3147	0.2065	0.2935	0.0206	0.0587
Friuli-Ven.	18.72%	0.0794	0.0047	0.0548	0.0005	0.011
Veneto	13.99%	0.5317	0.4366	0.5129	0.0437	0.1026
Trentino	45.61%	0.2518	0.1797	0.2457	0.018	0.0491
Lombardia	31.97%	1.2164	0.5244	1.082	0.0524	0.2164
Liguria	33.02%	0.2261	0.1396	0.2223	0.014	0.0445
Valle d'Ao.	47.36%	0.048	0.0448	0.0477	0.0045	0.0095
Piemonte	39.49%	0.9505	0.5425	0.9078	0.0543	0.1816
Italy				**[Mtoe]**	**0.247**	**0.839**
				[%]	**1.21%**	**4.12%**

Table 10: Summary of estimated consumption and potential savings (data discounted to 2017)

5. Conclusion

In this work, the first results of an ongoing UNICAS-ENEA experimental study were presented, showing a high variability in the benefits of installing individual heat metering and thermoregulation systems in residential buildings supplied by centralized heating systems. Although some of the buildings under study have even increased their consumption, an average saving of around 8% was observed during the first heating season and 10% at the end of the second heating season after the installation of the systems.

In order to assess the potential impact of the installation of individual heat metering and thermoregulation systems in buildings required by Legislative Decree 102/2014 and subsequent amendments, an analysis of energy consumption for space heating in the Italian residential sector was carried out through the characterization of the building stock in each region.

The analysis shows that the total savings achievable on a national basis updated to 2017 is between 0.247 and 0.839 Mtoe, values respectively associated with a benefit for thermoregulation and individual heat metering of 10% and 20%.

However, a more accurate calibration of the calculation model should be obtained through: i) a better characterization of thermal transmittances for each climatic zone and/or Italian region (also drawing on the regional databases under construction), ii) the determination of the number of buildings that have already installed metering and temperature control systems, iii) the retrieval of official consumption data for space heating in the Italian and regional residential area.

The authors believe that it is necessary to extend the experimental study to a substantial number of multi apartment buildings in order to identify the average benefit applicable to the Italian territory and the possible factors of influence.

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