A new heat cost allocation method for social housing

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Abstract

To promote energy saving in the residential sector Directive 2012/27/EU has set the obligation for buildings supplied by central heating sources to install individual heat metering and accounting systems. However, in social housing, bills based exclusively on individual consumption should be unfair due to some unfavourable situations, such as first and top floors, presence of unheated common spaces, north oriented dwellings. Nevertheless, fair heat accounting rules should be introduced especially in social housing buildings, which are often thermally underperforming with inefficient heating plants and tenants are commonly low-income people and elderly. On the other hand, common regulations for heat accounting providing compensation to avoid inequalities among tenants have not been set and different approaches on this topic are present among EU Member States. In this paper the authors present a new heat accounting method for social housing based on the estimation of extra-consumptions due to building inefficiencies. According to this method, extra-consumptions are charged to all tenants in order to encourage energy efficient retrofit interventions. Finally, the new method has been experimented in a typical social housing building in Italy and compared to other methods applicable in EU, evidencing some advantages and weaknesses.

Keywords: Heat accounting, Energy Efficiency Retrofit; Social Housing, Users awareness, Space Heating, U-value

1. Introduction

As widely known, residential energy consumption in Europe accounts for about 45% of the total energy demand, of which about 80% attributable to space heating and cooling [1]. With the aim to reduce energy consumption in residential sector, the Energy Efficiency Directive (EED) [2] has recently obliged in EU Member States (MS) the installation of heat accounting systems in multi-apartment buildings supplied by a common heating source, when technically feasible and economically efficient [3]. Despite EU requires the definition and introduction of clear consumption-based cost allocation methods and the frequent informative billing for heating, cooling and hot water production, not all EU MS introduced specific rules at national level. Even for cooling, only two MS (Denmark and Estonia) defined clear rules on this topic [4].

As also highlighted by Canale et al. [5], the impact of the installation of heat accounting systems and thermostatic radiator valves in residential buildings on national scales is strongly dependent on adopted energy policies. As a matter of fact, EU strongly promotes the definition of effective policy drivers to encourage energy efficient behaviours of final users [6, 7]. However, defining fair methods for heat costs sharing among dwellings supplied by a centralized heating system is a complex task, due to legislative and regulatory issues involving political, social, economic and technical aspects.

Measuring or estimating the heat delivered to each apartment can be easily performed through Heat Meters (HM) or Heat Cost Allocators (HCA), respectively. However, the installation of such systems within a building introduces problems of fairness in allocating heat costs among tenants, even without considering the related issues in terms of accuracy and consumers' protection [8-10]. In fact, some of the apartments, such as the ones at first and top floors, the ones adjacent to unheated spaces or badly oriented, can even double their heat costs, though having the same energy behaviour and comfort level of their neighbours.

As a matter of fact, energy consumption for space heating is directly dependent on the users' behaviour (i.e. set point temperature, functioning hours of the heating plant, etc.) [11-13], on the climatic conditions (i.e. outdoor temperature, solar radiation etc.) but also on the morphological and constructive characteristics of buildings (e.g. thermal transmittances, air tightness, building envelope surface, shape factor) and heating systems (e.g. system efficiency), which greatly affect final consumption regardless of users' will. Thus, it is difficult to establish whether the heat measured is or not attributable to a given apartment.

This issue has been addressed by different authors in the scientific literature. Siggelsten [14] developed a method for estimating heat transfers between adjacent apartments in multi-apartment buildings in order to allocate the related heat costs. By applying the method to an existing multi-apartment building with 16 apartments, he demonstrated the possibility to use correction factors in a fairly cost-efficient manner. Michnikowski [15] presented a variation of the method proposed by Siggelsten for correcting errors in the allocation of heat costs in multi-family buildings. His method is based on the determination of the average internal temperature with the use of special HCA and on the analytical determination of the energy required for heating with the aim to correct the participation of individual apartments in the total energy consumption of a building. Davariu [16] proposed a method to correct the heat costs through the measured difference between the indoor comfort temperature and the outdoor one.However, as also highlighted by Liu et al. [17], all the cited papers emphasize the issue of "fairness" of heat cost allocation, but do not address the problem from a wider point of view, that is heat metering based on individual consumption should drive towards energy efficient behaviours in buildings.

The adoption of responsible behaviours aimed to achieve energy savings/efficiency has to be promoted through adequate regulatory drivers, especially in social housing, where economic constraints [18] and building characteristics should be carefully considered. In fact, social housing apartments are often randomly assigned, tenants pay for the surface and independently from the dwelling's energy need, first and top floors (generally the more unfavourable positions) not always have further advantages especially in cases of absence of lifts, yards or similar [19].

As a matter of fact, the improvement of energy efficiency of multi-family buildings is not always easily achievable. In fact, the decision to improve the insulation of building envelope components (such as the roof) does not solely depend on the will of individual tenants and landlords, but it should be agreed by the condominium meeting. Common properties determine a singular situation: it is up to all landlords to decide whether or not to improve building energy performance (i.e. through boiler replacement, insulation of common surfaces), while inefficiencies mostly affect only few dwellings. This often represents an obstacle for the approval of energy retrofits in residential buildings, because not all landlords are at the same time potential direct beneficiaries of the intervention. Such situation is even more complex when tenants are not the owner of the apartment, as often occur in social housing. Furthermore, the lack of transparency and simplicity of several heat cost allocation methods does not encourage virtuous behaviours and may lead to a perception of iniquity and to increasing disputes.

In this paper, the authors propose a heat cost allocation method for social housing aimed to address the above described issues and representing a driver for improving building energy efficiency without leading to discomfort conditions and to imbalances of the heating system. This method has been also proposed as a standard method to the Thermotechnical Committee for Energy and Environment associated with the Italian Standardization Body (UNI) and to the competent Italian Authority MISE, the Ministry of Economic Development. The proposed method is based on the estimation of the consumption due to the building's inefficiency, hereinafter called "extra-consumption". These latter represent in particular the consumption exceeding those that would occur if legal limits related to thermal transmittances were respected. It is proposed that extra-costs due to building inefficiency are temporary allocated to all tenants until a retrofit intervention is carried out and this should represent a driver for energy retrofits implementation. The main peculiarities of the proposed method are the following: *i)* the allocation of energy consumption of common parts of the building is proportional to the reference building energy performance (i.e. the minimum thermal transmittance provided by the current regulation) and it is not a pure correction of the consumption data; *ii)* all tenants are charged for common areas' inefficiency and, consequently, landlords should be encouraged to perform energy retrofits; *iii)* once performed the energy retrofit, landlords/tenants start paying only for their individual consumption without any compensation. Unlike methods already proposed in scientific literature, which mainly approach the problem with the aim to improve fairness in heat cost allocation, the one described by the authors is aimed also to strategically drive final users towards energy conscious behaviours and to promote buildings' efficiency retrofits.

The proposed method has been experimented in a social housing building in Italy, allowing at the same time a comparison between heat cost allocation methods adopted in some European countries.

In the following, after a brief analysis of heat cost allocation methods regulated in EU and focused in technical standards and scientific literature, the authors describe the proposed method (*section 2*) and present a case study for social housing in which an indirect heat accounting system was installed (*section 3)*. Finally, the results of the model in terms of heat cost sharing for a case study building are compared with other applicable methods, highlighting its strengths and weaknesses (*section 4*).

2. Methods for heat cost sharing and compensation of consumption readings

When specific rules are defined, energy costs for space heating, cooling and domestic hot water are divided into variable and fixed costs. The first ones are usually allocated according to readings gathered from individual meters or heat cost allocation devices. On the other hand, fixed costs, which generally include maintenance and operating costs, energy for auxiliary devices, such as circulating pumps, control systems etc., and third party services provided for metering and cost allocation, are divided among tenants, generally in proportion to the dwelling's floor area [20]. In Figure 1 the heat costs classification is presented.

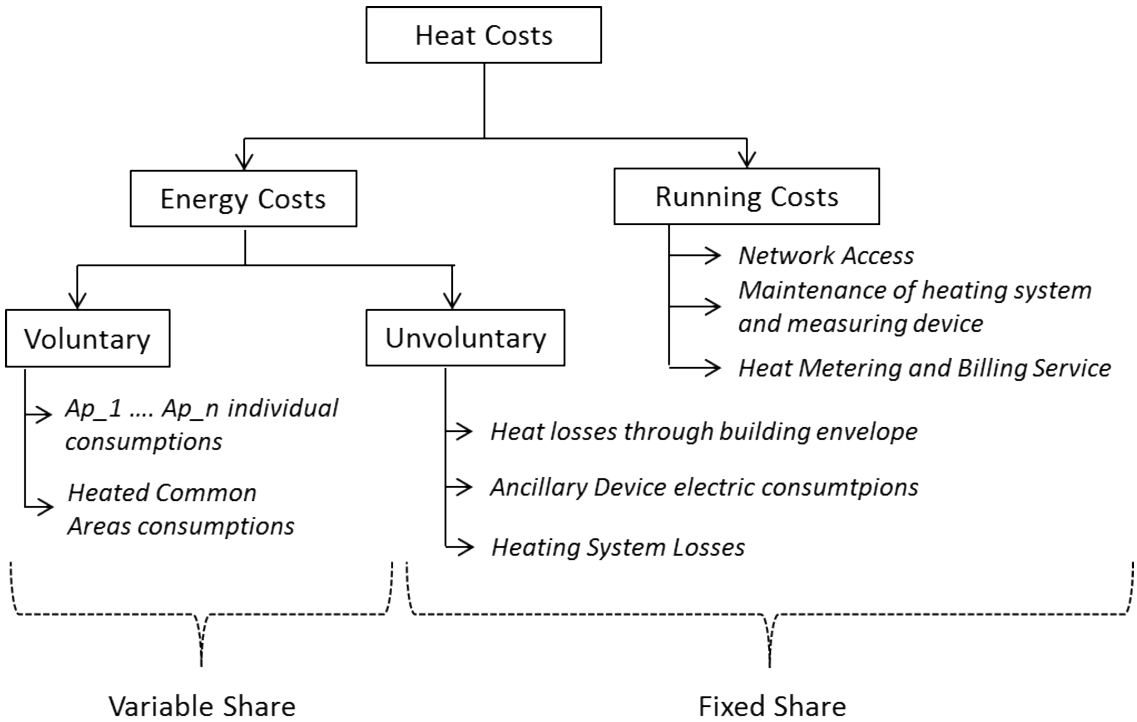


Figure 1 – Heat cost classification

Among EU MS the share of energy consumption for fixed costs ranges between a minimum of 25% to a maximum of 60% [4]. Such high variability is mainly attributable to the different characteristics of building stocks. Higher shares of fixed costs are, in fact, adopted in Eastern European Countries, such as Romania, Estonia, Slovakia and Poland, in which social housing is more spread and where buildings are more energy consuming (due to their poor insulation and to low performance of heating systems) and thermal control devices are not widespread. In Poland, a proposal is even being discussed aimed to bring to 90% the share of fixed costs in multi-family buildings not equipped with thermostatic radiator valves. In other countries (Germany, France, Austria, Croatia, Czech Republic, Denmark, Hungary) the share of fixed costs varies between 30% and 50%, whose choice is left to different players (landlords, service companies, heat suppliers, professionals etc.). Among non-MS, Switzerland applies the same cost allocation method above described, dividing the total expense in "general costs" and "consumption-based costs", assuming for the first one a share variable between 30% and 50%.

In Table 1 an overview of the existing heat cost allocation rules among different EU MS is presented.

Table 1 – Heat Allocation regulations in EU in terms of variable energy cost due to individual readings [4]

Member State	*Variable cost share*		*Note*	*Compensation*
	Min.	*Max.*		
Austria	55%	75%	Shares are defined through agreements between the energy company and users. If an agreement cannot be found, the energy cost is divided by 65% according to metered consumption and 35% by floor area.	Forbidden
Bulgaria	60%	75%	Heat cost allocation is performed by heat transmission companies, heat providers, or by qualified technicians. Compensation factors are rarely used.	Allowed
Croatia	10%	50%	-	Allowed
Czech Rep.	50%	70%	None should pay a share lower than -20% or higher than +100% of the building's average.	Mandatory
Denmark	50%	70%	Heat cost allocation is managed by the energy company or by the building owner.	Mandatory
Estonia	40%	60%	Fixed and variable costs shares are not specified in the current regulation. Typically, companies offering measurement and/or cost allocations systems and services provides also recommendations on heat cost sharing. Compensation factors are widely used.	Allowed
France	70%		Share for voluntary consumption is fixed by law. Compensation is allowed and managed by the condominium meeting	Allowed
Germany	50%	70%	The choice is agreed by the building owner in the rental contract with tenants. It is required that 70% of total cost is based on individual consumption.	Forbidden
Greece	Calculated case by case		Fixed energy costs are calculated as a function of the "indirect heat" delivered to the apartment through specific factors given by the Greek technical standard as a function of the dwelling's characteristics.	Allowed
Hungary	50%	70%	Heat costs allocation rules are defined only for district heating, no mention is done to similar rules for centralized heating systems. The condominium meeting can decide whether applying a different scheme, often with a detailed energetic calculation. Compensation is allowed and performed for single rooms in the dwelling.	Allowed
Italy	Minimum 70%		A detailed energy calculation performed by a qualified technician is required by law.	Forbidden
Latvia	Not regulated		There is not any obligation to adopt or not cost allocation rules based on actual consumption. Conversely, the choice of the calculation method is assigned to the condominium meeting. Compensation is allowed and performed by independent technicians.	Allowed
Lithuania	Not regulated		Apartment/building owners can decide the heat cost allocation method. The agreed method shall be authorised/validated by the National Commission for Energy Control and Prices.	Mandatory
Netherlands	Not regulated		If required by one or more tenant, a professional should be asked to check heat cost allocation performed by the service or heat company. The use of compensation factors is actually under discussion	Not applicable
Poland	Not regulated		It is currently under discussion the adoption of a min./max. range for variable heat consumption between 10 and 45%	---
Romania	Not regulated		It is currently under discussion the adoption of a share for variable heat consumption of 40%. Compensation is allowed and performed for single rooms in the dwelling.	Allowed
Slovakia	40%		Fixed by law, but adjustable to other ratio upon agreement	Allowed
Slovenia	50%	80%	Low and high consumptions per square meter in respect to the average are limited to 40% and 300% of the average itself, respectively. Compensations factors are allowed and estimated by independent technicians.	Allowed

In the following the fixed proportionality, responsibility and fairness sharing principles are presented and discussed.

2.1 Methods based on fixed proportionality principle

According to the "*fixed proportionality*" principle, the whole energy consumption should be charged with flat-rate generally based on floor area (or as an alternative on dwelling's heated volume, primary energy need, installed heat output), regardless of its actual consumption and, therefore, in proportion to the energy potentially consumed. This principle, although spread in several MS, does not promote single user's awareness in respect to his own energy consumption, since heat costs are allocated regardless from effective consumptions. As for example, this should not lead users to keep off their thermostats in hours and periods when the dwelling is uninhabited or to set adequate indoor comfort temperature.

2.2 Methods based on responsibility principle

The "*responsibility"* principle, such as the Italian one, is based on the actual energy measured through direct or indirect systems. This principle distinguishes between variable and fixed cost shares. The first one is attributable to the users' behaviour (the so-called voluntary consumption) while the second one (the so-called involuntary consumption) includes costs for maintenance and operation, energy for ancillary equipment, energy metering and allocation services. Fixed costs sometimes include also costs related to heating system inefficiency and to the consumption of common heated areas in the building. The variable share of energy consumption is allocated through the measured energy consumption (i.e. with direct method) or through the readings of heat cost allocators (i.e. indirect method) [21]. On the other hand, fixed costs are generally charged by flat-rate by means of suitable rate coefficients generally calculated through the estimated energy need, or installed radiator's heat output, or dwelling's floor area or heated volume. However, the responsibility principle does not represent an effective driver for users to improve the building energy efficiency. In fact, critical energy issues affect mainly few apartments (typically on the first and top floors) and energy consumption should be effectively reduced only through specific energy retrofits of the whole building and, consequently, with the agreement of the condominium meeting.

In Italy, according to Legislative Decree n. 102/2014 [22] and subsequent modifications which refers to technical standard UNI 10200 [23], the heat cost allocation is performed dividing *voluntary* and *involuntary* consumptions, calculated case by case as a function of the building characteristics. Although accurate, this method is quite complex and requires a preliminary energy audit of the building. Whether technical standard UNI 10200 is not applicable when differences of more than

50% in thermal energy need per square meter among dwellings in the building are found, it is allowed to allocate costs among tenants by attributing a share of at least 70% to individual consumptions (i.e. voluntary consumptions). The remaining share (i.e. the involuntary consumption) may be allocated with flat rate generally based on floor area. Involuntary consumption can be either calculated (analytic method), if specifications of the heating generation and distribution systems are available, or estimated (simplified method) through suitable coefficient (k_{inv}), depending on the building and heating system characteristics and performance.
Heat cost sharing based on "*stolen heat*" is widely spread in Greece [24, 25], where a compensation is applied directly in the calculation of the fixed costs based on the "indirect heat" of dwellings. In particular, the specific factor f_i takes into account residual heat dispersions through the building envelope when it is not heated, depending on the ratio of external to total surrounding surface of the dwelling, the dwelling's floor area, the insulation of the building and of the heating pipes and the apartment position within the building.

2.3 Methods based on fairness principle

The "*fairness*" principle takes into account the higher consumption of some dwellings within the building (e.g. those in the top and first floor), due to the incidence of higher external envelope component per floor area, the presence of adjacent unheated dwellings, different orientation (e.g. north-exposed dwellings or with large shading), by using specific corrective factors compensating unfavourable situations. Although this principle reduces the substantial inequality introduced by the allocation of energy consumption solely based on individual metering, it is believed that it is not fully functional to the EED goal of reducing energy consumptions due to inefficiency. Regarding the possibility to apply compensation factors for unfavourable situations, MS adopt different approaches. The use of corrective factors, in fact, is forbidden in Germany, Italy and Austria. On the other hand it is mandatory in Czech Republic, Denmark and Lithuania. Other MS allow the owners' assembly to set compensatory measures (e.g. Greece and France). Also in Switzerland compensation is mandatory and regulated by official standards.
Compensation methods proposed in technical and scientific literature mainly belong to two different categories: the ones related to the thermal comfort and the ones based on the estimation of the heat losses and transfers between adjacent apartments differently heated. Comfort-based compensation methods rely on the principle that tenants with apartments of the same size and with the same average thermal behaviour should pay the same. Among these methods, compensation according to the recorded thermostat set point temperatures [15] and to the accumulated on-time as well as the floor

space of each apartment [17] have been proposed. The "thermal comfort" method proposed by Davariu [16] considers a correction performed by means of the ratio between the mean indoor/outdoor temperature difference and the difference between the indoor comfort temperature and the outdoor temperature, which is proportional to the heat ideally consumed to ensure a certain thermal comfort. These methods identify the exposure, the position, and the greater incidence of building envelope of an apartment as main causes of inequality when heat costs are allocated through indirect systems. To this aim, the two methods defined by Swiss Federal Office of Energy (SFOE) are among the most detailed [26, 27] as described in the following:

- the "*reduction method*", in which the compensation is performed by reducing the allocation units (AU) of most exposed dwellings by means of given reduction factors;
- the "*reference room method*" in which a set of reference rooms is identified within the building (i.e. the room with the same use but with the lowest heat output) and heat accounting is performed through the knowledge of the installed radiators' heat output [28] and of the measured AU in dwellings.

Methods of the second kind focus the attention on the so-called "*stolen heat*" issue, which arises when one or more apartments in a multi-family building take advantage of the unavoidable thermal energy dispersed through adjacent apartments, setting to a minimum or turning off the thermostat. The "*stolen heat*" issue in buildings with certain share of unheated dwellings, has been debated in the scientific literature. In particular, Gafsi and Lefebvre [29] for a case study in Spain showed that it is possible to take up to 90% of the energy needed from adjacent apartments. Andersson [30] investigated an unheated apartment in Sweden, surrounded by heated adjacent apartments with the exception of one side, and demonstrated that it is possible to obtain more than 95% of the necessary thermal energy from adjacent apartments. In this respect, Siggelsten [14] first proposed a method to reallocate heat costs by calculating the heat transfers among adjacent dwellings without considering differences among dwellings in terms of internal heat sources or solar heat gains. Michnikowski [15] proposed the use of special heat cost allocators able to record also the average indoor temperature. Such method partially takes into account different heat sources in dwellings, suggesting that 50% of energy cost should be determined through heat cost allocators and the remaining 50% through the measured average indoor temperature. According to Michnikowski, this method has been applied for many years in Poland with positive results.

2.4 The "extra-consumption" proposed method

The adoption of heat cost allocation rules aims to promote both end users' virtuous behaviour ~~and~~ to achieve energy saving and efficiency in thermally underperforming buildings. In this context, the proposed method is based on the punctual estimation of extra-consumptions, which represents the share of energy consumption due to the lack of thermal insulation of the common parts of a building, and of the relate costs. The allocation of extra-consumptions and of the related costs to all tenants in the building is then performed and this should be a driver to promote energy retrofits in the building. The proposed method is briefly highlighted as follows:

a) extra-consumptions and the related extra-costs are estimated in the building;
b) all tenants are charged for extra-cost and, consequently, condominium meeting should be encouraged to promote energy retrofit interventions;
c) once the energy retrofit intervention has been effectively carried out, the extra-costs are zeroed and tenants start paying only for their individual consumptions.

The estimation of the heat losses coming from inadequate insulation of single dwellings and common parts of a building is performed through the calculation of the heat flow exceeding the corresponding one at reference conditions, which are provided by current technical regulation. To this aim the energy performance of single building elements and of common areas of the building (e.g. walls, windows, floor, ceiling, roof, …) are considered. On the other hand, the proposed method does not take into account both internal and external heat gains since it is not possible to modify them to improve building energy efficiency. Furthermore, internal heat gains depend on the users' habits and not on the building characteristics, whereas the external ones depend on uncontrollable variables such as the presence of new constructions and natural vegetation.

Therefore, voluntary and involuntary extra-consumption are allocated to the *i-th* dwelling through a specific "efficiency correction" factor $f_{ext,i}$, calculated as described in the following equation:

$$f_{ext,\,i} = \frac{HDD\ \cdot 0.024\ \cdot \sum_{j}\left[\left(U_{com,j} - U_{com,j}^{ref}\right)\cdot b_j \cdot\ A_{com,j}\right]}{Q_{H,ls,i}} \qquad (1)$$

Where:

- HDD are the Heating Degree Days, defined by the current regulation for the location, K;
- $U_{com,j}$ is the actual thermal transmittance of the *j-th* common building element, $Wm^{-2}K^{-1}$;
- U_{com}^{ref} is the reference thermal transmittance of the *j-th* common building element, defined by the current regulation as a function of the climatic zone), $Wm^{-2}K^{-1}$;
- b_j is the correction factor due to heat dispersions of unheated spaces [31], dimensionless
- $A_{com,j}$ is the surface of the *j-th* common building element, m^2;

– $Q_{H,ls,i}$ is the total heat loss for transmission and ventilation [32] for space heating of the *i-th* dwelling, kWh.

Correction factor $f_{ext,\,i}$ is set to zero when $U_{com,j}$ is lower than U_{com}^{rif}. Correction factors $f_{ext,i}$ are then used to allocate voluntary and involuntary extra-consumption for space heating of each *i-th* dwelling, respectively $EQ_{v,i}$ and $EQ_{u,i}$, through equations (2) and (3).

$$EQ_{v,i} = Q_{v,i} \cdot f_{ext,i} \qquad (2)$$

$$EQ_{inv,i} = Q_{inv,i} \cdot f_{ext,i} \qquad (3)$$

The total voluntary and involuntary extra-consumption, respectively $EQ_{v,tot}$ and $EQ_{u,tot}$, are finally estimated through equations (4) and (5).

$$EQ_{v,tot} = \sum_i EQ_{v,i} \qquad (4)$$

$$EQ_{inv,tot} = \sum_i EQ_{inv,i} \qquad (5)$$

The final energy extra-consumption is then allocated among tenants through equations (6) and (7), where m_i is the percentage of heated gross volume of the *i-th* dwelling.

$$Q_{com,\,v,\,i} = -EQ_{v,i} + m_i \cdot EQ_{v,tot} \qquad (6)$$

$$Q_{com,inv,\,i} = -EQ_{inv,i} + m_i \cdot EQ_{inv,tot} \qquad (7)$$

As for example, in table 2 the informative scheme of heat sharing and of the related voluntary and involuntary consumptions estimations is presented, highlighting extra-consumptions due to the roof, the building envelope and floors not effectively insulated.

Table 2 –Calculation and accounting scheme of Extra-Consumptions

Voluntary Consumption							
Dwelling	*Measured Voluntary Consunption*	*Extra-Consumption*			*Extra-Consumption Share*		*Share for Voluntary Consumption*
		Common Roof	*Common Walls*	*Common Floor*	*Share, %*	*Share, kWh*	
Top floor	$Q_{v,\,i}$	$-EQ_{\,v,j,\,i}$	$-EQ_{\,v,j,\,i}$		m_i	$+m_i \cdot EQ_{v,tot}$	$Q_{v,\,i} + Q_{com,v,\,i}$
...	$Q_{v,\,i}$		$-EQ_{\,v,j,\,i}$		m_i	$+m_i \cdot EQ_{v,tot}$	$Q_{v,\,i} + Q_{com,v,\,i}$
...	...		...		…	...	…
First floor	$Q_{v,\,i}$		$-EQ_{\,v,j,\,i}$	$-EQ_{\,v,j,\,i}$	m_i	$+m_i \cdot EQ_{v,tot}$	$Q_{v,\,i} + Q_{com,v,\,i}$
Total	$\sum Q_{v,\,i}$	$-EQ_{v,tot}$			100%	$EQ_{v,tot}$	$\sum Q_{v,\,i}$
Involuntary Consumption							
Dwelling	*Estimated Involuntary Consumption*	*Extra-Consumption*			*Extra-Consumption Share*		*Share for Involuntary Consumption*
		Common Roof	*Common Walls*	*Common Floor*	*Share, %*	*Share, kWh*	
Top floor	$Q_{inv,\,i}$	$-EQ_{\,inv,j,\,i}$	$-EQ_{\,inv,j,\,i}$		m_i	$+m_i \cdot EQ_{inv,tot}$	$Q_{inv,\,i} + Q_{com,inv,\,i}$
...	$Q_{inv,\,i}$		$-EQ_{\,inv,j,\,i}$		m_i	$+m_i \cdot EQ_{inv,tot}$	$Q_{inv,\,i} + Q_{com,inv\,i}$
...	...		...		…	...	…
First floor	$Q_{inv,\,i}$		$-EQ_{\,inv,j,\,i}$	$-EQ_{\,inv,j,\,i}$	m_i	$+m_i \cdot EQ_{inv,tot}$	$Q_{inv,\,i} + Q_{com,inv,\,i}$
Total	$\sum Q_{inv,\,i}$	$-EQ_{inv,tot}$			100%	$EQ_{inv,tot}$	$\sum Q_{inv,\,i}$

In the authors' opinion, the proposed method allows to highlight the building inefficiency in terms of extra-consumption and of the related extra-costs. Since such inefficiency is allocated to all tenants, possible retrofit interventions on the common parts of the building should be encouraged and promoted. This is even more applicable for social housing buildings in which tenants should push the Public Institution (which is often the owner of the building or of the most part of the building) to implement energy retrofit interventions. Extra-consumption and the related cost compensation are then zeroed when the building is well insulated in compliance with applicable laws in force and heat cost sharing should be based only on effective individual consumptions, in agreement with EED. On the other hand, in certain conditions the heat cost sharing through the proposed method may generate almost similar bills among tenants (i.e. a sort of flat-rate) and this should lead to maintain the status quo in the building, avoiding the EED intended goal.

In the following, the developed method is experimented in a typical social housing building in Italy and compared with other applicable methods available for heat cost sharing.

3. The case study: a Social Housing Building in Italy

The case study investigated by the authors is represented by a social housing building located in Anagni, Central Italy. The building was constructed in 1979 by ATER, the Territorial Agency for Social Housing, and it is composed by eight dwellings served by a central heating system supplied by natural gas, which consumption is measured through a G16 class 1.5 MID approved diaphragm smart gas meter [33]. The heating plant has been equipped with programmable thermostats in each dwelling and electronic thermostatic radiator valves on each radiator. Voluntary and involuntary consumptions are gathered through an indirect allocation system and a direct class 2 MID approved heat meter in the boiler room. The system is remotely accessed through a GSM communication system allowing frequent readings and billing. Natural gas for hot water production and cooking purposes is supplied by individual boilers to each dwelling. The building is part of a social housing complex of three buildings currently undergoing a larger investigation by the authors in cooperation with ENEA and ATER.

The building consists of two connected blocks. The first one, made up of two dwellings on two floors, is located above the front porch (dwelling type C). The second one, located above garages, consists of six dwellings (two for each floor) of which three North-West oriented (dwelling type A), and 3 South-West oriented (dwelling type B). In Figure 2, 3 and 4 some pictures, the layout schemes and the cross-section of the investigated building are depicted, respectively.

Figure 2 – The investigated building

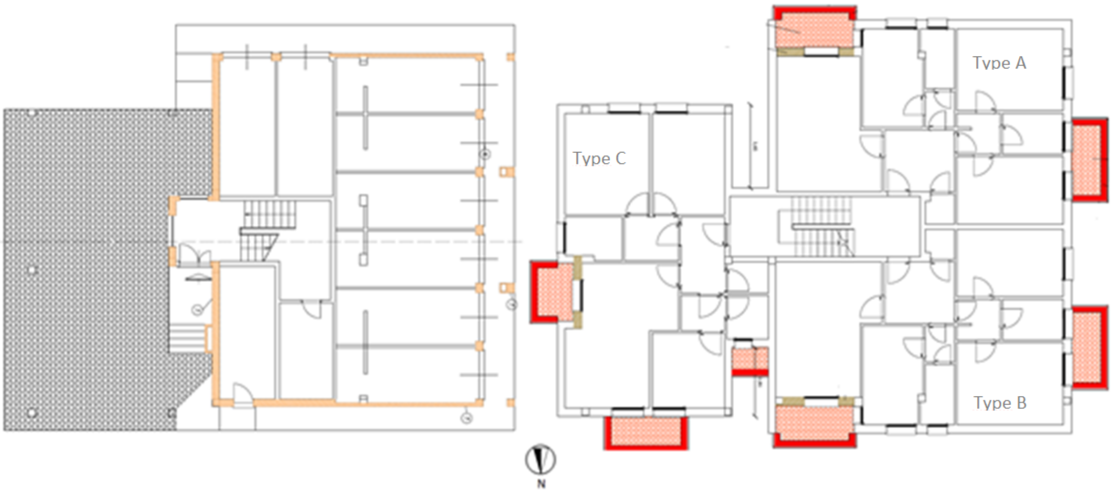


Figure 3 - Layout schemes of the building (basement and typical floor)

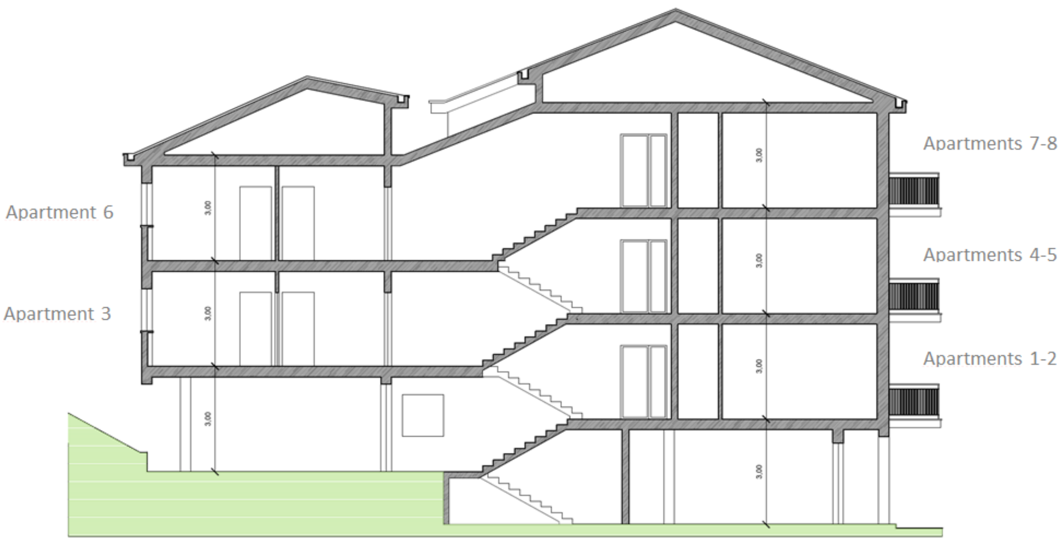


Figure 4 - Cross section of the investigated building

The reinforced concrete building investigated is a typical Italian social housing building in terms of thermo-physical characteristics, and maintenance status. As most of social housing buildings in Italy, the investigated building would require a major renovation both for improving the building envelope insulation and the efficiency of the heating plant. Most tenants are low-income and elderly people and their attitude to interact with automation systems such as programmable thermostats and thermostatic radiator valves is quite low.

Type A and B apartments present a net floor area of about 79 m^2, whereas type C apartments of about 86 m^2. The net ceiling height in dwellings is 2.7 m. It is important to point out that the two type C apartments present both a large external envelope component towards unheated space (the under-roof and the porch). On the other hand, type A and type B apartments present large heat fluxes towards unheated space only at first (towards the garages) and top floor (towards the under-roof), whereas apartments of the mid floor are sandwiched between adjacent heated apartments. With regard to the heating plant, the distribution of the heat carrier fluid is performed through vertical mains. Pipes are uninsulated and mainly run into the external walls. All dwellings are equipped with cast iron radiators.

U-values of single building elements have been estimated by the authors through data obtained by historical analysis or analogies with similar and coeval buildings using specific technical databases [34]. The main thermal and physical characteristics of the investigated building are listed in Table 3.

Table 3 – Thermal and Physical Characteristics of the investigated building

Building Element	*Description*	*Layers (from indoor to outdoor)*	*Thickness [m]*	*Estimated actual U-value [Wm^{-2}K]*	*Reference* U-value [Wm^{-2}K]*
Ceiling	Uninsulated pitched roof on unheated space	Lime/gypsum plaster	0.02	1.67	0.26
		Concrete	0.20		
		Waterproofing layer (bitumen)	0.004		
		Tiles	0.015		
External walls	Uninsulated concrete/hollow brick wall with air gap	Lime/gypsum plaster	0.02	1.12	0.32
		Hollow clay bricks	0.10		
		Air gap	0.08		
		Hollow concrete bricks	0.10		
Internal	Uninsulated hollow	Lime/gypsum plaster	0.01	1.77	-

walls	brick wall	Hollow clay bricks	0.10		
		Lime/gypsum plaster	0.01		
Floors	Single fired wall and floor tiles	Lime/gypsum plaster	0.02	1.30	0.32
		Hollow core concrete	0.18		
		Lean concrete	0.05		
		Floor tiles	0.01		
Windows	Single-glazed windows with wooden frame	---	---	4.90	1.80

* referred to the Climatic Zone "D" for retrofit requirements (see Annex 1 of Decree of Ministry of Economic Development (MISE) on date 2015/06/26)

Recently, the building has been equipped with an indirect heat cost allocation system and thermostatic radiator valves, since the obligation set by Legislative Decree 102/14. The indirect heat accounting system installed is represented by insertion-time counters compensated with the inlet temperature of the heating fluid [21], compliant with national technical standard UNI 11388 [35], while temperature control of single rooms is obtained through electronic valves controlled by a programmable thermostat. In this way, each apartment is autonomous and consisting of a single thermal zone. Finally, an external temperature probe allows continuous monitoring of the outdoor temperature.

4. Results and discussions

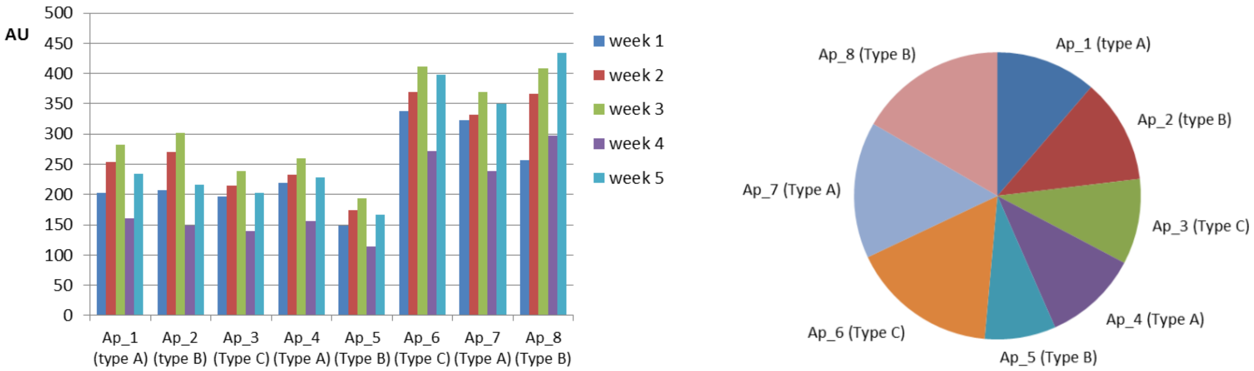
In the following the results in terms of share for only variable energy consumption according to the above described fixed proportionality, responsibility and fairness allocation principles are presented. To this aim, in the following Table 4 authors report the total cost for heating registered in the whole heating season 2016-2017.

Table 4 - Energy costs for space heating for the whole heating season 2016-2017

Cost Description	*€*
Natural Gas Consumption	€ 5.498,80
Maintenance (boiler and circulating pumps, thermostatic radiator valves and radiators)	€ 766,00
Electrical Energy for circulating pumps and boiler	€ 100,00

Heat accounting service and billing	€ 242,00
Total cost for space heating (2016-2017)	€ 6.606,80

The individual consumptions has been gathered with a two-weekly frequency and the related trends of a typical month and of the whole heating season have been depicted in figure 5.



a) b)

Figure 5: Individual consumptions trend for: a) a typical month, b) the whole season heat sharing

In Table 5 the extra-consumptions estimated by the authors are reported for the case study social housing building.

Table 5 – Voluntary and involuntary extra-consumptions according to the proposed method

Floor	*Dwelling*	*Floor Area [m2]*	*Measured Consump. [kWh]*	*Extra-Consumption [kWh]*		*Extra-Consumption Share*		*Consumption Share [kWh]*
				Common Roof	*Common Floor*	*%*	*[kWh]*	
1st	Ap_1 (type A)	78.98	9128		-1576	12.2%	+2565	10117
	Ap_2 (type B)	78.98	9496		-1846	12.2%	+2565	10215
	Ap_3 (Type C)	85.73	7752		-1981	13.3%	+2784	8555
2nd	Ap_4 (Type A)	78.98	8613			12.2%	+2565	11178
	Ap_5 (Type B)	78.98	6461			12.2%	+2565	9026
3rd	Ap_6 (Type C)	85.73	13342	-4645		13.3%	+2784	11480
	Ap_7 (Type A)	78.98	12391	-5157		12.2%	+2565	9798
	Ap_8 (Type B)	78.98	13416	-5750		12.2%	+2565	10231
Total		*645.34*	*80599*	*-15553*	*-5403*	*100%*	*+20956*	*80599*

In the following Tables 6, 7 and 8 and in Figure 6 the heat cost shares calculated according to methods belonging to the above described proportionality, responsibility and fairness principles are respectively presented.

Table 6 – Fixed Proportionality principle: Heat costs share 2016-2017 in the investigated building

Floor	*Apartment*	*Floor Area*			*Energy Need*			*Installed heat output*		
		m^2	*Share, %*	*Share, €*	*MWh*	*Share, %*	*Share, €*	*kW*	*Share, %*	*Share, €*
1st	Ap_1 (type A)	79.0	12.2%	672.97	18.7	10.7%	586.97	9.6	12.9%	707.05
	Ap_2 (type B)	79.0	12.2%	672.97	16.7	9.6%	525.25	9.1	12.2%	669.51
	Ap_3 (Type C)	85.7	13.3%	730.49	30.3	17.3%	951.59	8.8	11.8%	649.94
2nd	Ap_4 (Type A)	79.0	12.2%	672.97	13.4	7.7%	421.62	7.6	10.1%	557.35
	Ap_5 (Type B)	79.0	12.2%	672.97	12.7	7.3%	400.02	7.4	9.9%	546.38
3rd	Ap_6 (Type C)	85.7	13.3%	730.49	31.4	18.0%	987.38	11.0	14.7%	808.39
	Ap_7 (Type A)	79.0	12.2%	672.97	26.2	15.0%	823.79	10.2	13.7%	752.31
	Ap_8 (Type B)	79.0	12.2%	672.97	25.5	14.6%	802.19	11.0	14.7%	807.87

From data in table 6 it can be pointed out that the flat-rate charging based on the floor area (even with the same floor area) differs considerably with the ones based on the energy need and on the installed radiators' heat output. This should not be surprising since the same floor area corresponds to different external envelope components and thermal loads, depending on the floor, the exposure and the transmittance of single building elements. The huge deviation between energy need and installed radiators' heat output methods is also particularly interesting. In fact, such deviation may seem incomprehensible if we do not take into account that the former is representative of the average energy load in standard conditions, the latter of the peak load (and therefore without considering free heat gains). Moreover, since such estimations are often carried out by different technicians and often through different reference standards for the radiators' heat output estimation, they lead to huge deviations (e.g. in Ap_1, Ap_2 and Ap_3). The comparison is particularly interesting since, although the fixed proportionality principle is no longer allowed in numerous MS, it is the most common for fixed costs sharing and, often, for involuntary ones. Comparing these methods, it emerges that, despite the simplicity and uniform distribution of costs, the floor area method is not representative neither of the potential individual consumptions nor of the heat output, favouring above all the more dispersing apartments (i.e. AP_6, Ap_7 and Ap_8, located on the top floor).

Table 7 - Responsibility principle: Heat cost share 2016-2017 in the investigated building

Floor	*Apartment*	*Individual consumptions*			*Voluntary/Involuntary (Italy)*				*70/30 (EU)*	
		AU	*Share, %*	*Share, €*	*Vol. Share, %*	*Unvol. Share, %*	*Share, %*	*Share, €*	*Share, %*	*Share, €*
1st	Ap_1 (type A)	3651	11.0%	607.18	11.3%	10.7%	11.2%	613.25	11.4%	626.92
	Ap_2 (type B)	3798	11.1%	609.28	11.8%	9.6%	11.2%	615.36	11.4%	628.39
	Ap_3 (Type C)	3101	9.4%	519.13	9.6%	17.3%	11.7%	640.91	10.6%	582.53
2nd	Ap_4 (Type A)	3445	10.5%	578.69	10.7%	7.7%	9.9%	543.64	11.0%	606.98
	Ap_5 (Type B)	2584	7.8%	431.02	8.0%	7.3%	7.8%	429.99	9.2%	503.61
3rd	Ap_6 (Type C)	5337	17.0%	934.28	16.6%	18.0%	16.9%	930.67	15.9%	873.14
	Ap_7 (Type A)	4956	15.5%	851.03	15.4%	15.0%	15.3%	839.62	14.5%	797.61
	Ap_8 (Type B)	5367	17.6%	968.19	16.6%	14.6%	16.1%	885.35	16.0%	879.62

From data in Table 7 it can be pointed out that allocation methods based on the responsibility principle (i.e. on the actual consumptions of each dwelling) penalize on average the more unfavourable dwellings in terms of energy need (e.g. those on the top or on the first floor). An exception is represented by those users who, thanks to the reduced use in terms of on-off hours or to the higher propensity to save energy in terms of lower set point temperatures (e.g. Ap_3), behave intentionally to consume less. This results in a high economic load, leading to charge some tenants up to twice the energy costs (e.g. Ap_8 compared with Ap_5), and it is only partly mitigated by the "Voluntary/Involuntary" and by the percentage reduction "70/30" methods aimed to balance actual consumption with the expected needs. Finally, it is interesting to highlight that the less critical apartments from the thermal losses point of view (i.e. Ap_4 and Ap_5) are also those that never present a share of actual consumption lower than potential ones. This is probably due to the oversized heating plant and/or to the stolen heat issue.

Table 8 - Fairness principle: Heat cost share 2016-2017 in the investigated building

Floor	*Ap.and Type*	*Swiss Method (reduction factor)*				*Greek Method*				*Proposed Method*			
		Comp. factor	*AUc*	*Share, %*	*Share, €*	*Fixed share*	*Var. Share*	*Share, %*	*Share, €*	*Extra-Cons. factor*	*AUc*	*Share, %*	*Share, €*
1st	Ap_1 (A)	-13.1%	3747	11.6%	639.11	3.3%	8.2%	11.5%	632.77	-17.3%	4047	12.6%	690.20
	Ap_2 (B)	-12.0%	3944	12.2%	672.70	3.0%	8.5%	11.5%	631.82	-19.4%	4086	12.7%	696.88
	Ap_3 (C)	-23.3%	2807	8.7%	478.71	4.5%	7.0%	11.5%	630.29	-25.6%	3422	10.6%	583.65
2nd	Ap_4 (A)	-3.1%	3943	12.2%	672.47	2.8%	7.7%	10.5%	577.19	0.0%	4471	13.9%	762.61
	Ap_5 (B)	-2.0%	2989	9.3%	509.74	2.6%	5.8%	8.4%	463.11	0.0%	3610	11.2%	615.77
3rd	Ap_6 (C)	-23.3%	4830	15.0%	823.86	3.8%	12.0%	15.8%	866.28	-34.8%	4592	14.2%	783.24
	Ap_7 (A)	-17.0%	4854	15.1%	827.86	3.9%	11.1%	15.0%	826.14	-41.6%	3919	12.2%	668.45
	Ap_8 (B)	-19.1%	5126	15.9%	874.35	3.8%	12.1%	15.8%	871.20	-42.9%	4092	12.7%	698.00

Regarding the use of "fairness” principle in a typical social housing building, data in Table 8 show that compensation methods available in literature (e.g. the Swiss and Greek methods) do not allow an effective compensation of inequalities within the building. These inequalities are mainly due to the energetic inefficiencies of the building, if compared to the “voluntary/involuntary” and to the “70/30” sharing methods. To this aim, the method proposed in this paper seems to be much more effective, while maintaining the principle of responsibility and awareness of consumption and sharing among different tenants the costs related to the energy inefficiency of the common parts. The deviations between different compensation methods shows that the effects of compensation of the proposed method are much more incisive on the apartments at the top floor (about -40%) making the share of energy costs comparable between apartments with similar floor area and of the same type (with the same on-off hours and set point temperatures).

In Figure 6 an overview of the results in terms of heat share for each apartment in the investigated building is presented.

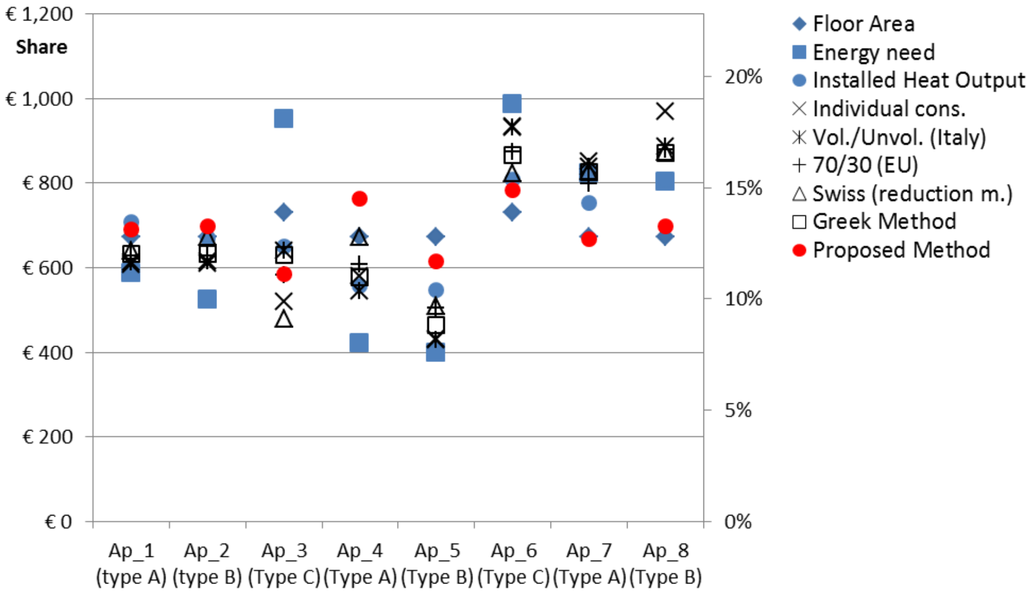


Figure 6 - Comparison between different cost allocation methods in the investigated social housing building

From the analysis of Figure 6 it can be highlighted that huge deviations clearly emerge among different allocation methods, especially for those apartments presenting higher propensity to heat saving (e.g. Ap_3) or larger heat losses (e.g. Ap_6, Ap_7 and Ap_8). The proposed method seems to be fairly sustainable since shares for disadvantaged apartments are corrected and the propensity to heat saving of single tenants is however encouraged.

5. Conclusions

Heat cost allocation for social housing has been little investigated in literature, despite particularly impacting on the low-income social classes and determining issues related to fuel poverty. The present research shows that heat allocation methods available in literature should be almost ineffective in social housing where buildings are often thermally underperforming and users are vulnerable. In particular:

- methods based on the fixed proportionality principle do not boost virtuous end users' behaviour since they do not promote the rational use of energy and not encourage the adoption of energy efficient retrofit interventions in the building. This occur both when flat-rate are adopted based on the floor area or on potential consumption (e.g. energy need and installed radiators' heat output);

- methods based on the responsibility principle through the promotion of a more conscious use of energy in residential buildings, excessively penalize disadvantaged apartments due to the poor energy performance of social housing buildings. Thus, heat cost sharing based only on individual consumption leads to different shares (up to double) for dwellings with identical floor area, as occurred in the case study building;
- existing methods based on fairness principle partially take into account the inequality of the assignment of social housing apartments (generally based only on the surface principle). However, by not taking into account high differences in heat transfer coefficients of the apartments they lead to huge differences in heat cost sharing among tenants. As occurred in the case study building, the use of such methods reduces but does not eliminate unfairness in heat sharing in large underperforming buildings. On the other hand, the complexity of these methods does not highlight the extra-costs causes, therefore users' virtuous behaviour are not always encouraged and increasing disputes may occur among tenants.

The proposed method, based on the estimation of extra-consumptions due to energy inefficiency of social housing buildings, introduces drivers for both improving building energy performance and reallocating heat costs in a more fair manner. This method overcomes the contrast between the principles of responsibility and equity. The authors applied this method to a typical social housing building in Central Italy showing, moreover, the potential to reduce the gap between who has the charge to implement energy efficiency interventions (i.e. the condominium entire meeting) and the beneficiary of the interventions (often only few dwellings).

In the authors' opinion, the use of the proposed method brings to the attention of landlord/tenants the building thermal inefficiency and may encourage possible retrofit interventions on the common parts of the building, especially in social housing buildings. On the other hand, in certain conditions the heat cost sharing through the proposed method may generate almost similar bills among tenants and this should lead to maintain the status quo in the building, being in contrast with the EED intended goal.

This method has also been proposed as standard method to the Italian Standardization body UNI-CTI and to the Italian Authority (MISE).

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Nomenclature

Acronyms

AEEGSI	Italian Authority for Electrical Energy, Gas and Water System
Ap	Apartment
ATER	Territorial Agency for Social Housing
CTI	Italian Thermotechnical Committee
EED	Energy Efficiency Directive
ENEA	National Agency for new Technologies, Energy and Economic Sustainable Development
EU	European Union
HCA	Electronic heat cost allocator
HM	Direct heat meter
ITC	Insertion time counter
MID	Measuring Instrument Directive
MISE	Ministry of Economic Development
MS	Member State
SFOE	Swiss Federal Office of Energy
UNI	Italian Standardization Body

Symbols

$A_{com,j}$	surface of the *j-th* common building element, m^2
AU	Allocation Unit, dimensionless
AUc	Compensated Allocation Unit, dimensionless
b_j	correction factor due to heat dispersions of unheated spaces, dimensionless
$EQ_{inv,\,i}$	Involuntary extra-consumption of the *i-th* dwelling, kWh
$EQ_{inv,tot}$	Total Involuntary extra-consumption of the building, kWh
$EQ_{v,\,i}$	Voluntary extra-consumption of the *i-th* dwelling, kWh
$EQ_{v,tot}$	Total Voluntary extra-consumption of the building, kWh
f_i	Correction factor (Greek method), dimensionless
$f_{ext,\,i}$	Correction factor (proposed method), dimensionless
HDD	Heating Degree Days, K
k_{inv}	Coefficient for involuntary consumption, dimensionless
m_i	Percentage of heated gross volume of the *i-th* dwelling, dimensionless
$Q_{H,ls,i}$	total heat loss for transmission and ventilation of the *i-th* dwelling, kWh

$Q_{com,\,v,\,i}$	Voluntary Consumption of common parts of the *i-th* dwelling, kWh
$Q_{com,inv,\,i}$	Involuntary Consumption of common parts of the *i-th* dwelling, kWh
$Q_{inv,\,i}$	Involuntary consumption of the *i-th* dwelling, kWh
$Q_{v,\,i}$	Voluntary consumption of the *i-th* dwelling, kWh
$U_{com,j}$	actual thermal transmittance of the *j-th* common building element, $Wm^{-2}K^{-1}$
U_{com}^{ref}	reference thermal transmittance of the *j-th* common building element, $Wm^{-2}K^{-1}$

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