Energy poverty in a changing climate: the challenge of "hot homes"

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Abstract
Energy poverty is traditionally and historically identified mainly as an issue of inadequate heating of homes, which arises when people, due to economic hardship, are unable to heat their homes to a satisfactory level of comfort at an acceptable cost. However, within the context of a climate change, with more and more frequent hot summers and heat waves, the need for "cool houses" is becoming crucial, also in terms of health impacts on vulnerable consumers. So, energy poverty and its impacts shall be defined considering the overall household energy needs both in winter and in summer.

This is particularly true for those countries where the climate is various, with large differences in terms of heating and cooling needs. Among these, Italy represents a good example, with climates going from the almost-North-African hot Southern areas to the almost-Scandinavian Alpine areas.

This work is focused on studying the problem of combined winter and summer energy poverty, addressing, in particular, the case of Italy. First, the issue of defining a minimum energy need and an energy poverty indicator is discussed. Then, the calculation of the minimum energy need for heating and cooling is performed for 140 types of buildings across the whole country and this is converted into a minimum energy cost for each household. Then, the issue of cooling is addressed directly, by analysing the impact not only of paying higher electricity bills, but also of installing and maintaining a cooling system (64 % of Italian household declare not to have one) and the related costs. Finally, the impact in terms of energy poverty increase, due to cooling, is addressed, considering local differences among different areas. Last but not least, a focus on how to support vulnerable consumers in the energy transition, by taking into account the impacts of climate change, is performed.

Introduction and literature review
Energy poverty (EP) is traditionally and historically identified mainly with an issue of inadequate heating of homes, which arises when people, due to economic hardship, are unable to heat their homes to a satisfactory level of comfort at an affordable cost (BB 1991).

However, following the effects connected with climate change and evolutions in the behaviors and needs of families, the analysis of the phenomenon is starting to be extended to the overall climatization of the buildings, thus also cooling (THS 2019), and other essentials services (such as mobility, being able to cook hot meals or have hot water available for personal hygiene purposes or use essential electric appliances) that allow the individual and his/her family to have an active participation within the society (MLM 2017).

The understanding of energy poverty in "summer" or in hot climates is still at the beginning. It was started, in Europe, with the above-mentioned study by (THS 2019), but there are still few studies about it in this continent and thus a comprehensive understanding of the phenomenon is far to be reached. One of the most remarkable studies is (BH 2020), where the option to exploit natural ventilation is assessed to reduce cooling needs and improve tenants' comfort in social housing. Some more data have been found, recently, in papers produced in other countries such as Brazil (MA 2020), Japan (TT 2020), Palestine

(HP 2020) and Australia (CS 2021). The latter also addresses health consequences related to energy poverty. Moreover, a general focus on energy poverty and cooling in the Global South is offered by (MAB 2019).

Also considering EU regulations (like those contained in the "Clean energy for all Europeans package"), it is evident that energy poverty represents a social issue, subject to the attention and study by European and national governments. This is particularly true in the light of the serious economic problems that have affected the global economy in the recent years, especially after COVID-19 pandemic. Moreover, the pressures to have a stronger European commitment towards environmental sustainability (decarbonization) might lead to an increase in costs for families. Governments are therefore trying to identify possible mitigation solutions to the phenomenon by acting on the three main factors that are strictly connected to the problem: high energy prices, low incomes, and low energy efficiency of buildings. However, only by gaining a full understanding of energy poverty from all sides, it will be possible to address this issue with targeted and effective policies.

According to the results of the study presented in this paper, in case of "minimum comfort" (keeping a temperature of at least 18 °C for heating and not less than 28 °C for cooling of the houses), around 12 % of Italian families would be forced to meet such an "energy" cost to fall in a condition of energy poverty. By rising comfort conditions inside the dwellings to what, for example, is suggested by laws and regulations in Italy (going to 20 °C for heating and to 26 °C for cooling – DPR 74/2013), the number of energy poor families would increase to 13 %. Moreover, if the issue of purchasing, installing, and maintaining a cooling system is addressed, the number of energy poor families increases of around 500 thousand additional units (around 2 %). The lack of energy basic services not only causes issues of inequality and social exclusion, but has also some externalities on the community connected to the larger probability to recur to health services, and, therefore, exert larger pressure on the whole society in terms of costs and occupation of health facilities, as well as of absence from work and social exclusion, with the well-known consequences. The analysis will be presented starting from the explanation of the applied methodology in order to assess the issue of energy poverty in summer, followed by the results for the Italian case and the proposal of policies to support energy poor citizens. Finally, some conclusions on possible future developments, including the consideration of long-term effects of energy poverty (such as chronic diseases and health issues), will be presented.

ENERGY POVERTY INDICATOR

As it is well-known, there are several energy poverty indicators proposed by international literature end experts, such as the ones selected from literature by the Energy Poverty Observatory (EPOV), however there is still no unique indicator that is applicable to the whole European Union (EU). Currently, there are four primary and twenty-four secondary indicators that can be used, alone or in a combination, to define energy poverty. Moreover, several Member States haven't defined a unique indicator yet.

Among the indicators proposed by EPOV, however, the four primary ones are mostly related to heating or arrear into paying energy bills. With regards to cooling, only one of the secondary indicators is directly referring to it, by assessing how many families, in a country (or in the overall EU) are complaining to not be able to adequately cool their houses.

There are three main issues with this definition of indicators:

- first, with the primary indicators, the problem is not fully addressed;
- second, the only indicator related to cooling is a subjective and not an objective one;
- finally, other issues that might be related to comfort and social inclusion (such as an adequate set of efficient electrical appliances and lights and the need of mobility) are not included yet.

A partial solution has come from the European Energy Poverty Index (EEPI, OE 2019), that combines both the domestic part of energy poverty (quality of dwellings, perceived discomfort in summer and winter, energy expenditures) to the transport issue (energy expenditure, access and affordability of public transport).

However, all these parameters are based on statistical analyses and none of them is taking into account the actual energy need of the building and the household. A family can be energy poor and spending a very low part of its income on heating or cooling, thus putting the health of its components at risk. Another one might spend a high part of its income on energy but can be wasting it.

The indicator contained in the Italian National Energy Strategy (SEN 2017), derived from (FL 2015) offers an approach in the sense of "Low Income High Costs" (LIHC) indicators, where the ratio between energy expenses and household income (or, in the Italian case, the average monthly expenses of the household, since the few statistics about income cannot be related to energy expenditures) is compared to a statistically determined threshold in order to assess whether a subject is in energy poverty or not.

Later, in Italy, a different approach, however, focused on the "winter energy poverty" issue, has been proposed by (FLB 2017), where the household energy need (and not just its expense) is assessed; it is based on the following equation:

$$\boldsymbol{EP_i = I[\left(E_i^{tot} - E_i^{minheat}\right) < \sigma]} \quad (1)$$

where

EP_i is the energy poverty condition of *i*-family;

E_i^{tot} is the total monthly expenditure of the *i*-family;

$E_i^{minheat}$ is the minimum heating need expenditure of the i-family over the year, divided by twelve;

σ is the expenditure threshold that identifies a family as poor according to ISTAT, varying with the number of family members; for this study, the reference values for 2015 have been used.

Methodology

The study has been conducted with a modelling approach. The methodology involves four main steps, that are intertwined. Figure 1 shows a general representation of the methodology which will then be applied to a case study focused on the Italian situation.

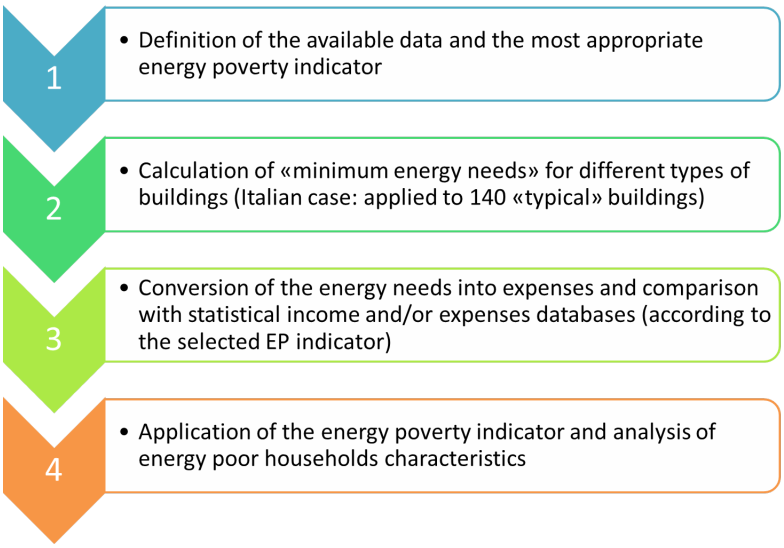

Figure 1. Energy poverty analysis methodology.

AVAILABLE DATABASES

The first and most important issue, if an objective EP indicator is used, is to find a database that allows to connect at least household incomes with their energy consumption and/or expenditure. For the Italian case, the most-complete database on household characteristics and their financial situation is given by the "Household Budget Survey", performed every year by the Italian National Statistics Institute (ISTAT). It doesn't contain household incomes, but it uses the households' monthly expenditures as a proxy of their income. In this case, the reference data are the "research micro-data" available for 2015. The survey aims at recording, for several weeks over a year, the expenditures of 15,000 households in Italy, by asking them to report all the costs sustained to purchase goods and services for the family. The reported data are converted in average monthly expenditures. The reference population is composed by all the families, and the unit is the household itself, intended as a group of people living together, bound by wedding, relativeness, adoption or affection, and sharing the living expenditures and/or the income. The household/family is also asked to answer some questions about its composition and socio-economic status. Each family is characterized also with a coefficient that allows to "report it to the universe", or to all the similar families; thus, from a database of 15,000 families it is possible to extend the results to all the 25.8 million families in the country.

ENERGY POVERTY INDICATOR

For this work, it has been chosen to use a modified indicator that, starting from the one proposed in the SEN, is considering also the minimum cooling expenditure of the household and the electrical appliances in a parameter called $E_i^{minenergy}$:

$$\boldsymbol{EP_i = I[(E_i^{tot} - E_i^{minenergy}) < \sigma]} \qquad (2)$$

In particular, $E_i^{minenergy}$ is calculated as follows:

- minimum heating need expenditure of the family;
- minimum cooling expenditure for those families without air conditioning (64 %);
- real electricity expenditure for all families (that, for those with air conditioning, includes it);
- expenditures related to the purchase, installation and maintenance of cooling systems, for those families without air conditioning.

DEFINITION AND CALCULATION OF MINIMUM ENERGY NEEDS FOR DIFFERENT TYPES OF BUILDINGS

To calculate the energy needs, a proprietary software, developed by RSE, called CARAPACE (CCG 2014 and MRR 2016) has been used, that allows to assess heating and cooling needs of a building by selecting the following inputs:

- building type: single-family building, multi-family building (2–8 apartments), small condominium (9–15 apartments), large condominium (16+ apartments);
- climatic zone: zones B to F, based on Heating Degree Days – HDD (zone A, the "warmest" includes just 2 small municipalities in Southern Italy that have been modelled as those in zone B);
- building age: seven classes from "built before 1920" to "built after 2006", that take into account the building techniques and regulatory requirements in different timespans.

The software has been enriched with weather hourly data from 1990 to 2010 and then for 2015 and 2017 (the latter not available for climatic zones C and D): in the analysed case, it has been chosen to use weather data from 2015, due to their availability for all the zones and the year being the same as the referenced ISTAT database. The software is built in such a way that all the parameters that affect a building thermal performance, plus those related to the heating and cooling system, can be customized. However, for each combination of building type, climatic zone and building age, a "typical" building shape, based on statistical data on construction techniques, surfaces, volumes, etc. …, has been inserted in the software. For this work, the 140 "typical buildings" already available have been used, as representative for the whole Italian building stock.

The software performs its calculation by taking in input also some parameters related to temperature settings and on/off times of the heating system, both in the winter and summer configuration; moreover, it allows for the temperature settings for the calculation of the minimum energy to be determined in two ways:

- by using the Italian laws and regulations (DPR 74/2013), where the heating temperature is set at 20 °C (±2 °C) and the cooling temperature is set at 26 °C (±2 °C) or no more than 5 °C less than the outdoor temperature;
- by using a criterium of "minimum comfort" with heating temperature at 18 °C (the minimum allowed by the legislation and identified by the World Health Organization and the threshold not to have serious impacts on human health) and cooling temperature at 28 °C (as the extreme "discomfort" foreseen by the Italian legislation).

For the presented analysis, the first criterion was used (choosing 20 °C and 26 °C as heating and cooling temperature, respectively) in order to be conservative in the estimation of the number of energy poor households and "guarantee" families a satisfactory comfort. The start and end date and the daily hours of use of the heating and cooling systems have been chosen as those defined by the above-mentioned Italian legislation (DPR 74/2013) for heating and by the standard UNI/TS 11300 for cooling, depending on the climatic zone.

The validation of the software was performed when it was programmed and it is periodically updated with the latest energy efficiency requirements (Capozza et al. 2014, Madonna et al. 2016, Croci et al. 2018).

CALCULATION OF MINIMUM ENERGY EXPENDITURES

The minimum energy needs have been converted into energy consumption by considering:

- heating supplied by radiators connected to a natural gas boiler, with efficiency 0.9 (the most common system in Italy);
- cooling supplied by a heat pump with COP 3.

The expenditures have been then calculated by applying the prices reported in Eurostat as average prices for natural gas (EGAS 2015) and electricity (EEL 2015), including taxes and levies, in Italy for 2015:

- €0.08355/kWh for natural gas;
- €0.24390/kWh for electricity.

For more than 16.4 million families (around 64 % of the 25.8 million Italian families) that don't have a cooling system yet, the costs of buying, installing and maintaining it had to be calculated. In particular, the cost for purchase and installation has been calculated as an average over the standard costs proposed by the main market players, over an extensive investigation performed by the authors. Most of the providers offer to split the cost in 20 monthly instalments, so the overall cost has been divided by 20, that is the best available option for a family that doesn't have enough money to purchase the whole system all at once. The maintenance cost is, instead, calculated annually so, in order to sum them, it had to be divided by 12. With regards to the purchase and installation costs, they have been calculated based on the number of rooms in the house, considered proportional to the cooling system type (mono-split, dual-split, multi-split). All considered costs are reported in Table 1.

APPLICATION OF THE ENERGY POVERTY INDICATOR AND ANALYSIS OF THE FAMILIES

Once all the energy-related expenditures have been calculated on a monthly-basis, they can be inserted in the national database and the above-explained EP indicator can be applied. From the total monthly expenditures of the families, all the energy-related expenditures are subtracted and then the residual expenditures (E_i^{tot}-$E_i^{minenergy}$) are compared to the poverty threshold. Finally, the characteristics of energy poor households are analysed.

Results

In this paragraph, the main results of the analysis are presented, in general terms (total number of energy poor consumers), and, more in specific, with focus on the quota of total expenditures related to the satisfaction of energy needs, on the type of families that are in EP and on their main characteristics.

ENERGY NEEDS FOR DIFFERENT TYPES OF BUILDINGS

The results obtained from the running of the software on the 140 types of households are not reported in detail, but are available in (MRB 2020). A sample for large condominiums is shown in Figure 2. It can be noted that, for heating, the need is fast decreasing with the age of the building (V1 are those built before 1920, V7 those built after 2006) and is strongly connected to the climatic zone, with the maximum in Zone F

Table 1. Purchase, installation and maintenance costs for cooling systems.

Number of rooms	Cooling system type	Average purchase and installation cost [€]	Ordinary maintenance [€/y]	External unit maintenance [€/y]	Gas recharge [€/y]	Total installation and maintenance costs [€/month]*
1–3	Mono-split	975	40	100	50	**65**
4–5	Dual-split	1,150	60	115	65	**78**
6+	Multi-split	1,650	80	130	80	**107**

** The monthly costs are an average obtained by splitting the yearly costs by 12 and the purchase and installation cost in 20 instalments, as stated above.*

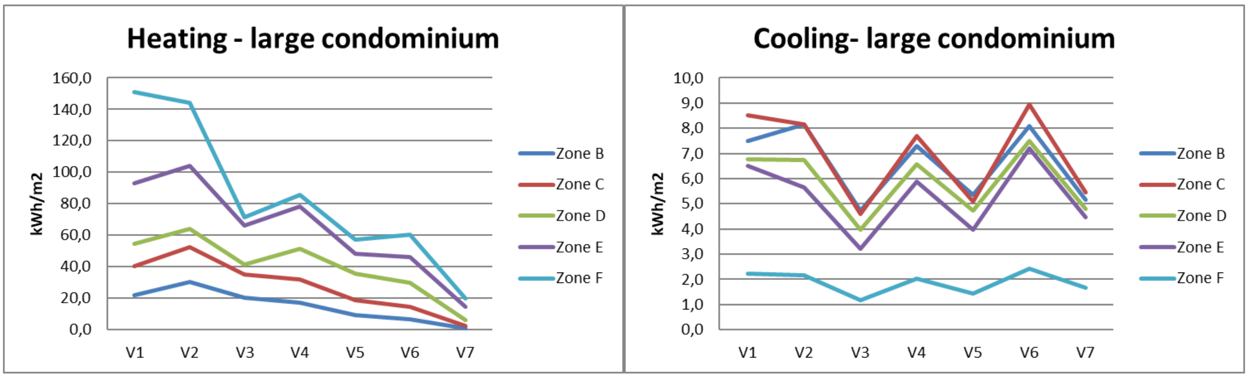

Figure 2. Heating and cooling needs for large condominiums.

(HDD>3,000) and the minimum in Zone B (600<HDD<900). For cooling, this is not entirely true, with Zone C and Zone B quite exchangeable and very close to the other two zones. Only buildings in Zone F (that includes mostly municipalities on the Alps and Appennines mountains) have a significantly lower cooling need. This might be explained by the fact that the climatic zones have always been defined based on HDD, while Cooling Degree Days (CDD) and cooling needs have not been used in the official definitions. Since heating needs tend to be higher in flat areas, this explains the low variation between the four central zones, while, being Zone F mostly in mountainous areas, the cooling needs become much lower.

The same applies to all types of buildings: for heating the minimum values (from 1.1 kWh/m^2 for large condominiums to 7.4 kWh/m^2 for single-family buildings) are in those built after 2006 in Zone B while the maximum values (from 147 kWh/m^2 for small condominiums to 235 kWh/m^2 for single-family buildings) are in those built before 1920 in Zone F; for cooling, the minimum is always in Zone F, but in buildings from different ages (from 1.1 kWh/m^2 for small condominiums built before 1920 to 1.5 kWh/m^2 for single-family buildings built between 1980 and 1989), while the maximum is in Zones B, C or D, depending on the type of building (from 7 kWh/m^2 for single-family buildings between 1970 and 1979 in Zone D to 9.3 kWh/m^2 for small condominium built between 1920 and 1949 in Zone C).

ENERGY POOR CONSUMERS AND THEIR EXPENDITURES SHARE

The number of energy poor families and consumers has been calculated in both the cases of only heating and heating plus cooling (that includes also purchase, installation and maintenance costs for the cooling system). The results are reported in Table 2. Around 500,000 families, corresponding to 980,000 consumers, risk to become energy poor if the cooling case is considered.

The average size of the energy poor household is lowered from 2.94 to 2.80, meaning that, with cooling, more singles and couples are falling into energy poverty than large families. This is supported also by the evidence in the family composition, reported in Table 3.

The non-energy poor families would be distributed more in the upper part of the table, with an overall share of singles and couples equal to 64 % and only 19 % families from 4 people up (4 % from 5 people up).

Table 2. Total number of energy poor families and consumers.

Case	Households (×1000)	Consumers (×1000)
Heating	3,303	9,678
% on Italian families	13 %	16 %
Heating + cooling	3,808	10,660
% on Italian families	15 %	18 %
Total difference	505	982
% difference	15 %	10 %

The share of energy expenditure over the total expenditure is then reported in Table 4[1]. For energy poor households, the share of total expenditure used to purchase electricity and natural gas for heating is 8.5 %, while for non-energy poor households is less than half of it (3.8 %). The cost of electrical energy for cooling is not a large part of the overall energy costs (less than 1 %) but, if also the cost of purchasing, installing and maintaining the cooling system is considered, the share goes up to 15.8 % for energy poor households, while it is only 6.4 % for non-energy poor. This implies that a large part of energy poor families' income (for which expenditures are used as a proxy) is spent on energy services, limiting their residual expenditure capacity for other goods or services such as food, mobility, education, health, entertainment.

ANALYSIS OF ENERGY POOR HOUSEHOLDS

For the socio-economic analysis, the considered parameters are building type, building age, house ownership and urban context.

With regards to the building type, the increase in number of energy poor households between the heating and the heating + cooling case is almost equally split in the four categories. Most of the energy poor live in multi-family or small condominiums, while non-energy poor are more equally distributed in the three multi-apartment categories, with 31 % of them in large condominiums, 24 % in small condominiums, 30 % in multi-family buildings and 15 % in single-family buildings.

1. The average is the weighted average between energy poor households and non-energy poor households.

Table 3. Energy poverty according to family composition.

Family composition	Heating (households ×1000)	Heating (households %)	Heating+ cooling (households ×1000)	Heating+ cooling (households %)	Total difference (households ×1000)	% difference
1	650	20 %	898	24 %	248	+38 %
2	749	23 %	882	23 %	133	+18 %
3	677	20 %	737	19 %	60	+9 %
4	777	24 %	816	21 %	39	+5 %
5	306	9 %	330	9 %	24	+8 %
6	144	4 %	145	4 %	2	+1 %

Table 4. Expenditures split for different types of households.

% on total household expenditure	Energy poor households	Non-energy poor households	Average
Total energy expenditure ($E_i^{minenergy}$)	15.8 %	6.4 %	6.9 %
Energy use expenditure	8.5 %	3.8 %	4.1 %
Minimum heating + cooling expenditure	4.4 %	2.2 %	2.3 %
Heating expenditure	3.5 %	1.8 %	1.9 %
Cooling expenditure	0.9 %	0.4 %	0.4 %
Purchase & Installation – cooling system	4.7 %	2.0 %	2.1 %
Maintenance – cooling system	1.6 %	0.6 %	0.7 %

Table 5. Comparison based on the building type.

Building type	Heating (households ×1000)	Heating (households %)	Heating+ cooling (households ×1000)	Heating+ cooling (households %)	Total difference (households ×1000)	% difference
Single-family	568	17 %	637	17 %	70	12 %
Multi-family	1,090	33 %	1,268	33 %	178	16 %
Small condominium	902	27 %	1,038	27 %	136	15 %
Large condominium	743	22 %	865	22 %	122	16 %

In terms of building age, the largest difference between non-energy poor and energy poor is for those living in houses built between 1946 and 1960 (less non-energy poor) and after 1991 (less energy-poor). With regards to the two climatization cases, the largest difference is on the oldest buildings, but this can be explained by the fact that it is less frequent to have a pre-installed cooling system on those, so a larger share of families need to purchase and install a cooling system, thus increasing their expenditures.

When considering the ownership of the house, non-energy poor own their houses in 74 % of the cases, are renting it in 15 % of the cases, 3 % of them has a usufruct contract and 8 % lives in free houses. The significant difference between them and energy poor consumers can be found mostly on the proportion between ownership and rental. If the comparison between the heating and the heating + cooling case is considered, there is almost the same % increase for families that own, rent or live in usufruct. However, the question arises whether tenants have the permit to purchase and install a cooling system and whether the costs shall be sustained by the tenant or the landlord. In the second case, for sure maintenance costs are on the tenant, but the overall issue arises for 230,000 households (considering also those in free use[2]).

When evaluating the urban context, 17 % of non-energy poor live in metropolitan cities and 53 % of them in rural areas. The share for suburbs and large non-metropolitan cities is the same for energy poor and non-energy poor. Considering the case of heating and heating + cooling, the relative increase of energy poor is lower in the suburbs and large cities than in metropolitan cities and rural areas.

2. This formula is usually common for poor people supported by social services, living in public houses or for people living in a house belonging to a relative (usually people living in buildings owned by their parents or grandparents).

ANALYSIS OF THE GEOGRAPHICAL CONTEXT

If the share of energy poor people is considered across the whole Italian peninsula, there is a wide difference between the north and the south. Also considering only the heating case, the southern part of the country shows the largest number of energy poor families. However, this is explained by the fact that in the same area poverty is quite spread, so energy represents just an extra burden to those households already struggling in terms of financial availability.

When considering the comparative cases between heating and heating + cooling, the difference doesn't seem much, with Southern Italy still much poorer than the North. However, there are some local exceptions, such as Piedmont and Trentino – Alto Adige, but also in some areas in Central Italy, as shown in Figure 5, where the increase in number of energy poor families is quite high. This might be explained by the fact that, in those areas, cooling systems are less spread, thus the purchase, installation and maintenance of a cooling system becomes a burden for more families.

Discussion, conclusions and future developments

Due to climate change and global warming, the need of "hot homes" is becoming a "competitor" of the need of "cool homes". This is strongly linked to health issues: it is true that the World Health Organization (WHO) declares that a prolonged indoor time under 18 °C can have serious consequences, also warm temperatures (especially very hot ones, as it happens during

Table 6. Comparison based on the building age.

Construction time (building age)	Heating (households ×1000)	Heating (households %)	Heating+ cooling (households ×1000)	Heating+ cooling (households %)	Total difference (households ×1000)	% difference
Before 1920	130	4 %	156	4 %	26	20 %
1921–1945	358	11 %	431	11 %	73	20 %
1946–1960	457	14 %	505	13 %	48	10 %
1961–1975	1,396	42 %	1,622	43 %	226	16 %
1976–1990	496	15 %	569	15 %	73	15 %
1991–2005	261	8 %	295	8 %	34	13 %
After 2006	206	6 %	231	6 %	25	12 %

Table 7. Comparison based on the house ownership.

Ownership	Heating (households ×1000)	Heating (households %)	Heating+ cooling (households ×1000)	Heating+ cooling (households %)	Total difference (households ×1000)	% difference
Tenant – renting	1,235	37 %	1,431	38 %	196	16 %
Owner	1,646	50 %	1,922	50 %	275	17 %
Tenant – usufruct	65	2 %	77	2 %	12	18 %
Free use	356	11 %	378	10 %	22	6 %

Table 8. Comparison based on the urban context.

Urban context	Heating (households ×1000)	Heating (households %)	Heating+ cooling (households ×1000)	Heating+ cooling (households %)	Total difference (households ×1000)	% difference
Metropolitan city	440	13 %	521	14 %	81	19 %
Suburbs of metropolitan cities and cities with >50,000 people	946	29 %	1,061	28 %	115	12 %
Municipalities with <50,000 people	1,917	58 %	2,226	58 %	309	16 %

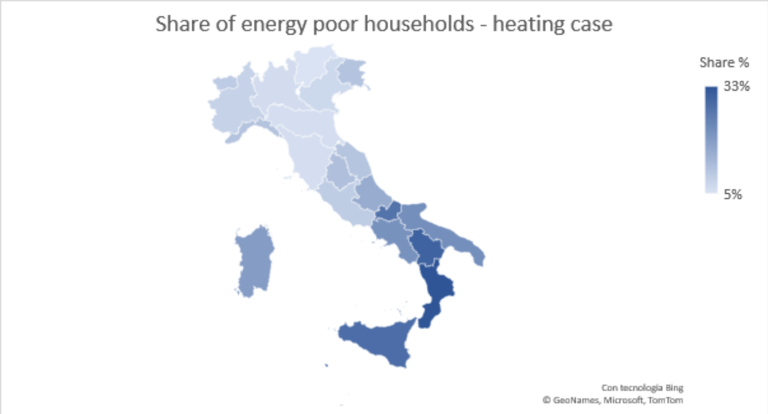

Figure 3. Distribution of energy poor households across the Italian peninsula – heating case.

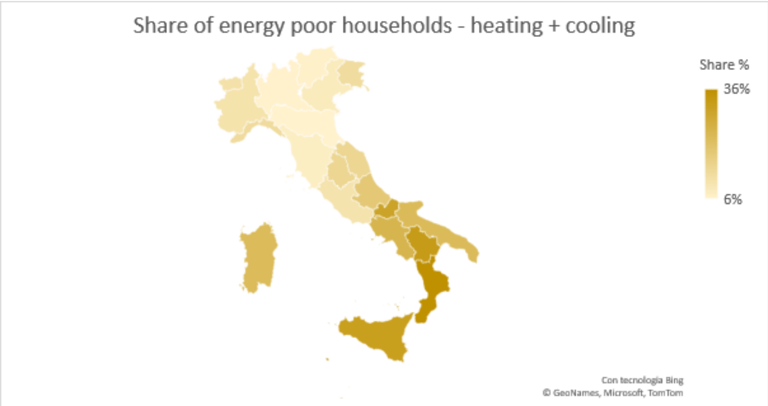

Figure 4. Distribution of energy poor households across the Italian peninsula – heating + cooling case.

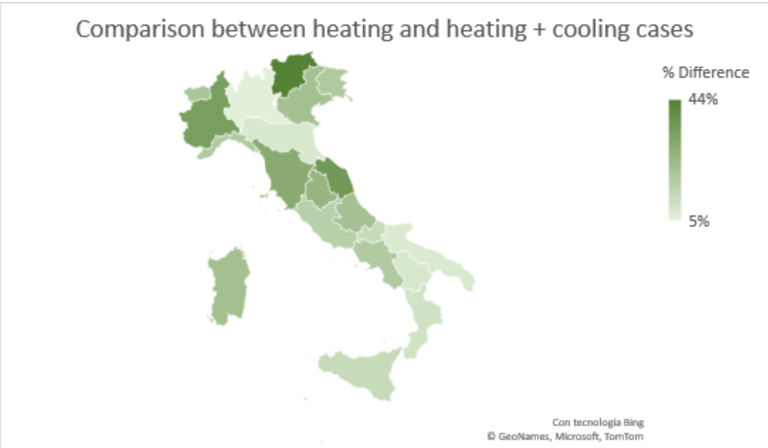

Figure 5. Comparison between heating and heating + cooling cases.

heat waves) can compromise human health, with more immediate effects than those due to cold temperatures.

Thus, the issue of energy poverty shall be addressed considering also what might be the cost of cooling a house. As shown in the previous paragraphs, a good methodology would be the one that assesses a minimum heating and cooling need, based on the features of a building, and then associates it with energy costs. Such "minimum need" energy costs can be used to calculate objective EP indicators such as the most-widely used, LIHC, and its derived ones (such as the indicator used in this work). Moreover, this allows to neutralize the subjective heating and cooling preferences. This might be a constraint and a limitation, so the choice of minimum heating and cooling temperatures shall be reasonable and accurately supported by regulations and/or scientific references.

The application of such methodology to the Italian case has shown that cooling itself is not such a burden on the overall family expenditure. The most impacting costs are those related to the purchase, installation and maintenance of a cooling system: in fact, 64 % (16.4 million) of Italian families still don't have.

The increase in number of energy poor people, considering different parameters such as the building age, the urban context, the ownership of the house, etc. is not significantly different in their subcategories. However, there is a wide difference when analysing the geographical spread: the coldest regions in Northern Italy and a couple of regions in Central Italy are the most impacted, in terms of number of extra-energy poor, while in the Southern part of the country the impact is much lower. This might seem strange but, due to the construction features of the buildings and the lack of cooling systems in colder areas, it appears in line with some conclusions drawn at European level, where Finnish people were found to be vulnerable to "summer energy poverty" (Thomson et al., 2019).

Overall, for the Italian case study, the impact on energy poverty of purchasing, installing, operating and maintaining a cooling system is an increase of more than 500,000 additional units (+2 %) in the number of energy poor families, corresponding to 982,000 consumers. Considering the incremental cooling needs due to climate change, this number can only increase in the future.

Policy makers should take these observations into account when designing subsidy regulations dedicated to tackling energy poverty: considering the Italian case, for example, the current subsidies foresee a support in the payment of energy bills (called "Social bonus") for people whose income is below a certain threshold (that increases only if the family has at least 4 under-age children) and its amount is calculated, for electricity, based on the household composition, for natural gas, based on the climatic zone. However, this has some shortcomings:

- first, the type of building, its age and the urban context aren't taken into account, even if these parameters have a strong effect on the energy consumption, both for heating and cooling: it is difficult to implement, but a subsidy proportional to standardized energy needs would be a greater support;
- second, in the case of cooling, the climatic zones should be defined in a different way than for heating, since the distribution of CDD is not the same as that of HDD, and electricity subsidy should be proportional to CDD;
- third, a subsidy in the payment of energy is useful but it is a "short term" solution, that doesn't solve the issue at its roots; moreover, it doesn't initiate a behavioural change that could lead family towards saving energy; it could also be detrimental, instilling "laziness", because someone else is paying (part of) the energy bills;
- moreover, it is not applicable for buildings not connected to the national network, such as those in isolated areas (for electricity) or those in some rural areas and in Sardinia (for natural gas), that however have to generate or buy energy from other sources (e.g. by installing PV panels and accumulators for electricity or by using propane tanks connected to the building gas boiler for heating);
- finally, a strong set of subsidies is needed in order to support vulnerable people in renovating their houses or "force" landlords to improve energy efficiency.

About the last point, at the moment in Italy there is the Ecobonus, that gives the chance to improve buildings energy efficiency and get a tax refund, proportional to the amount spent (there is however a maximum threshold) and to the type of project: for example, the tax refund can go from 50 % for the replacement of doors and windows in single-family buildings to 85 % for a massive renovation of condominiums. For 2020, 2021 and 2022 a further step has been added and it is possible, for some energy efficiency intervention, to get a tax refund up to 110 % of the expenditures (Superbonus). However, these policies show some shortcomings as well:

- the Ecobonus doesn't cover the whole amount of the energy efficiency project, so some funds still need to be available to the household; moreover, it is possible to give the tax refund to banks and financial institutions as a partial coverage for a mortgage but, for poor people, a mortgage might still not be available and affordable;
- the Superbonus gives a chance, also to poor people, to get all the money they need to perform the renovation of the building, but it covers only energy-efficiency related parts of the renovation (e.g. the insulation of the roof is covered, but not the roof renovation itself, that might be very expensive); moreover, the maximum allowed expenditures for each type of intervention don't always reflect the market situation; finally, this policy is supported with the funds related to COVID-19 recovery, and it is only valid until 2022;
- both policies are focused on renewable energy and/or heating needs, but they cover the cost of heat pumps only if it is also used for heating and don't include the installation of a cooling system.

Moreover, all these measures are, in theory, accessible for people living in "free use", with the agreement of the landlord, but not for tenants (that is the condition of 38 % of energy poor) and, however, there is the question whether a temporary tenant should spend a high amount of money to perform structural works. On the other hand, landlords have no direct interest in improving energy efficiency of the rented buildings, because they don't have the direct advantage (savings on energy bills) and there are no energy efficiency constraints on the rental market. To overcome this issue, a policy that sets a minimum energy efficiency standard to put a house for rental can be what might force landlords to act. All these proposals require, however, a high financial commitment by the government and other public administrations, both at national and local levels.

To consider all the topics mentioned above, the next steps of this work are:

- the estimate of energy poverty evolution to 2050 and, if possible, 2100, using climate change forecast data for different scenarios;
- a deeper evaluation of policy implications, including what is proposed in the EU Green Deal and what it might do to tackle energy poverty at its roots;
- the evaluation of health impacts of energy poverty, to assess whether the costs of increasing energy efficiency in buildings are comparable to the costs undergone by the national health system to take care of the poor health of vulnerable consumers;

- complementing this study, that is purely a modelling engineering and statistical work, with social studies that allow to fully characterize the energy vulnerable households and plan long-term actions to support them.

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