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Modeling building energy demand profiles and district heating networks for low carbon urban areas

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Abstract

Urban energy consumptions growth has become an urgent topic that requires solutions for significantly reduce carbon emission in the next decades. This paper aims in exploring the integration of building performance improvement and low carbon district heat technological choices by considering the upgrade of conversion technologies, efficiency and the exploitation of local resources.

The paper is based on a GIS-based model that spatially characterize the space heating demand of urban buildings. Starting from clustering buildings with similar thermo-physical characteristics, the total energy use of buildings can be depicted and compared with the energy balance data of the city in order to scale the bottom-up results for matching the total load. Reasonable energy efficiency measures are further proposed by considering three different scenarios up to 2050. Long-term building scenarios are applied to a district heating simulation model for investigating how the reduction of building heat demand will impact the district heating production and operations. In particular, the combination of the building model and the district heating model aims at exploring the effects of district network expansion or new low carbon investments from an economic and environmental perspective. The model has been successfully applied to the city of Turin, Italy and the city of Stockholm, Sweden. The flexibility of the approach may allow it to be easily adjusted to different urban areas for providing indications on cost-effective strategies for efficient, low-carbon heat solutions in integrated energy systems. Results highlight that finding synergies between the demand and supply sector will lead to environmental and economic benefits, in particular for district-heated cities.

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Keywords: urban planning; heat strategies; buildings; district heating network; scenarios analysis

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1. Introduction

Urban areas require two-thirds of primary energy demand and are responsible for 70% of total carbon emissions [1]. The European Union set up specific goals in order to cut carbon emissions with respect to 1990 levels of 40% by 2030 and of 80% by 2050 [2]. Cities offer many opportunities toward the required energy transition to which all sectors may significantly contribute. Urban buildings are responsible for the more than 60% of building final energy consumption [1] and in Europe, about 90% of emissions reduction to 2050 is required by this sector [2]. The building sector may cut carbon emissions through energy conservation measures, energy efficiency measures in the supply and new energy supply options. The European Energy Performance of Building Directive 2002/91/EC - EPBD regulation and its recast [3] set out new energy performance of buildings, in particular, all new buildings should be nearly Zero Energy Buildings (nZEBs) by the end of 2020. Despite energy savings related to new buildings, a high energy savings potential is available from the renovation of existing buildings. Many urban areas may be targeted to improve the quality of the existing building stock. Anyway, for cities that are district heated, the improvement of building energy efficiency and the consequent change in thermal demand may affect the operation of heat supply plants and heating distribution network, in particular if the district heating is CHP based.

Some previous studies addressed the relation between energy change in demand due to building renovation and the impact on district heating. Specifically, Difs et al. [4] studied the impact of three different energy conservation measures on the district heating system in Linköping, Sweden. They highlighted that electricity savings have a critical role in the identification of the energy planning strategy and that some measures may have negative impacts on the energy systems. Lidberg et al. [5] proposed to apply four renovation measures to a case study building in Borlänge, Sweden and evaluated their impact on the district-heating network. They showed that with all the retrofit measures the environmental impact is positive. Anyway, they stressed that the conclusion strongly depends on the local generation mix. Similar studies have been performed by [6] in Växjö, Sweden concluding that is fundamental to consider the interaction between end-use savings and supply systems.

In this research, the economic and environmental impact of different long-term building renovation measures on district heating operation and investment strategies to 2050 is analyzed by coupling building simulation and scenarios analyses to a district heating simulation model. The procedure is applied to two very different realities - Torino, Italy and Stockholm, Sweden - in order to demonstrate the validity of the approach and to provide key consideration about urban heat strategies in district-heated areas. Section 2 describes the analytical framework of the study, Section 3 presents the case studies and Section 4 provides main conclusions and insights of the work.

Nomenclature

AB	apartment blocks
MF	multi-family
DH	district heating
ECM	energy conservation measures
GIS	geographic information system
HDD	heating degree-days
TH	terraced-house
SF	single-family
SH	space heating
S/V	shape factor, surface to volume ratio
TLCC	total discounted life cycle cost

2. Methodology

The proposed methodology aims at supporting the understanding of the relationship between building energy renovation investments and district heating supply choices from an economic and environmental perspective. In fact, when the heat demand changes due to building renovation, a smaller/larger amount of DH is produced, impacting the fuel used by the heat plants, the operation conditions of the network but also the new investment plans and business model.

The methodology is divided into two main steps related to the buildings stock and the district heating network that will be described respectively in Section 2.1. and 2.2 Two simulation models are coupled together in order to evaluate the total life cycle cost and the emission savings under different scenarios assumptions (Section 2.3). Changes in energy performances and the relative costs due to envelope retrofit of residential buildings are the input of a district heating simulation model. The schematic of the methodology is summarized in Fig.1.

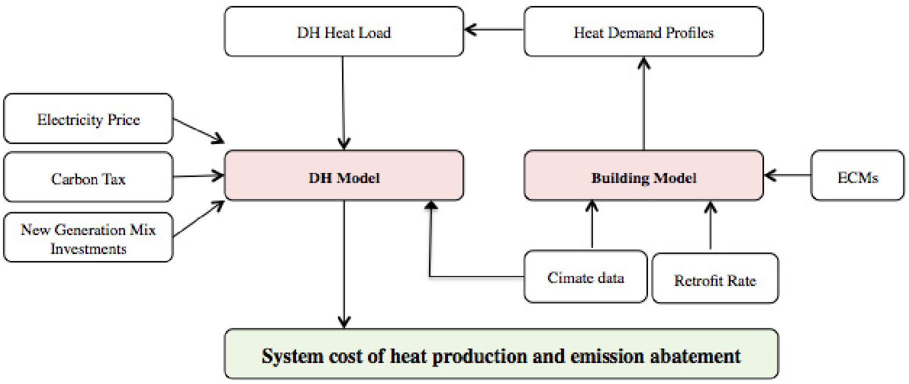

Fig. 1. Schematic of the methodology.

2.1. The building stock model

The proposed model allows performing long-term scenario analyses related to urban building stocks energy evolution. A complete description of the model is provided in the Annex of Chapter 4 of [1]. The base of the model consists in the identification of the main building urban archetypes: urban buildings are clustered according to their compactness (S/V) and their construction period [7, 8, 9]. This step can be performed in many ways (e.g. calculation of building geometries with GIS tools and census data for Torino, statistical data for Stockholm) and leads to a full description of the urban residential environment in terms of heated volumes and thermos-physical characteristics (dependent on the construction period) of buildings. The GIS is very helpful for supporting territorial analysis since it allows to geo-refer each urban building and to estimate main geometries (base surfaces, volumes, number of floors etc.) of each item. To the identified archetypes, specific energy intensities for space heating are assigned through monitoring campaign and energy audit. In case real consumption data are not available, building simulation software may support the preliminary estimations of building energy performances. The bottom-up model results should be calibrated for matching the energy balance load (top-down data) of the city. At that point, different renovation packages of measures can be simulated for each archetype. The penetration of building renovation measures may follow different paths of renovation rates and, consider market constraints, it is supposed to start from 2020 (Eq.1).

$$V_{ren,TOT} = \sum_j \sum_i \left[V_{ex,TOT} * n_i * r_{i,j}\right] \quad (1)$$

where:

$V_{ren,TOT}$ = total volume retrofitted up to 2050 (m^3);

j= building archetype;
i= step of time period (5 time periods);
$r_{i,j}$= renovation rate of building type j in the time step ni ;
$V_{ex,TOT}$ = existing volume at the time t;
n_i = numbers of years with retrofit rate r_i .

The energy intensities variate accordingly to the volumes evolution and the chosen measures' energy intensities. The selection of the retrofit measures depends on the scenarios to be examined; details for these specific case studies are provided in Section 3.

The global discounted cost of the building ECMs over the time horizon (2050) is calculated as Eq.2. The cost evaluation includes operation and maintenance costs, fuel costs and new investments.

$$C_{G,b} = \sum_j \sum_{i=1}^{n} \left[C_{INV,i,j} + (O\&M_{a,j,r} + O\&M_{a,j,e} + C_{e,d,j}) * t_j - RV_{i,j} \right] * d_i \quad (2)$$

where:

$C_{G,b}$= total cost of buildings (2050) discounted to 2010 level ;
j= building archetype;
i= step of the time periods;
n= total number of time periods (equal to 5);
$C_{INV,i,j}$ = investment cost occurred in the time period i for the building type j;
$O\&M_{a,r,j}$ = yearly O&M cost for the retrofitted archetype j in the time step i;
$O\&M_{a,e,j}$ = yearly O&M cost for the not retrofitted archetype j in the time step i;
$C_{e,d,j}$ = energy cost occurred in the time period i for the building archetype j not connected to the DH network;
t_i = number of years of the time step i (equal to 5);
$RV_{i,j}$ = residual value of the investment occurred in the time period i for the building type j;
d_i = present value factor for the mid-year of each time period (2.5, 10, 20, 30, 35) and discount rate of the time step i (3.5% above the inflation).

The yearly space heating energy cost for the buildings that are connected to the district heating network has not be considered in this application since it is already included in the DH model.

2.2. The DH Model

A DH simulation model has been developed to evaluate the effects of energy demand variations and new investments in heat production technologies on the global life cycle cost of the energy system. The model uses two existing yearly hourly load curves from the existing network (of a warm and cold year). The thermal load is divided into residential and services heat demand; the residential heat demand is divided into space heating and domestic hot water demand by assuming that the minimum load during summer is to supply the residential hot water demand.

For each simulation period (decades) new buildings energy requirements, as well as the energy savings derived from the renovation of the existing stock, may be inserted in the model. Moreover, investments in new capacity or network expansion may be simulated; the variable and fix O&M costs are calculated by the model for both new investments and the existing plants. Dynamic changes in distribution losses as function of line density are included in the evaluations. A price for electric generation from CHP is considered (value of coproduced electricity is assumed to be equivalent to the one of electric power plants) as well as a carbon tax equal to the one of IEA 2DS scenario [1]. The electricity price is fixed to 25 €/MWh in Sweden and 76 €/MWh in Italy. The details of the model and cost analysis data related to new investments and network expansion can be found in the Annex of Chapter 4 of [1].

The installed capacity is arranged by the model in merit order according to the hourly heat production costs and the demand to be supplied. The corresponding heat production cost is calculated for each hour considering the two load curves (cold and warm year). The yearly levelized cost of heat is consequently derived (Eq. 3).

$$LCOH = \sum_{i=1}^{n=5} \frac{Ecost_i * d_i}{Edhtot_i} \tag{3}$$

where:

LCOH = discounted levelized cost of heat up until the mid-year of the calculation period;
$E_{cost,i}$ = fuel cost, running and fix O&M for the plants, O&M for the distribution network, connection costs;
d_i = present value factor for the mid-year of each decade (calculated with discount rate of 3.5 % above the inflation, PV = 1/(1+r)^n, r = 0-3.5 % and n is 2.5, 10, 20, 30, 35 years);
EDH_{tot} = delivered heat from DH during each period.

The global cost of operating the network and supplying heat to the users is therefore calculated following Eq.4.

$$C_{G,dh} = \sum_{i=1}^{n=5} (LCOH_i * Edhb_i + C_{INV,dh,i} * d_i) \tag{4}$$

where:

$C_{G,dh}$= total discounted life cycle cost considering the energy cost, investments in new district heating capacity and network expansion;
LCOH = discounted levelized cost of heat up to the mid-year of each decade i;
$E_{dh,b,i}$ = delivered district heat to the buildings during the decade i;
$C_{INV,dh,i}$ = investment costs in new DH capacity during the decade i;
d_i = present value factor for the mid-year of each decade (calculated with discount rate of 3.5 % above the inflation, PV = 1/(1+r)^n, r = 0-3.5 % and n is 2.5, 10, 20, 30, 35 years).

CO_2 emission to 2050 due to the operation of the DH network are consequently evaluated as in Eq. 5. The estimation of emissions considers the heat generation mix of the district heating system and the efficiency of the plants stock. The CO_2 equivalent emission factor of methane (CH_4) and nitrous oxides (N_2O) are included and are respectively equal to 23 kg_{CO2}/kg_{CH4} and 296 $kg_{CO2}/kg_{N2O;}$

$$CO_{2,dh,tot} = \sum_{j=1}^{n=5} (\sum_{i=1}^{n=8760} ((CO2eh_{xi} * Eplant_{xi})/Edhtot_i)_j * Edhb_j \tag{5}$$

where:

$CO_{2,dh,tot}$ = total CO_2 emissions to 2050;
n= total number of time periods (equal to 5);
$E_{dh,b,i}$ = the heat delivered to the urban building;
$CO_{2,eh,xi}$ = equivalent carbon emission for heat production from plant x in hour i considering the fuel type, the efficiency of the plant and the full credit for electricity production for CHP.
$E_{plant,x,i}$= heat produced from plant x in hour i considering the merit order of plants, the demand variation and the availability of the plant. No variation in the electricity to heat quota have been considered;
$E_{dh,tot,i}$ = total yearly delivered heat.

2.3. The integration

The evolution of the urban space heating requirements (generated by the building model described in Section 2.1) become one of the inputs of the DH model in terms of variation of the total thermal loads and the expansion of the network impact the share of DH connected and disconnected volume. The space heating consumption of non-residential buildings has been maintained constant in this specific application.

The evaluation of the total system cost (TLCC) to 2050 discounted at 2010 levels is expressed by Eq. 6.

$$TLCC = C_{G,dh} + C_{G,b} \quad (6)$$

where:

TLCC= total discounted life cycle cost considering the energy cost, investments new district heating capacity and investments in energy conservation measures in buildings;
$C_{G,b}$ = total cost of buildings referred to 2050 discounted at 2010 level. Eq. 2;
$C_{G,dh}$ = total cost of the DH network 2050 discounted at 2010 level. Eq. 4;

Carbon emissions to 2050 are the evaluated as the sum of DH network related emissions and buildings not connected to the DH system related emissions (Eq. 7).

$$CO_{2,tot} = CO_{2,dh,tot} + C_{2,b,tot} \quad (7)$$

where:

$CO_{2,dh,tot}$ = total CO_2 emissions to 2050 related to the DH network;
$CO_{2,b,tot}$ = total CO_2 emissions to 2050 related to buildings that are not connected to the DH network (considering the city generation mix and efficiency of technologies);

3. The case studies

The methodology has been applied to the cities of Torino, Italy and Stockholm, Sweden. In order to test the methodology, these areas have been chosen due to their consistent differences in terms of both building stock and DH network characteristics, aside from climatic conditions.

The municipality of Torino is sited in the North of Italy (2617 HDD at 20°C), has about 900,000 inhabitants and the 35% of the urban volume is supplied by a recent 100% natural gas based district heating network owned by one single company. The DH heat generation mix is composed by 740 MW of natural gas CHP, 1000 MW of gas auxiliary boilers, 12,500 Mm^3 of daily storage; the yearly average delivered DH energy is about 2000 GWh_{th} (~ 90% from CHP and 10% by gas boilers) and 950 GWh_{el}. Only the 7% of district heat supplies non-residential buildings while all the remaining heat is used for supplying heat to residential buildings connected to the network. The network has the possibility to expand at relatively low costs.

The building stock is characterized by about 36,000 residential buildings occupying a volume of 177 Mm^3 of which 139 Mm^3 is heated; non-residential buildings occupy a volume of 36.23 Mm^3 (68.1% industrial activities, 16.4% educational activities, 11.8% office buildings, 1.7% sport activities, 1.4% churches and 0.6% little commercial activities). Residential buildings are mostly compact (AB) and have been built before the ‘80s (Fig. 2a). The average space heating consumption of the residential stock is about 48 kWh/m^3 while one of DH connected buildings is lower (higher compactness) and equal to 31 kWh/m^3 [10] (Fig. 2b). According to [7], 36 residential building archetypes have been identified combining four classes of compactness and nine classes of construction periods (indicated as E1, E2 …E9). For Torino, the volume of each class has been identified through a geometrical characterization by using GIS tools [10, 11] and statistical data [12]. Energy performances of the stock have been assessed by using real data and are referred to the works of [10,11]. Low insulation levels of the built environment have been identified as responsible for the low building performances [11].

The city of Stockholm, Sweden (4210 HDD at 18°C) has about 900,000 inhabitants and approximately the 80% of the urban buildings (85% of residential building volume) are supplied by the old local DH network, managed by six different companies. The existing buildings that are not connected to the DH system are mostly characterized by high connection costs and the economic benefits to expand the network to these areas are limited. The district heat generation mix accounts of 3340 MW of which 15% fossil fuel based, 60% biomass-based, 20% waste heat and 25% heat pumps. The building stock is characterized by 120 Mm^3 of residential buildings and 78 Mm^3 of non-residential buildings (51% offices, 15% commercial) [13]. Residential buildings have been clustered according to 18 building archetypes (Fig.3). The average residential building space heating consumption is 55 kWh/m^3 while the average of connected buildings is 42 kWh/m^3 (Fig. 3). Acting on regulation and control systems has been identified as a key strategy for improving the thermal performances of buildings.

a b

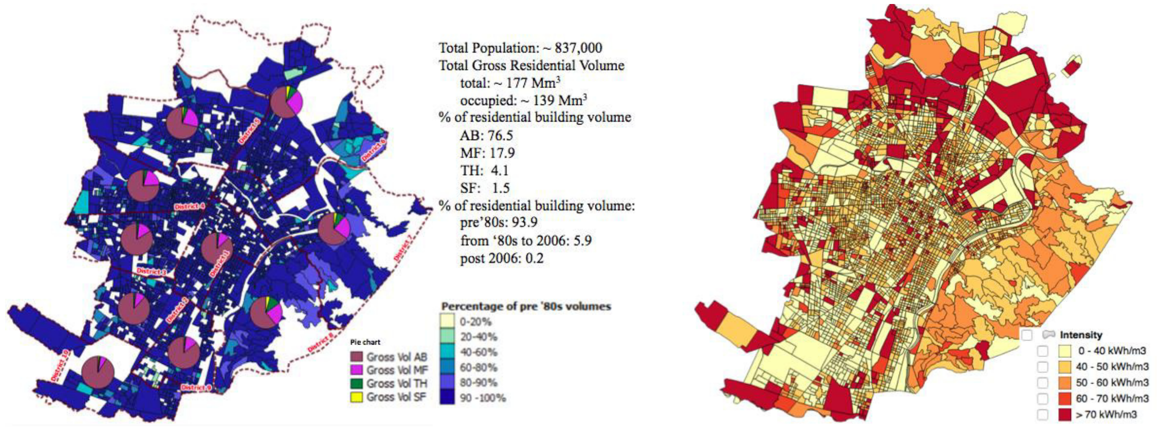

Fig. 2. (a) distribution of residential volumes in Turin; (b) distribution of SH energy intensities.

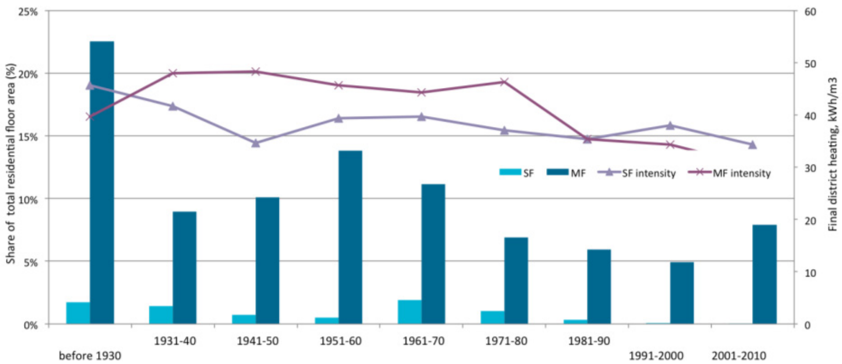

Fig. 3. Residential volumes and SH intensities in Stockholm.

Three energy and carbon emissions scenarios are proposed considering the baseline scenarios plus two different energy conservation measures in buildings combined with new investments in DH (Tab.1).

Table 1. Proposed Scenarios.

Scenario name	Building measure	DH measures	
		Torino	Stockholm
Baseline - B	1% penetration rate with measures allowing 10% energy savings (e.g. window substitution)	Regular O&M + 11Mm^3 of network expansion	Regular O&M
Medium – M	2% penetration rate with measures allowing 30% energy savings (e.g. new insulation)	1unit of 106 MW CHP fueled by refused derived fuel (2020) + 250 MW of heat pumps (2025)+ 11 MW of solar thermal heat plant fields with multiple borehole seasonal storage and heat pump (2030) + decommissioning of 260 MW of existing capacity (2025) *scenarios ME and AE considers an expansion of 43 Mm^3 of the DH network	2 unit of 150 MW CHP fueled by refused derived fuel (2020) + 150 MW of solar thermal heat plant fields with multiple borehole seasonal storage and heat pump (2040) + decommissioning of 240 + 80 MW of existing capacity (2020 and 2040)
Aggressive - A	3% penetration rate with measures allowing 50% energy savings (e.g. coat, mechanical ventilation)		

Building measures have been proposed considering previous EU projects [7] and adapted to the conditions of the two cities [1] (Fig. 4 and Fig. 6). Costs of the renovation measures have been estimated by reflecting the GIS geometries and the Italian reference costs of materials [14, 15] for Torino while in Stockholm the measures and cost data are taken from a national strategy for energy renovations [16]. Some of the cost data are also taken from a dataset collecting the results of 44 renovations projects [17] . The considered volume is equal to 100 Mm^3 in Torino – 57 Mm^3 connected to the network and 43 Mm^3 of maximum expansion possibilities (Fig.5a and Fig. 5b) - (not connected buildings are supposed to be heated by traditional gas boilers with efficiency equal to 0.8). 150 Mm^3 has been considered as boundary conditions in Stockholm (all connected to the DH network).

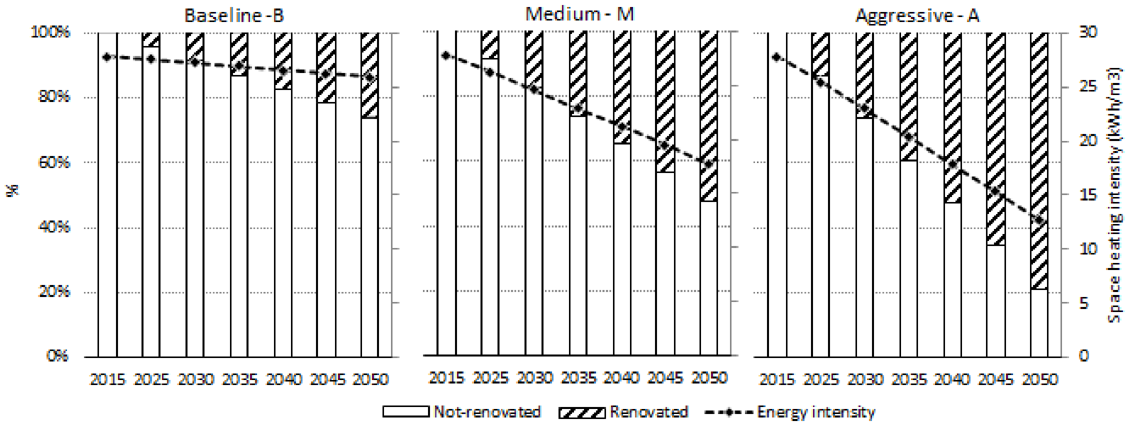

Fig. 4. Percentage of renovated volume and SH energy intensities values under different scenarios in Torino

a b

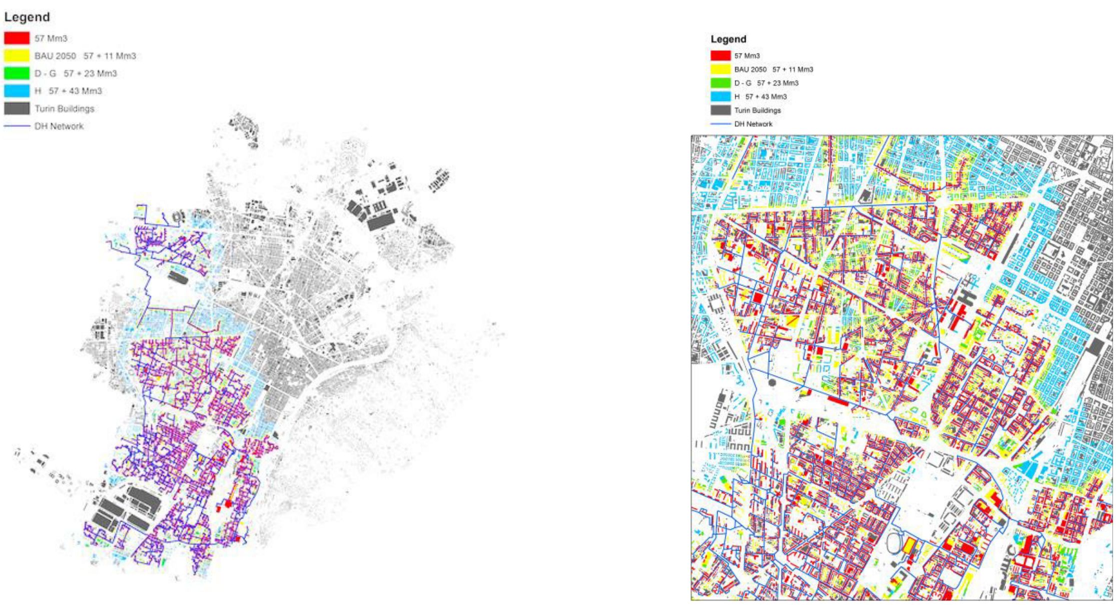

Fig. 5. (a) map of DH connected volumes (57 Mm^3) and potential expansion (43 Mm^3) in Torino; (b) detailed view of the central area.

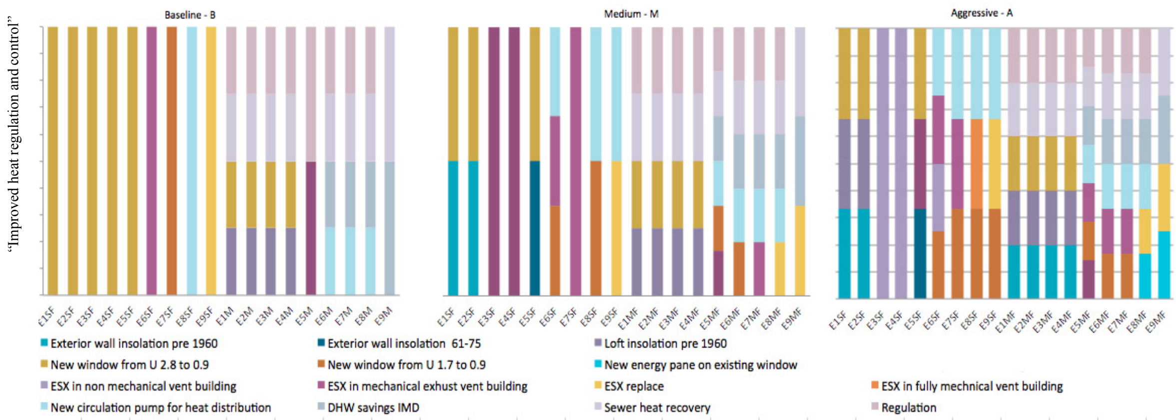

Fig. 6. Measured applied to the different archetypes under several scenarios in Stockholm

4. Results

The results are presented in terms of total discounted life cycle cost and emissions savings for the different scenarios. Scenarios M and A are compared to the baseline B by looking at total discounted life cycle cost - broken down as operational cost (fuel cost plus operation and maintenance), new investments in buildings and district heating – and total CO_2 savings.

In Torino (Fig. 7), baseline conditions represent the situation in which energy saving measures in buildings are not coordinated with any interventions in the district heat network. Operational costs are the main cost voice and both global costs and emissions are higher with respect to the other scenarios.

Investments in low carbon district heating (scenario M) allow reducing of about 20% the carbon emissions with respect to the baseline. Under this scenario, the savings in fuel cost due to demand reduction and fuel switching are higher than the sustained investments in buildings. A further expansion of the network is beneficial in terms of emissions (scenario ME) allowing to disconnect individual existing boilers and to save around 28% of emissions. For the same reason, benefits can be also seen in terms of fuel costs. Obviously, emissions savings are greater (33%) with stronger measures in buildings (scenario AE).

In terms of global system costs, the medium and aggressive scenarios permit to reduce or maintain the same level of TLCC cost with respect to the baseline. Main reasons are the reduction of fuel combustion related to the decrease of the thermal demand and the consequent possibility of reducing the heat production from low merit order power plants (scenario M). Coupling the expansion of the network (scenarios ME and AE) to the reduction of thermal demand is beneficial since it allows maintaining the heat production at levels closer to heat output capacity, avoiding a lower use of CHP plants. Without network expansions, the global cost of the scenario AE would have been higher compared to baseline. This also means that, at a certain point, the benefits related to energy conservation measures in DH connected buildings start to diminish and going further, even if technically feasible, will comport investments that are not offset by economic savings.

Similarly to Torino, in Stockholm (Fig. 8), scenario B does not take into account any synergies between building investments in energy renovation and new supply choices in DH. The cost and emissions of this scenario are higher or equal to all the other scenarios, showing that catching the interrelationship between the two sectors can be crucial to achieving environmental and economic benefits. Results indicate that investments in low-carbon technologies for the heat generation mix are able to significantly cut the emissions (roughly 45% in the M scenario). In scenario A, fuel savings are offset by new investments: the global cost does not increase with respect to baseline, but considering the larger necessary investments, emissions savings increases of just 5%-units compared to scenario M. Considering that the network could not expand significantly, aggressive measures in buildings should be carefully planned in order to fully utilize the investments in new capacity. Scenario A indicates the limit over which is not proficient performing deeper building energy renovation. More evidently than for Turin, high heat demand savings cannot be met by network expansion. Consequently, building measures should necessary been thought in order to reduce the peaks of the thermal demand, but not to strongly decrease the operation hours of the base load plants. In such way, base load heat plants may work longer and the new investments in peak plants can be reduced. An alteration of the annual heat profile will also change the size of new investments in baseload plants. Results are valid for this specific generation mix and DH structure, but can provide an indication to other similar Nordic realities with comparable networks.

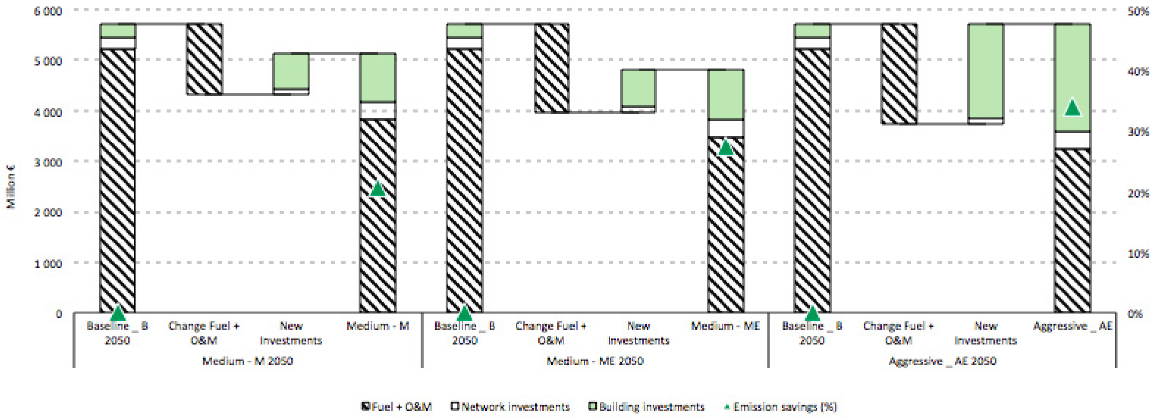

Fig. 7. Results in terms of global life cycle cost discounted at 2010 levels and emission savings for Torino.

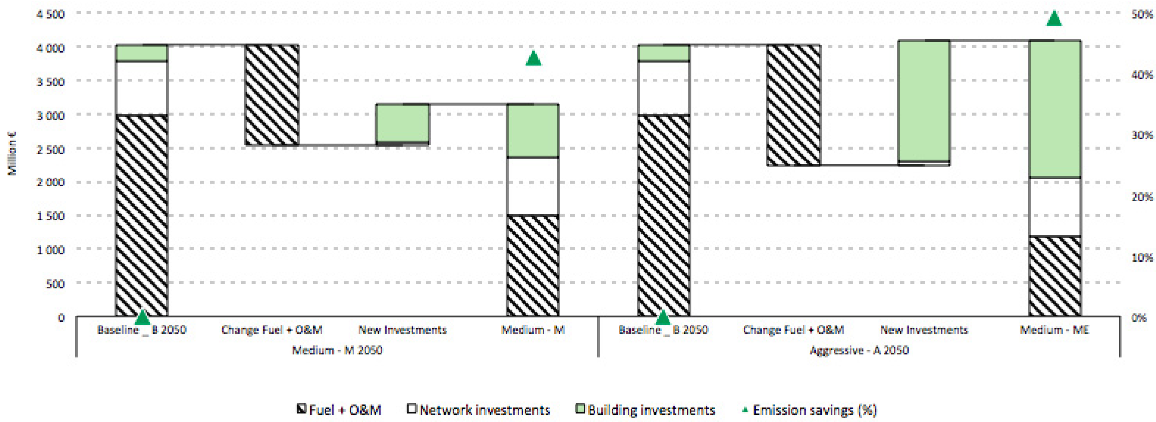

Fig. 8. Results in terms of global life cycle cost discounted at 2010 levels and emission savings for Stockholm.

From both case studies it is possible to learn that renovation measures in buildings should be chosen in order to be cost-effective and, in the particular case of district heated areas, it is necessary to find synergies between the installation of new DH capacity and the choice of building investments. A correct and integrated coordination between the two sectors may be beneficial both for reducing the total life cycle cost and for cutting carbon emissions. By shifting from single building perspective to a system perspective it is possible to catch interrelationship traditionally neglected such as the increase of distribution losses with the decrease of the heat density or the indirect impact on CHP performances. Moreover, setting the DH business strategy in new capacity considering the evolution of the thermal demand may avoid unnecessary investments on the DH side. Building measures allowing peaks' reduction are always beneficial since reducing the production of low merit order plants (with marginal production cost can be as much as 10 times higher), but at the same time maintaining a high utilization of base load capacity is fundamental for the proficiency of the DH companies. The selection of the right building measures should, therefore, be carefully defined.

5. Conclusions

European buildings are large energy consumers with high energy savings potential. A great priority is reserved to improve the energy performances of existing buildings. In district heated cities, a variation of the thermal loads may impact the operation conditions of the DH network as well as modifying the future investment strategies.

This paper proposes a scenario analysis that integrates investments in both buildings renovation and new heat generation capacity for district heated urban areas. The developed methodology allows understanding how district heating heat loads variate when specific energy conservation measures in buildings are planned and explore the impact of different investments strategies on the total discounted life cycle costs and on CO_2 emissions.

The method is applied to two case study cities, Torino in Italy and Stockholm in Sweden. They are characterized by differences in terms of climate, fuel generation mix, building typologies and district heating network characteristics. Results strongly depend on the specific local conditions, but the case studies may represent valuable examples of chances that DH utility companies could face with the variation of space heating loads.

Main results highlight that energy savings measures in buildings should be carefully planned, in particular in areas where DH is highly diffused. After certain levels of load reduction, benefits from energy conservation start to decrease and when the network cannot expand, it may even become not proficient. Besides areas like Stockholm where the saturation of connections, particularly in Europe, limited expansion possibilities may be frequent for the specific urban environmental (e.g. rivers) or heritage (e.g. historical centers) features and barriers. Measures reducing peak loads allows reducing the operation of low merit order plants and are always positive, but sufficient utilization factors of base loads plants should be guaranteed, in particular if CHP. In terms of investment plans, the reduction of peaks may avoid unnecessary investments on DH side.

Preliminary considerations on the benefits, in terms of both total life cycle cost and emissions reduction potential, of an integrated approach with respect to the traditional sectoral approach, is highlighted in the research. Integrated analysis can, in fact, provide opportunities for planning the future energy system to match future building needs (e.g. low temperature networks etc.). The proposed methodology can support the design of urban energy policies for incentivizing both ECM in buildings and new investments in DH taking into account the synergies between the two sectors. Additionally, due to its flexibility, it can be applied to other urban areas. Further works will imply sensitivity analyses on energy prices as well as the completion between other, both individual or district heating, low carbon technologies. Specifically, further works will involve the use of the TIMES model, based on linear programming optimization, at the urban scale.

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References

[1] International Energy Agency, Energy Technology Perspectives 2016, OECD/IEA, Paris, 2016.
[2] European Council, "A Roadmap for moving to a competitive low-carbon economy in 2050", Brussels, 2011.
[3] European Parliament (2010). Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the Energy Performance of Buildings (Recast); Official Journal of the European Union: Brussels, Belgium.
[4] K. Difs, M. Bennstam, L. Trygg, L. Nordenstam, Energy conservation measures in buildings heated by district heating e a local energy system perspective. Energy 35 (2010) 3194-3203.
[5] T. Lidberg, T. Olofsson, L. Trygg, System impact of energy efficient building refurbishment within a district heated region, Energy 106 (2016) 45 – 53.
[6] N. Le Truong, A. Dodoo, L. Gustavsson, Effects of heat and electricity saving measures in district-heated multistory residential buildings, Applied Energy 118 (2014) 57–67.

[7] TABULA (Typology Approach for Building Stock Energy Assessment), TABULA Project (2009-2012), http://episcope.eu/iee-project/tabula/, last access: July 2015.
[8] S. Torabi Moghadam, G. Mutani, P. Lombardi, GIS-Based Energy Consumption Model at the Urban Scale for the Building Stock, 9th International Conference, Improving Energy Efficiency in Commercial Buildings & Smart Communities Conference (IEECB & SC'16), Frankfurt 16-18 March2016 (in press)
[9] S. Torabi Moghadam, P. Lombardi, G. Mutani, A. Osello, F.M. Ugliotti, BIM-GIS modelling for sustainable urban development, Towards Post-Carbon Cities, SBE16 Turin, Italy, 18-19 February 2016, (in press).
[10] G. Mutani, C. Delmastro, M. Gargiulo, S.P. Corgnati, Characterization of building thermal energy consumption at the urban scale, Energy Procedia, 71st Conference of the Italian Thermal Machines Engineering Association, ATI2016, 14-16 September 2016, Turin, Italy, (in press).
[11] G. Mutani, G. Vicentini, Buildings' Energy Consumption, Energy Savings Potential and the Availability of Renewable Energy Sources in Urban Spaces, Journal of civil engineering and architecture research 2(2015), 1102-1115.
[12] ISTAT. (2015). ISTAT website homepage. http://www.istat.it, Accessed: July 2016
[13] SEA (2013), Energistatistik för småhus 2012, Swedish Energy Agency, Eskilstuna.
[14] Prezziario Regionale, Regione Piemonte, http://www.regione.piemonte.it/oopp/prezzario/, last access: July 2016.
[15] C. Becchio, D.G. Ferrando, E. Fregonara, N. Milani, C. Quercia, V. Serra, The cost-optimal methodology for the energy retrofit of an ex-industrial building located in Northern Italy, Energy and Buildings 127 (2016), 590-602.
[16] Swedish Energy Agency (SEA) and Swedish National Board of Housing, Building and Planning (SNBH) (2013)." Förslag till nationell strategi för energieffektiviserande renovering av byggnader – Gemensamt uppdrag Energimyndigheten och Boverket" ET2013:24. ISBN 978-91-7563-049-6
[17] Swedish Energy Agency (2014). Complied dataset of 44 renovation projects of multifamily dwellings from two research programs BeBo and Rekorderlig Renovering,