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Conference Paper Urban typologies and heat energy demand. A case-study in the Italian context

51st Congress of the European Regional Science Association: "New Challenges for European Regions and Urban Areas in a Globalised World", 30 August - 3 September 2011, Barcelona, Spain

Provided in Cooperation with:

European Regional Science Association (ERSA)

Suggested Citation: Troglio, Elisabetta; Haas, Tigran; Doni, Matteo (2011) : Urban typologies and heat energy demand. A case-study in the Italian context, 51st Congress of the European Regional Science Association: "New Challenges for European Regions and Urban Areas in a Globalised World", 30 August - 3 September 2011, Barcelona, Spain, European Regional Science Association (ERSA), Louvain-la-Neuve

This Version is available at: https://hdl.handle.net/10419/120235

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1. Global climate change as urban issue

Global climate change - with its social, economic, political, cultural, and ecological dimensions (and the impact on our spatial, physical, and planning patterns) - is one of the principal challenges facing humanity. The cities of today are the greatest assemblage of material resources, human capital, and goods and services the planet has ever seen, in which now more than half of the world population live, about three fourths of world resources are being consumed as we speak, and one fifth of the emission are produced (IPCC, 2007). Urbanization is the defining phenomenon and process of this century. The impact of rapid urbanization coupled with population growth will be felt most acutely in developing countries, where the built up area is expected to increase threefold while the urban population doubles by 2030. Forecasts shows that by that time cities will use 75% of the total energy produced (IEA, 2008). Since human activities are mainly located in buildings, they play a key role in energy demand, using over 40% of the global primary energy. Despite the opportunities coming from technologies and passive house solutions to reduce the energy demand at the building level, most of the potential within the building sector remains unused (IEA, 2008). From this troubling perspective, both city sustainability and the resilience of cities become the main issues at hand.

In the last century we have, as citizens as well as professionals working with urban development and planning, developed a disconnection from nature that has contributed to the greatest crisis in the history of mankind and the greatest threat to the natural eco-balance of our planet and our built environment – to our cities. There is no doubt in the mind of any urbanist that, to avoid the looming environmental disaster, one of the greatest cultural and technological transformations that we (as citizens, not consumers) must undertake, pertains to the way we plan, design, build, maintain, govern, and use our cities.

2. Background of the project

"[...] planners rarely focus explicitly on energy issues, planning decisions influence energy use and production in profound, long-lasting ways" (Park et al., 2004) Starting from the necessity to control the global climate change, the Kyoto Protocol and the Bali Road Map have recognized the importance of common international actions to reduce CO_2 emissions. Nowadays, large parts of the world population (50-60%) are living in urban areas, which represent the most energy consuming systems (Buckley *et al.*, 2009). Local governments are therefore asked to take new responsibilities in terms of energy management, adopting the urban scale as level of action, developing new methods and strategies to bring energy sustainability (saving/producing) and environmental quality into the cities.

At European level, different countries and cities have started projects related with urban energy saving and energy-saving districts, but the request for a more integrated approach and further analysis of the role of morphology and land use organization is increasing. At the same time, attention to energy modeling at the urban and district scale is rising, thanks to improvements in the IT-technologies that allow complicated calculations (Rapp *et al.*, 2009). The development of a new energetic and environmental planning approach that can set energy as primary key – leading to a high level of urban efficiency and having a broad effect on other urban areas – is hence highly important.

Different studies have pointed out the fundamental energetic role of urban morphology and typology (Ratti *et al.*, 2004). The intermediate scale between city and building, and its relation with energy and sustainability has been undertaken under the point of view of modeling and projects/best practices:

- Scientific contributions on the relationship between urban morphology, energy, and environment.

Tools for environmental prediction based on urban texture has been first implemented at the University of Cambridge in the 90s by Nick Baker, Carlo Ratti, Paul Richens, and Koen Steemers, and further developed at the Senseable City Laboratory (Massachusetts Institute of Technology, Boston). The approach is based on a novel technique of image processing of simple raster images (DEMs, Digital Elevation Models) that represent the urban form. Using this technique, it is possible to map and analyze environmental and energy performance of urban textures, focusing on several indicators (Carneiro *et al.*, 2008; Ratti *et al.*, 2007; Morello *et al.*, 2009).

Besides the DEM approach, different models have been developed with the aim to evaluate the energetic role at urban scale. These models can be classified into two main groups, related with the data-source used: statistic surveys or detailed analyses of the built stock. To the first group belongs, among others, BREHOMES – Building Research Establishment Housing Model for Energy Studies (Dickson *et al.*, 1996). The second group contains models such as DECoRuM – Domestic Energy, Carbon counting and Carbon Reduction Model (Gupta, 2005), EEP – Energy Environment Prediction (Rylatt *et al.*, 2003), and SEP – Solar Energy Planning System (Rylatt *et al.*, 2001).

Although innovative in their aims, these models exhibit two major drawbacks related with the statistic-based approach, that reduces the detail achievable due to statistic aggregation of the data (first group), and the cross relation between set up of the database and model (second group), which decreases the applicability outside the country in which the model has been designed.

- Projects/best practices.

There are many examples showing that district energy efficiency can be achieved if the morphology is taken into account since the beginning of the design process, by adopting a procedure which considers local climatic conditions and energy sources. More appropriate technologies (CHP, heat pumps, district heating, PV panels, etc.) can then be integrated, achieving a more sustainable development (IEA, 2008).

Some very well known examples – like Vauban in Freiburg, BedZED and Greenwich Peninsula in London, Kronsberg in Hannover, and Hammarby Sjöstad in Stockholm have already enlighten the validity of a project that integrates physical planning, evaluation of local resources and constraints, including social and economic aspects, with a vision on future urban management and social cohesion objectives (Beatley, 2000).

Sustainable Urbanism can therefore be viewed as a new and emerging framework for interdisciplinary urban planning, design, and management of our regions, cities, towns, neighborhoods, and urban blocks. It explores sustainability and urban design in a rapidly changing and urbanizing world, by focusing on the processes that shape the form and function of the built environment in its full complexity – the infrastructures, land developments, built landscapes, and facilities that collectively make up metropolitan regions (Droege, 2006, Farr, 2007).

The synergy of multi-modal transportation, sustainable economics, ecology and natural resource management, socio-cultural aspects, and physical-urban form become crucial for creating livable cities and communities of place that, together with their hinterlands, produce sustainable metropolitan-regional cities. This can be achieved only through a new prism – that of 'sustainable (green) thinking and holistic regional design', through which comprehensive physical planning and sustainable urbanism become crucial (Haas, 2010).

The importance of sustainability and energy in the planning and housing building sector to achieve the goals set by international agreements and increasing the quality of life is widely recognized (Shackley *et al.*, 2002). The contribution coming from new technologies and modeling could generate a better understanding of the relation between urban design and consumed energy, improving planning system and development policies, while reducing general costs and environmental impacts.

3. Purpose of the project

"There are essential linkages between material and energy consumption and urban form, and particularly land use and transportation patterns" (Newman et al., 2004)

The project aims to estimate the heat energy demand of the City of Gorgonzola, part of the metropolitan area of Milan – Italy, starting from analyzing the energetic performances of the existing typologies.



Figure 1 – The City of Gorgonzola in the metropolitan area of Milan – Italy.

Although the energy used in the dwelling system for different activities (heating, cooling, lighting, etc.) vary with the climate condition, at the Italian level studies show that 70% of the total emissions are related with heating (ENEA, 2008). Consequently, identifying the most

consuming areas, which are affected both by the shape of the buildings and construction materials (and thus by building's age), is fundamental to reduce energy impacts and emissions, while improving the economic, social, and environmental sustainability.

The level of analysis concerns the link between buildings and urban structure, where morphology and land use organization are legible and evaluable (Doni *et al.*, 2010). Even though central in order to achieve better knowledge of the energetic behavior of cities, the effects of different urban form and typologies on energy demand represent a field scarcely deepened by literature, which is gaining attention in the last years (Diappi, 2000). Therefore, the broader aim of the research is to compare different *typologies* with their performances related with heat energy demand, in order to offer an overview of the whole city and identify the most energy consuming areas, linking heat energy demand to the urban form.

Purpose of the research is to develop a model that can lead to a strong integration between energy, urban design and planning system, able to help Public Administration, decision makers, planners, and housing companies to take into consideration the concepts of energy saving, efficiency, and mix, improving the coordination between different levels of energy planning and including energy as a variable into urban planning policies.

Thanks to a better understanding of the energy behavior of the city dwellings, it will be possible for the Public Administration to define design guidelines, renovation processes, and an urban management system able to take into account the distinctive geographic and urban context of the city, evaluating the fallouts of development choices. Moreover, the project can support the identification of the best technological solution for Distributed Energy Resources (DER) at urban scale, and identifying possibilities for energy reduction at building scale.

4. Methodology

"A number of tools exist for predicting the energy and environmental performances at an individual building level. However, there are few tools available to predict performances at an urban scale." (Jones et al., 2007)

The evaluation model for heat energy demand discussed in this paper, has as starting and central point of the analyses urban typologies and morphology, moving from the building to aggregations of them, from building scale to an urban/district one. The basic assumption is that, by identifying different typologies, it is possible to apply homogeneous parameters to

buildings with similar geometry, which has a direct influence on thermal gains and losses, and consequently on heat energy demand (Grosso *et al.*, 2005).

Different methods of analysis has been used in order to implement a model able to take into account the characteristics of the built environment (typologies) and the effects on heat energy demand, overcoming the problem of a statistic based model. The research plan has included literature reviews about the latest model for energy evaluation, their potentials and drawbacks, which have helped us to set up our model for heat energy demand. Moreover, analyses have been carried on related with the built stock's characteristics of Gorgonzola, in order to identify the characteristics of the materials, relate them with the corresponding U-values, and set parameters for thermal gains and losses.

At the building level have been adopted some simplifications, in particular related with the roof geometry, which in this study is not considered.

The model adopts an innovative approach which uses a dynamic and georeferenced method, allowing to estimate the energy behavior of the "real" city (Rapp *et al.*, 2009). Geographic Information System (ArcMap®) is used as analysis platform, implementing a database and providing operational tools able to support the evaluation and decision process of public administrations and technicians. Thanks to that, the limits of existing evaluation methods for heat energy demand (i.e. BREHOMES, CCP model and DREAM city) can be overcome. GIS is used in order to consider morphological aspects coming from different scales, and allowing calculation of thousands of buildings at the same time. The use of GIS is a key factor that allows keeping information updated, integrating geographic data and sharing information easily.

4.1 Analyses procedure

In order to calculate the heat energy demand based on typologies, it has been necessary to set up a database, containing information related with building geometry (i.e. square meters, envelope surface, density, etc.) and land/building attributes (building's age, typology, function, etc.). Some of the data are based on cartographic analyses, while other are performed directly with ArcMap® using the geometric information coming from the city map.

First steps of the analyses have been related with:

- *Building typology* (dwelling), identified according with the built environment characteristics of a city (i.e. traditional urban block, regular urban block, detached housing, slab housing, terraced housing, etc.).
- *Buildings' age*, fundamental parameter for associate the U-values of walls and glazing surfaces. The thresholds considered vary according with the built environment characteristics/information available.
- Building elevation, calculated as difference between ground level and eaves level.



Figure 2 – detail of buildings elevation map

After creating the database, it is possible to perform calculation for each dwelling related with the geometrical data and building form's parameters. Among them:

- Number of floors, calculated using 3 meters as average space between two floors;
- Building perimeter, footprint, and volume;
- *Ratio between footprint and perimeter*, in order to evaluate the complexity of the building form;
- *Ratio between footprint and volume*, in order to evaluate the compactness of the building form;
- Ratio between number of floors and footprint, in order to evaluate the building density;
- *Ratio between building envelope* (total surface of walls and roof) *and volume*, in order to evaluate the compactness index.

These parameters describe the building's form and its geometry, which deeply influence thermal gains and losses of a building, and thus the energetic behavior of the city built environment.

Using ArcMap® it is possible to calculate the previous geometrical aspects for each building, which are related with the built environment of the city. These values are summarized in the table below, which express the average values that are considered distinctive of the typologies identified.

Parameters	Detached houses	Terraced houses	Slab housing	Warehouse	Historical block	Traditional urban block
Main function	Residential	Residential	Residential	Industrial, offices	Mix use	Mix use
Number of floors	≤ 3	≤ 3	≥3	$\leq 5/6$	≤ 3	$\geq 1 \leq 8$
Footprint	≤ 400	≤ 900	> 40 < 1000	> 100	> 150	> 40
Footprint/perimeter	≤7,4	≤ 5,6	>1 < 6,1	> 1,9	> 2,3	> 0,6
Footprint/volume	< 0,45	< 0,43	> 0,03 < 0,15	< 0,40	< 0,23	>0,03
Building envelope/volume	> 0,41	> 0,46	$\geq 0,25$ $\leq 1,36$	Average value 0,62	Average value 0,59	≥ 0,3
Perimeter	-	-	≤ 350	> 100	> 50	-
Internal/external walls	Iw=Ew	Iw <ew< th=""><th>Iw=Ew</th><th>Iw=Ew</th><th>Iw<ew< th=""><th>Iw<ew< th=""></ew<></th></ew<></th></ew<>	Iw=Ew	Iw=Ew	Iw <ew< th=""><th>Iw<ew< th=""></ew<></th></ew<>	Iw <ew< th=""></ew<>

Table 1 - Typologies and geometric-function parameters used in the analyses.



Figure 3 – Percentage of buildings belonging to the different typologies (left) and percentage of built volume corresponding to each typology.

As figure 3 shows, the built environment is mainly characterized by detached houses (37,8%), slab housing (19,1%) and traditional urban block (20,2%).



Figure 4 – Average useable floor area (sqm) for each typology (left) and average volume

(right).



Figure 5 – Global useable floor area (sqm) for each typology (left) and total volume (right) for each typology.

4.2 Defining the age of the buildings and the thermal transmittance

The age of a building has direct influence on the energetic behavior of a construction, due to different materials and technologies used. Therefore, the age is a key parameter for associate the thermal transmittance of walls and glazing surfaces, due to different U-values.

Due to lack of data related with the age of each building belonging to the City of Gorgonzola, a detailed analyzes using the historical maps has been conducted.



Moving away from the national characteristics of the built environment, the majority of the dwelling in Lombardy has been built after the Second World War (1951-1961), while the last decade has been characterized by a renovation process (Ruggieri *et al.*, 2007). The analyses show that over 60% of the built

environment has been realized before the law 373/76, which first introduced the energy saving concept in building. The data coming from the historical maps do not take into account renovation process, underlining a possible limit of the approach in term of accuracy.

Nonetheless, this procedure allowed us to define the age of the building and the related U-values, overcoming the lack of data and studies in the Italian context.

The methodology used to calculate the thermal transmittance of walls is based on the UNI EN ISO 6946, where transmittance (U) depends on thermal resistance (R), which is related on thermal conductivity (λ). Since for each age correspond specific construction techniques and materials, has been possible to use existing researches and analyses that have connected building age and U-values. In particular has been used for this study the *Abacus of Italian walls structure in existing buildings (Abaco delle strutture murarie utilizzate in Italia in edifici esistenti*, UNI/TS 11300-1, Appendice "B", 2008).

Besides walls, also glazing surfaces have an important energetic role, both regarding characteristics of the windows and percentage on the façade. The first parameter has been defined using sample buildings for each typology, calculating the percentage of glazing surfaces on the total walls. After obtaining the data, they have been associated to the correspondent U-values (UNI/TS 11300-1, part C.3).



Typology	average	max	min
Detached house	09,03%	12,06%	05,52%
Terraced house	10,19%	18,61%	07,48%
Slab housing	13,84%	21,39%	06,88%
Warehouse	14,00%	12,00%	05,52%
Historical block	13,88%	19,53%	08,56%
Traditional urban block	15,02%	24,07%	08,75%

Figure 6 – *Minimum, average and maximum percentage of glazing surface for the different typologies.*

4.3 Evaluation of the heat energy demand

After setting up the database, each typology has been clustered according with the building's age. For example, the typology *detached housing* can have buildings which belong to the *n* different age groups identified.

This classification is necessary in order to associate the right U-values and calculate the related heat energy demand.

	Historical block	Traditional urban block	Detached house	Slab housing	Terraced house
1865	7 (7)	12 (204)	np	1(1)	5 (6)
1934	2 (2)	2 (2)	5 (5)	4(4)	2(2)
1956	-	10 (10)	5 (5)	2(2)	5(5)
1971	5 (10)	16 (109)	43 (547)	20 (208)	20 (98)
1982	1 (1)	9 (54)	10 (10)	8(8)	12(12)
1994	-	9 (30)	24 (285)	20 (191)	10 (118)
2008	2 (2)	3 (3)	10 (34)	10 (33)	5 (10)

Table 2 – Matrix age-typology and number of sample buildings analyzed. On bracket the total amount of buildings belonging to each cluster.

The heat energy demand has been calculated through CASAnova, educational software that allows to estimate the heating/cooling energy demand, and the temperature behavior in buildings.

CASAnova – developed by Fachgebiet Bauphysik & Solarenergie, University of Siegen, Germany – allows relating building geometry, orientation, thermal insulation, glazing, solar heat gains, heating demand, heating, and primary energy or overheating in summer. The software assigns automatically the climate values, based on the average external degrees, defining as heating period the period in which the average monthly temperature is below a reference value, set at 20° in this study. All the other parameters have been set according with the characteristics of the built environment of the City of Gorgonzola.

5. Results

Thanks to the approach based on typologies and age, it has been possible to run the analysis for the heat energy demand only to selected sample buildings (20-25% of the total), applying then the average results (kWh/sqm/year) to the whole cluster.

	Historical block	Traditional urban block	Detached house	Slab housing	Terraced house
Year of construction	kWh/sqm/year average	kWh/sqm/year average	kWh/sqm/year average	kWh/sqm/year average	kWh/sqm/year average
1865	250	253	n.p	200	287
1934	206	250	313	230	285
1956	n.p	201	255	205	268
1971	201	185	252	174	250
1982	129	146	201	104	186
1994	n.p	133	145	88	114
2008	59	70	117	69	90

Table 3 – Average value of heat energy demand (kWh/sqm/year) per typology and age.

The average heat energy demand of the built environment (MWh/year) has then been calculated, giving an overview of the energetic behavior of the city, both on historical perspective and geographical localization.



Figure 7 – *Average heat energy demand for each typology and age.*

Results of the analyses show that typologies characterized by high compactness of the building's form (*slab housing* and *historical block*) have for all the age considered the lowest heat energy demand values per square meter. These outcomes are strongly related with the built form, which can partly overcome the negative impact related with material and technology used. Most of the buildings belonging to these categories (65%) have been realized before the 70s, when the energy saving issues in building was not considered as a priority. Another typology that has a good performance is the *terraced houses* one. In this case the values can be explained as results of better construction techniques and materials, which have partially overcome the lack of compactness.

The low performances of the groups *detached houses* and *traditional urban block* can be explained by building's form characteristic (detached houses), and low energy performance of the materials used (traditional urban block).



Figure 8 – *Average heat energy demand per typology, expressed in kWh/sqm/year (left) and MWh/year (right).*

The outcomes of the study underline the fundamental role of the form of buildings on the heat energy demand. Despite this, the construction technologies and the choice of the materials can influence the final energy performances of buildings. It follows that, in order to achieve the highest performances and reduce the heat energy demand needed, the design has to consider both building's form, in which compactness is the key word, and choice of materials.

The model to estimate the heat energy demand based on typologies can be a basis for larger applications for Italian administrations, housing companies, and planners/designers.

Aggregating the results at the typology level, it is possible to give an overview of the different performances regarding both heat energy demand (kWh/sqm/year) and *total heat energy demand* (MWh/year). The main results have contributed to understand the link between energy-typology-city and prioritize policies and actions.

During the process of review of the urban plan, in which this study is included, the results have been taken into account, bringing new specific rules for enhance the energy performances of the built environments.



Figure 9 – Detail of average heat energy demand per typology (kWh/sqm/year).



Figure 10 – Detail of density of heat energy demand (MWh/year).



Figure 11 – Detail of heat energy demand per existing buildings (kWh/sqm/year)

Thanks to the outputs, knowledge about heat energy demand for different urban typologies of cities has been gained, allowing to:

- Calibrate and asset the most efficient technologies (DER) for specific urban typologies (new and existing housing stock);
- Evaluate energy performances of districts, which can be used also to monitor the impact of development strategies and buildings' renovation.

The model can be considered as strategic tool – which can be constantly updated – that cities and developers can use to define and calibrate development and management policies, achieving better results in the planning for sustainability and reducing energy costs. The radical transformation of how cities work implies, for most urbanists, a radical change in the way they plan and design. At the same time, we cannot forget that the human aspects of urban

form remain essential - maybe more now than ever before. We need to plan, design, and maintain various places - foremost through understanding their identity (individuality), structure (physical pattern), meaning (practical-emotional impact), and setting (relation to environment) (Haas, 2012).

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