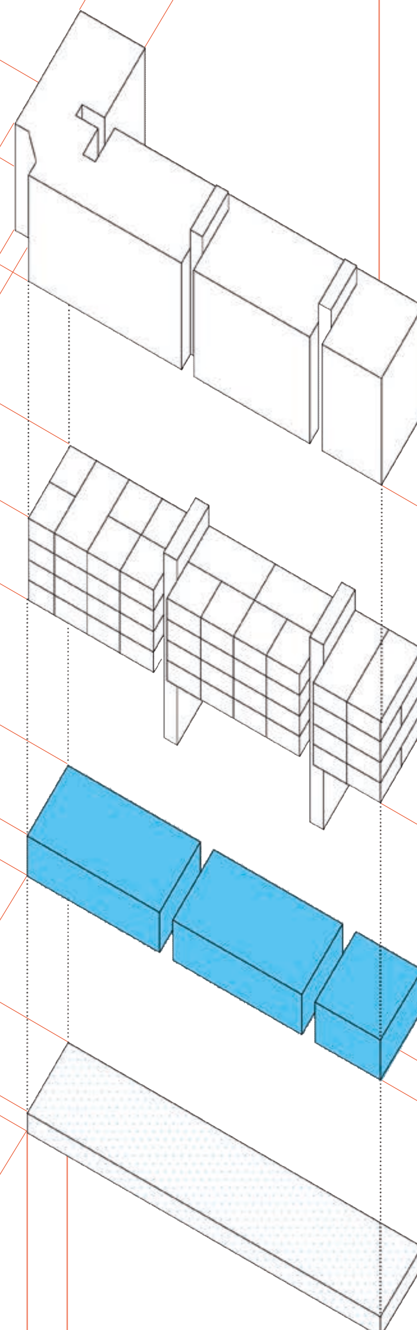
FORMS OF ENERGY

Architectural guidelines for the design of residential buildings being able to interact with the Smart Grid

Elena Scattolini

Maria-Anna Segreto



FORMS OF ENERGY
Architectural guidelines for the design of residential buildings being able to interact with the Smart Grid

Elena Scattolini, Maria-Anna Segreto

2016 ENEA
National Agency for new Technologies, Energy and Sustainable Economic Development

ISBN: 978-88-8286-332-6

Copy editing: Giuliano Ghisu
Cover: Flavio Miglietta
Printing: Laboratorio Tecnografico ENEA - Frascati

Table of contents

Abstract (Italiano)

Il seguente lavoro rappresenta la tesi di dottorato di Elena Scattolini, discussa nel febbraio 2016 presso il Politecnico di Milano, Dipartimento di Architettura e Studi Urbani. La tesi è stata svolta in collaborazione con ENEA, Laboratorio LAERTE: correlatrice del lavoro di ricerca è l'Ing. Maria-Anna Segreto. Relatore interno al Politecnico è la Professoressa Ilaria Valente e il correlatore di Dipartimento il Prof. Marco Bovati.

Il processo energetico di produzione, distribuzione e utilizzo di energia è oggi investito da profondi cambiamenti a scala globale. La diffusione delle fonti energetiche rinnovabili, il progressivo esaurirsi delle fonti fossili e la liberalizzazione del mercato energetico stanno trasformando un modello tradizionalmente centralizzato di produzione, con una conseguente distribuzione ad "albero" e monodirezionale, in un modello a rete, in cui i punti di produzione e utilizzo di energia corrispondono ai molteplici nodi della rete stessa. Si parla oggi di "democratizzazione" dell' energia, poichè gli attori coinvolti non sono più semplici consumatori, ma diventano "prosumers" (contemporaneamente *producers* e *consumers*). Il tema energetico abbraccia la scala urbana della rete diventando in grado di disegnare nuove geografie, secondo logiche che non son più prettamente politiche, ma che coinvolgono allo stesso tempo l'aspetto economico, ecologico e sociale. Il seguente lavoro introduce una riflessione sul tema del progetto in relazione alla gestione del processo energetico. I cambiamenti in atto determinano la necessità di un nuovo e rivoluzionario approccio alla progettazione, in cui l'energia possa diventare elemento cardine del processo progettuale, dalla scala del dettaglio alla scala della città. Come progettare l' edificio e la città in chiave energetica? Quali tipologie rispondono alla necessità di una maggiore flessibilità energetica nei confronti della rete? Esistono modalità insediative che più facilmente si integrano alla cosiddetta rete intelligente rispetto ad altre?

Convinzione alla base di questo lavoro di ricerca è che proprio questo cambiamento sia in grado di generare novità tecniche e concettuali così forti da costituire un momento di profondo sconvolgimento nel Progetto di Architettura, sia per quanto riguarda il progetto del nuovo che l' azione di rigenerazione del patrimonio edilizio esistente. Scopo di questo lavoro è dunque quello di individuare linee guida per la progettazione architettonica di edifici e brani di città che, attraverso il loro carattere formale e distributivo, siano in grado di favorire la gestione dei flussi energetici e ancor più di diventare attori attivi all' interno della nuova rete energetica.

Abstract (English)

Elena Scattolini's doctoral research has been discussed at Politecnico of Milan, Department of Architecture and Urban Studies, at February 2016. The following PhD research has been conducted with the cooperation of ENEA: internal scientific supervisor has been Eng. Maria-Anna Segreto, while Politecnico's supervisor has been Prof. Ilaria Valente and co-supervisor Prof. Marco Bovati.

The process of production, distribution and usage of energy is today run over by deep changes on a global scale. Spread of renewable energies, gradual depletion of fossil fuels and liberalization of the energy market are together commuting the traditional energy model, which was traditionally based on centralized production and mono-directional distribution in a new energy system, where energy producers and users overlap into the energy network. Today a "democratization" of the energy is indeed occurring, since all the actors involved in the process are not only consumers but "prosumers" (producers and consumers at the same time).

The energy topic is nowadays able to define new boundaries, according to economical, ecological and social aspects never considered before.

This research work introduces a new reflection on architectural design related to the energy management. The above mentioned changes should indeed produce a new and innovative design approach, where energy becomes a key point of the whole design process, from the detail scale to the urban one. This new vision is not anymore only related to traditional energy saving and fulfill of energy performance standards, but to the management of energy flows in an innovative and dialectical relationship between buildings, cities and the energy grid.

How we should design buildings and cities from the energy point of view? Which are the building types which better fulfill energy flexibility towards the grid? Are there any urban settlements which better integrate to the new Smart Grid?

The deep on-going change in the energy chain has currently only partially involved architectural and urban design. The main belief of this research work is that this change could instead produce technical and theoretical innovations on the architectural design project, both for the design of new buildings and neighborhoods and for retrofitting of existing ones.

The main purpose of this research work is therefore to identify architectural guidelines for the design of both buildings and urban neighborhoods which could lead to better management of energy flows, so as to become active actors into the new smart grid.

Key words

Architectural and Urban Design, Forms of Energy, Energy Policies, Distributed Generation, Smart Grid, nZEB, Energy Management, Energy Demand, Energy Supply, Loads Modulation, Architectural Design Guidelines, Building Tipology, Hybrid Building, Functional Program, Mixité, Temporal Flexibility, Dwelling Typology, Users' Behavior, Energy Simulation, Energy Storage, Urban Morphology, Energy District, Virtual Building Urban Strategies

SECTION 1

THEORETICAL CONTRIBUTION

CHAPTER 1

PREFACE

"Architecture begins when engineering ends"

(W. Gropius)

1.1 Energy emergency: global challenge for a sustainable development

Energy efficiency is the corner stone of modern low carbon economies: the efficient use of energy has been the goal of many initiatives over the past two decades and improving energy efficiency is a global ambition both in the emerging as well as in the most industrialized countries. Indeed energy used by nations with emerging economies (Southeast Asia, Middle East, South America and Africa) will grow at an average annual rate of 3,2% and will exceed by 2020 that for the developed countries (North America, Western Europe, Japan, Australia and New Zealand) (**1**). The energy efficiency issue has become increasingly important among public debate and energy policies of industrialized countries because of the key role of energy in the economic growth, welfare, and technological and social progress.
In 2008, following a request from the G8, the International Energy Agency (IEA) developed its *«25 Energy efficiency Policy Recommendations»*, a package of proven cost-effective policies that countries should implement.
The Recommendations were defined for seven priority areas:
- Cross sectoral
- Buildings
- Appliances and equipments
- Lighting
- Transport
- Industries
- Energy utilities

The IEA estimates that if implemented globally without delay, the proposed actions could save as much as 7.6 gigatonnes (Gt) CO_2 / year by 2030 (**2**).
The buildings' sector is included in the 7 points due to the buildings' great potential for cost-effective energy savings: buildings are the largest consumers of energy in Europe, accounting for nearly 40% of the total consumption and 36% of the greenhouse gas emissions (EC, 2013) (**3**). Given the many possibilities to substantially reduce buildings' energy requirements, the potential savings of energy efficiency in the building sector would greatly contribute to a society – wide reduction of energy consumption. The implications of such a potential reduction should not be underestimated, as the scale of energy efficiency in buildings is large enough to influence security policy, climate preservation and public health on a national and global scale.
The crucial role of the building sector is recognizable by analyzing some

of the main European, national and local legislations and targets related to energy efficiency policies for the future. Here below the main European targets and future scenarios related to energy efficiency are summarized to underline the main goals of international policies and to point up the strong relation between energy policies and building design.

1.1.1 2020 Climate and Energy Package

The "20-20-20" targets are part of the 2020 Climate and Energy Package and they are set to be achieved by 2020. The three key objectives envisages the following goals:
a- A 20% reduction in EU greenhouse gas emissions from 1990 levels
b- Raising the share of EU energy consumption produced from renewable resources to 20%
c- A 20% improvement in the EU's energy efficiency
The targets were set by EU leaders in 2007, when they committed Europe to become a highly energy-efficient low carbon economy and they were enacted through the climate and energy package in 2009 (4). The 2020 Climate and Energy Package's three key points are considered as the main common goal to be reached by 2020 and as the starting points of all the main subsequent international and national guidelines, frameworks and directives, such as the 2010/31/EU Directive.

1.1.2 Directive 2010/31/EU || Towards the nZEB

On 2010 a Recast of the Energy Performance of Buildings Directive (EPBD) was adopted from the European Parliament: the Directive 2010/31/EU introduced the concept of nearly Zero Energy Buildings.
In point (3) of the Directive the influence of building sector in the European total energy consumption is urgently underlined as it is written that "reduction of energy consumption and the use of energy from renewable sources (5) in the building sector constitute important measures needed to reduce the Union' s energy dependency and greenhouse gas emissions"(6).
Article 9 of the Directive requires that "Member States shall ensure that by 31 December 2020 all new buildings are nearly zero-energy buildings; and after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings". Member States shall furthermore "draw up national plans for increasing the number of nearly zero-energy buildings" and "following the leading example of the public sector, develop policies and take measures such as the setting of targets

in order to stimulate the transformation of buildings that are refurbished into nearly zero-energy buildings". Acknowledging the diversity of the European building sector, EPBD requires MS to define specifically national approaches to the design of nZEB and plans "reflecting their national, regional or local conditions"(7). A nZEB is defined as a building with a very high energy performance and with a low amount of energy required supplied to a significant extend by onsite and nearby renewable sources, including energy from renewable sources produced on-site or nearby (8).
However, the significance of "nearly" zero energy building still remains ambiguous, as it doesn't set any quantitative standard, allowing for personal and subjective interpretations.
Also, EPBD underlines the importance of existing building stock in the total energy balance: for this reason the EU MS should also prepare implementation plans that have to take into account measures to move the existing building stock towards nZEB levels.
nZEBs require an integrated design approach since they represent a huge "change, at technical, economical and cultural levels: technical because it imposes a new way to design and construct buildings; economical because it imposes that one looks at the operation cost and not only at the investment; cultural because it is unavoidable that the language of architecture has to change" (9).

1.1.3 2030 framework

The 2030 framework has been presented from the European Commission on 22nd January 2014 and it focuses on further improvements and goals to be reached by 2030 in order to move towards a lower carbon economy. Here the following the three defined points:
a- Reducing greenhouse gas emissions by 40% (compared to 1990's values)
b- Increasing the share of renewable energy to at least 27%
c- A 27% improvement in energy efficiency. The role of energy efficiency in the 2030 framework will be further considered in a review of the Energy Efficiency Directive due to be concluded later in 2014
The framework is proposed as a constant stimulus to progress towards a low-carbon, competitive and secure energy system (which will be in the future affordable for all consumers), it will increase security of energy supplies, allowing less dependence on imported energy and new opportunities for growth.
Energy efficiency is a global target because of social, ecological and eco-

nomic reasons. The traditional economy based on fossil fuels and centralized distribution is moving towards a new one based on decentralized and renewable sources. The strong relation between energy savings and buildings is stated or implied in all the European Directives for the future development: this is mainly because of the crucial role of the buildings' sector in total energy usage and the strong physical and spatial relation which can occur between energy renewable sources and buildings. Buildings should be in the future more and more able to manage with a new and flexible energy system: they should be architectures which produce, consume and store energy in a strong and deep relation with the new multidirectional energy market. The new necessary approach is a multidisciplinary one in which technology and design work together.
Architectural design should respond to energy efficiency needs with a new and more conscious approach which not only concern to the performance of the building skins or to the automation and engineering control, but it is also directly related to the design of spaces and to the urban morphology and building typology.

1.2 Structure of the research work

1.2.1 Aim of the research: research questions

As introduced in the previous paragraph, depletion of fossil fuels and a new environmental emergency are changing the energy system: it is indeed moving towards a multidirectional and active model based on the so called Smart Grid concept, so as the traditional centralized model of generation based on big plants for energy production and monodirectional distribution is consequently moving to an overcoming. Smart Grid concept is both a direct consequence of the increasing development of renewable energy sources (which introduced unpredictability into the energy system) and liberalization of the energy market. Because of these two factors the grid needs to be able to deal with multidirectional flows and the multiplication of energy producers, it needs to be "smarter" in the management of energy flows.
Until now research on buildings in relation to the Smart Grid has been mainly focused on studies on ICT (Information and Communication Technologies) for the automation and control of the energy flows: **challenge for architects** would be instead **to define possible design implications** and architectural guidelines for the design of buildings integrated into the new paradigm of energy distribution set on the Smart Grid system (**10**). In this regard, the present research aims to identify possible spatial

consequences of Smart Grids in the design of residential buildings.
To be integrated into Smart Grids, buildings should act at the same time as energy producers, storages and smart users. They should request energy to the grid when the market price is lower, while they should input energy into the system if it is stressed.
The aim of this thesis is therefore to get an answer to these main following questions:
- Is it possible to define some architectural design strategies for residential buildings in order to promote a better management, storage and distribution of energy in the Smart Grid paradigm?
- How the architectural design can fit with the Smart Grids´model?
The work focuses mainly on **residential buildings**, since they greatly contribute to the global energy consumption: according to the U.S Energy Information Administration at 2011 residential sector consumed 18% of the global use of energy (**11**).
The involved scales will be all the ones of architectural design from the building scale to the urban one.

1.2.2 Thesis structure

In order to facilitate the reading and understanding of the thesis, this section gives a brief description of the main structure of the work. According to the research methodology (described in the next paragraph), the thesis is organized in five main chapters plus conclusions.
The introduction (Chapter 1) includes a general overview on the main international policies and targets related to energy efficiency in relation to buildings, the main research questions, research methodology and the outcomes and contributions expected from this work.
Chapter 2 is an essay on the "forms of energy": the main positions and approaches to the energy question both at the building and urban scale are shortly analyzed. The Chapter is therefore organized in two main sections: the first focuses on the role of energy efficiency in building design from the vernacular architecture to contemporary cases, while the second investigates the relation between urban morphology and energy networks in architects' research. The purpose is to fix the state of art of architectural research on the topic.
Chapter 3 introduces the concept and main features of Distributed Generation and Smart Grid. The main issue of the research is here underlined as an introduction to the following chapter.
In Chapter 4 the main features a building should have to be as much as

possible flexible and efficient in the energy management are listed; subsequently architectural design strategies for the design of residential buildings interacting with the Smart Grid are identified. A case study is here developed: building simulations are conducted both in an existing building (state of art) and in a re-designed one (design project), in order to verify and test the identified design strategies at the building scale.
Finally, Chapter 5 is dedicated to the understanding of design implications of the Smart Grid at the urban scale of the neighborhood: again, the case study is carried on, in order to test possible relationships and implications of energy infrastructures on urban morphology.
Conclusions are the last section (Chapter 6): they summarize results of the work and they provide suggestions for further research. After the endnotes and general bibliography, the work presents an appendix, a collection of the main publications developed during the PhD research (articles plus poster and main attended international conferences as speaker).

1.2.3 Research methodology

The methodology is the analysis of the principles of methods, rules and postulates employed by a discipline. Types of research which can be used to develop a thesis are the practical research (the empirical study of the topic under research) and theoretical research (it mostly involves the perusal of mostly published researching works).The research methods adopted in this thesis include both aspects of a practical research and a theoretical one. They indeed include but are not limited to the following:
a- Literature review: it involves the research of concepts and ideas in the literature to justify the particular approach to the topic and the selection of methods, in order to demonstrate that the research contributes something new. Also, reviewing a literature on a certain topic can provide an academically enriching experience, presenting it in a new way, to be developed in the future. Literature review is largely used in Chapters 2 and 3: Chapter 2 is indeed a short essay related to the role of energy throughout history of architecture in the definition of architectural and urban form, while in Chapter 3 literature review is used to define the concepts of Distributed Generation and Smart Grid according to international policies and guidelines.
b- Comparative approach: It consists of a comparison between two or more items with the intent to identify and judge the relevant essence and laws. The comparative approach is used in the development of the first case study in Chapter 4: an existing building (state of art) and the same build-

ing, but redesigned, are compared in order to study the effects of design on the energy management of the building itself.
c- Case study and project references: They explore and investigate a real-life phenomena through contextual analysis of events or conditions. Case studies and project references are presented in chapters 4 and 5.
d- Quantitative tools and instruments: Quantitative research is explaining phenomena by collecting numerical data that are analyzed by using mathematically based methods. Particularly building simulations software will be used in Chapter IV, in order to collect data for the quantitative analysis (**12**).
The here above defined methods are integrated one to each other throughout the whole thesis.

1.2.4 Expected outcomes and contributions of the work

The deep change that is modifying systems of production and distribution of energy has necessarily to be considered in the future design of buildings, since buildings are the main actors interacting with the electrical grid. For this reason, architects cannot remain indifferent to such a change, but instead they are called to answer to the new needs of the energy system through architectural composition.
The main contribution of this work is to introduce a new debate on the design of buildings considering the issue of energy management of flows as a key theme from the first steps of design.
The reasoning on the energy issue should not be limited to the simple choice of high-performing materials or plants, but on the contrary it should consider the **building itself as an active actor in the management of energy flows**. The relationship between buildings and energy grid cannot be limited to the support of information technologies for the real-time control of the energy needs, but **the idea at the base of this work is that architectural design is able to affect energy management**, so that the issue of energy management is even preliminary to the design phase.
Through this work, **new architectural design strategies** for the design of residential buildings are provided and they are proved with a new approach that uses quantitative systems for validation of qualitative parameters. Expected outcomes are therefore related to features a building should have in order to be as much as possible energy flexible in the management of flows.

Notes - Chapter 1

(**1**) www.iea.org

(**2**) AA.VV., IEA, 25 Energy Efficiency Policy Recommendations,2011 Update

(**3**) KRANZL, L., ATANASIU, B., BONETA, M., BURGER, V., KENKMANN, T., MULLER, A., TOLEIKYTE, A., PAGLIANO, L., PIETROBON, M., ARMANI, R., nZEB *"Renovation in the building stock: policies, impact and economics"*, paper presented at the WSED World Sustainable Energy Days 2014, Wels, Austria, 25-28 February 2014

(**4**)ec.europa.eu/clima/policies/package

(**5**) The EPBD Directive 2010/31/Eu defines "energy from renewable sources" that one produced from renewable non-fossil sources, namely wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases

(**6**) AA.VV., Recast EPBD Directive 2010/31/EU, 19th May 2010

(7) AA.VV., Recast EPBD Directive 2010/31/EU, 19th May 2010

(**8**) ATANASIU B., *"Is cost optimality driving buildings towards nearly zero-energy buildings?"*, paper presented at the WSED World Sustainable Energy Days 2014, Wels, Austria, 25-28 February 2014

(**9**) BUTERA F. M., "Il Progetto sostenibile" in Dell´architettura di vetro e del Mediterraneo, 2010, pp. 58 - 65

(**10**) SCATTOLINI E., *"Buildings and smart grids: the architectural design of energy flexible residential buildings"*, PLEA 2015 - 31st International PLEA Conference - Ass. Building Green Features, Bologna, 2015

(**11**) www.eia.gov

(**12**) HART, C., Doing a Literature Review – Releasing the Social Science Research Imagination, SAGE Publications, London, Thousand Oaks, New Delhi, 1998

CHAPTER 2

FORMS OF ENERGY: AN ESSAY

“morphology - the study of changing shapes - is not only a study of material things, but has a dynamical aspect, under which we deal with the interpretation, in term of force, of the operations of energy”

(D’Arcy Thompson)

2.1 A foreword: design for energy

Given the complexity and breadth of the relationship between energy and architecture the following chapter, in the essay form, could only provide a quick overview on the main lines of theoretical and applied research related to the energy issue into the architectural discipline. This is particularly useful in order to frame the state of art in which the research work is developing. What will emerge is that research on the energy performance of the building and that one on the forms of development of the energy infrastructures at the urban scale have mostly traveled on parallel tracks and mainly they have not still established a common ground for dialogue.
For a further study of the topics, we advice to focus on the books of the Chapter 2 Bibliography at the end of the work.

2.1.1 Energy

The word energy comes from the Latin form *energia* and the Greek *energeia*, composed by *en-* (an intensive particle which corresponds to the form "in") and *erg-on* which means "activity, action, operation": it could be argued that energy means therefore capability to act. Today energy is defined as the capacity of a physical system to perform work.
Energy can be directly associated to an in-place process producing work (in this case it is proportional to the work done) or it can be on the contrary potential energy, a kind of stored energy which depends from position of the observed object or from configurations of its parts.
Energy is known in a variety of forms and it can be transformed from one form to another one according to the principle of conservation of energy (first law of thermodynamics): it means energy is neither created or destroyed. The six main forms of energy are: chemical, electrical, radiant, mechanical, nuclear and thermal energy. These six forms of energy are all related one another and one form can be converted or changed into other ones: transformability of one form to another one depends on the type and nobility status of the involved energies. Energy of a certain system is originally available and concentrated, but each energy transformation leads to degradation of part of it (second law of thermodynamics) so that during time it tends to become unavailable and fallen energy. For this reason the organization of any energy system can be considered as hierarchical, since "work requires more input energy that it produces as an output" (**1**).
The two laws of thermodynamics state that energy in a system is always quantitatively maintained (first law) but with different qualities (second law): "while in concept the first law is a sport of quantities, the second

law introduces the extremely important qualities and properties of energy. It differentiates between energy that is available to do work, or not, and therefore its qualitative state in an energy hierarchy"(2). The qualitative difference of energy forms is essential to understand more specifically the relationship between design and energy.
Energy in relation to buildings comes in two prevalent forms: electricity and thermal energy. Electrical energy is the one which is stored in charged particles within an electric field and it derives from processes of transformation of other types of energy (chemical, mechanical, thermal etc..). Energy is distributed throughout the grid to the users in the form of electricity. Thermal energy is instead the amount of energy of a thermodynamic system in a certain state of equilibrium and characterized by a given temperature. Thermal energy is considered a less noble form of energy from the electrical one since it cannot be converted into electrical work.
Energy issues are extremely relevant to contemporary society from the point of view of sustainable development: energy is indeed an interdisciplinary concept that embraces economic, social and environmental fields (3). For this reason the relationship between energy and architecture should not be resolved just within the architectural discipline, but rather it should involve several disciplines as a support and integration to the architectural one, such as technology, sociology, economy and engineering.

1. Gruppo 7 and Piero Bottoni, Casa Elettica, Monza, 1930

2.1.2 Energy and architecture

The interplay between architecture and energy is an ancient topic: the own founding act of architecture itself is the construction of a space for living, so as to protect humans from outside climatic conditions. The process of architectural design during history therefore consisted to work in combination with Nature, so as to take advantage of its potential to create adequate living conditions. Optimization of energy sources to achieve a state of comfort has always been one of the primary goals of architecture, but today the global energy crisis, pollution and waste of sources have made the energy issue of primary importance in relation to the architectural project.

Nowadays, alongside the term "architecture", adjectives such as ecological, sustainable and bioclimatic are placed with increasing emphasis, as if to state a qualifying accessory to complete its own meaning. After almost thirty years since the introduction and spread of the concept of "sustainable development", it is observed that it's gradually released from a space for reflection which was restricted to just a small community of specialists/pioneers to enter more and more into global market, regulatory apparatus, marketing and public opinion. The concept of environment has acquired new connotations, such as to believe that there is a "correct" architecture that conforms in term of the environment and an "incorrect" one that is not compliant from the environmental point of view. It would be instead more appropriate to bring back the discussion to the meaning itself of "architecture" as act of transformation of the environment, so as to realize a project as much as possible appropriate, esthetically valuable, functional and reasonable in its relation to the environment itself (4). The role of technique becomes in this sense essential in its relationship with the compositional architectural process, in order to make the building more efficient from an energy point of view and in its relation to the energy network.

It is interesting to refer to definition of techniques given by Vittorio Gregotti (5). He indeed underlines three main aspects which are able to identify and describe techniques in relation to architecture. If the first point runs mainly to technological apparatus, comprising materials and buildings' plants, the other two points are an interesting opportunity to go in with a more detailed reflection on the role of architectural composition in techniques.

He indeed states that it is possible to distinguish three aspects of techniques:

a- Materials techniques
b- Organizational techniques
c- Morphological techniques (**6**)

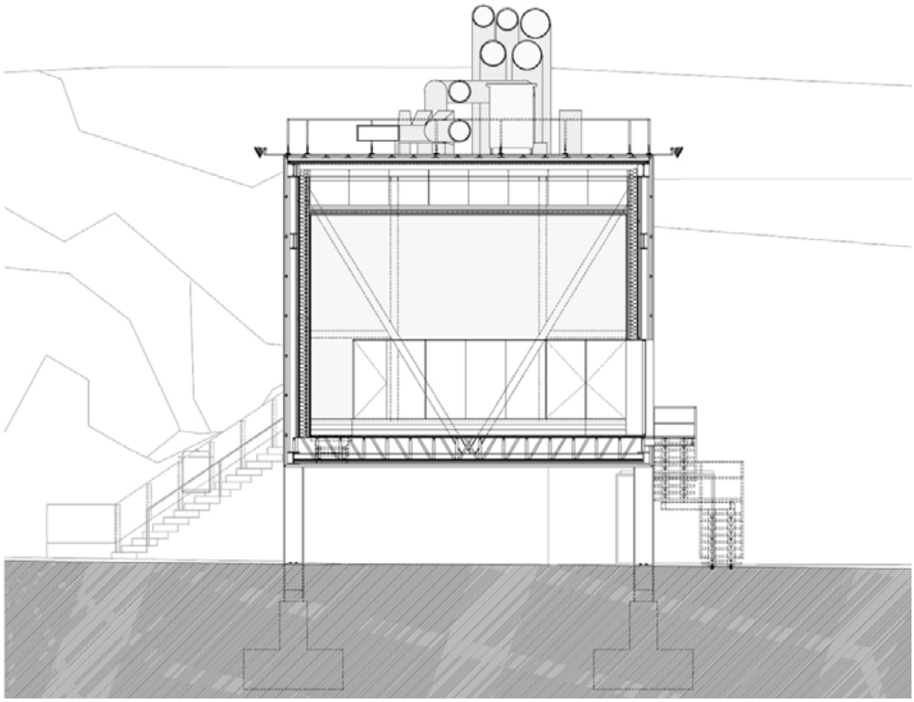
If the first point is the one which is usually associated with the meaning itself of architectural technique, the two other points are particularly interesting as they emphasize the technical character of compositional choices [refer to images 2/3/4/5 (notes 7 and **8**)]. In this respect, technique should not be intended as an un-natural and later apparatus of the project, a mere addition to adapt the building at a later time to preset parameters and specified requirements. On the contrary, the **technical element** and consequently even all those techniques and aspects that may affect the energy management, **should be thought as design elements since the first steps of architectural design**.

Reyner Banham talks about "**exposed energy**" to define those mechanical services which become an "exhibited" part of the architectural form. Banham in his essays and writings lamented the tendency of many architects to design an architecture without plants: he emphasizes the need to consider power plants as a pretext to experience new formal configurations; plants become in this way a preponderant part of the compositional process.

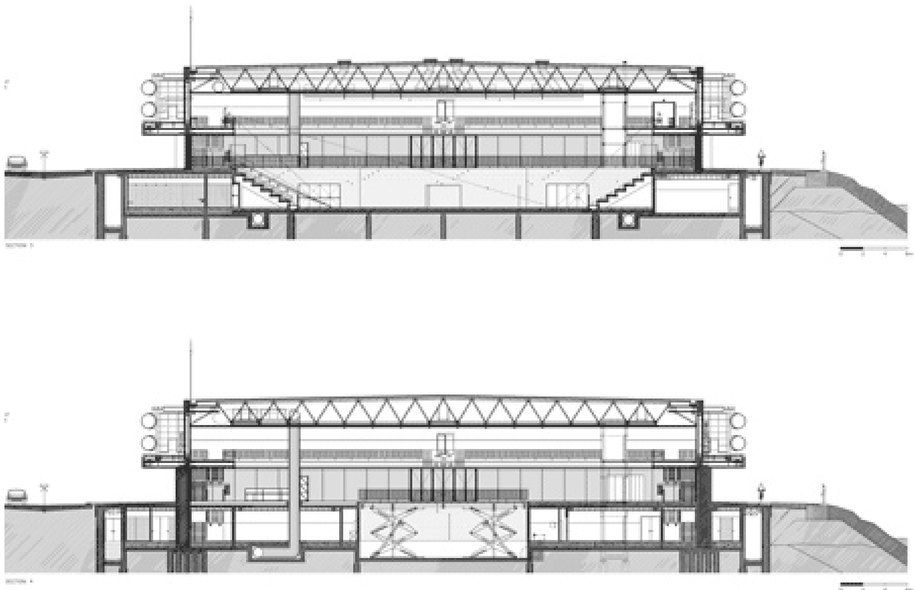
The energy issue, which unfortunately often materializes in a later addition of technical elements supporting the building, should be on the contrary founding of the architectural design and, as announced by Vittorio Gregotti, it should involve both morphological, typological and materials.

Nowadays, in the complex contemporary overview of sustainability in relation to architectural discipline, we could recognize two main approaches to the energy question.

On the one hand a strong commitment directed to buildings' energy performance developed, particularly focusing on residential buildings and according to the fascinating and more and more established idea of the own "ecological house" for everyone. In this direction technological research and international and national directives are thorough and extensive, mainly been focused on material aspects related to performances of the envelope, buildings' orientation, bioclimatic considerations and efficiency of the technological plants (**9**). Particularly architectural and technological research have been developed the concept of "passive" house or, more in general, "passive building"(**10**). In this approach the technical component is obviously very strong and even more evident when the production from

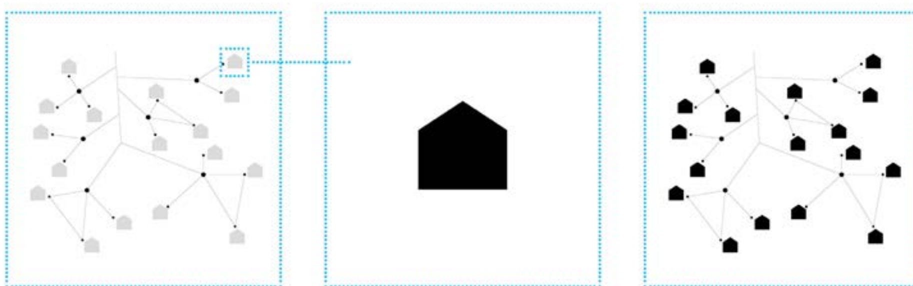


2/3. E. Souto de Moura, Audiovisual Auditorium, Graca Correia, Porto Alegre



4/5. E. Souto de Moura, Cultural Center of Viana do Castelo, 2013

renewable sources is integrated to the building itself.
On the other hand a new recent interest in the "forms of development" is growing up: this vein is focusing on manufacturing and storage, movement and flows, energy production and distribution. Energy crisis and the growing complexity in energy supply have indeed generated a new awareness of what the role of energy is in the development of contemporary urban systems. The new perspective introduced by these thorny issues leads to the need of a drastic rethinking of the whole energy system, together with a change of scale in dealing with the problematic. The architectural culture more recently has started to focus on the theme of flows of energy and its distribution, which necessarily pervade architectural spaces both at the large scale of the city and at the small scale of the building (**11**). This is even clear by the spread of Distributed Generation: it is a direct consequence of renewable energies which in turn are mainly integrated to buildings.
Next step should be done is an integrated approach in which building and urban scale work together in the definition of common goals related to the energy issue. The research on future relations between the energy network, buildings and urban settlements is therefore increasingly necessary, so as to carry on a conscious design at the different scales of energy chain into the architectural design. The two following paragraphs (2.2 and 2.3) propose an overview of the state of art in theoretical research and design relating to the two here above identified extensive architectural currents in relation to energy, particularly focusing on the different involved scales of the architectural project.
First paragraph (2.2) is an overview on what is today considered as an "energy efficient building" and which are the main aspects which have been developed during history of architecture by theoretical and applied research.
Second paragraph (2.3) is a summary of the most meaningful theoretical studies about possible relations between development of cities and energy networks.
Both the two paragraphs are defined through a critical reading of some historical and more recent significant theoretical experiences and design experiments. It will emerge that in the relationship energy/building the technological aspect has recently more and more been emphasized to become sometimes a mere mean to the maximization of energy performances at the expense of architectural compositional research. In contrast, in the field of studies on urban morphology in its relation with energy networks,



6. First square represents electric grid, while the second one represents the building as one of the users of the grid. Until now the grid and the building have been always designed separately one from each other: relationship between energy network and architecture has been mostly developed as utopian experiments at the urban scale or, on the contrary, as the development of engineering technologies for automation and control inside the building. Third square is instead the goal to be reached by architectural design: buildings are the hubs of the energy network, so that they are part of it and they should be designed to interact as much as possible with the grid itself theoretical research has defined during time really interesting and innovative morphological models, which have been often precursors of contemporary trends, but they have not been enough supported by an adequate technological apparatus, mostly remaining as utopias.

2.2 Architectural forms of energy

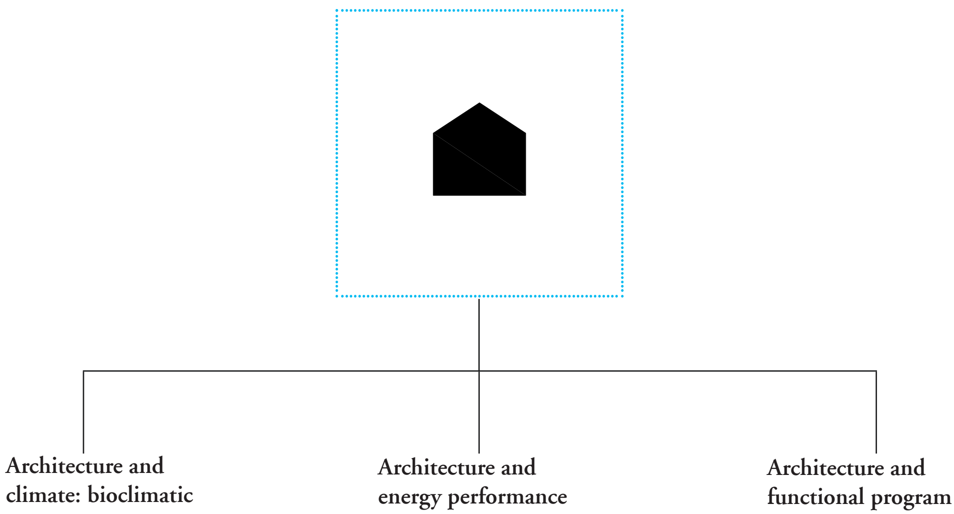
The relationship between buildings and energy has been tackled by multiple approaches referring to contributions of different disciplines. In the following paragraphs, the duo energy/building has been shortly analyzed according to those key themes that have mostly guided development of theoretical and applied research on energy efficient buildings. Starting from the concept of bioclimatic architecture, which has ruled the construction process since the outset, the concept of energy performance will be briefly analyzed to finally introduce the theme of functional program of the building and its possible implications on the energy management of buildings.

2.2.1 Architecture and climate: bioclimatic

As already underlined, relationship between architecture and energy is one of the most crucial issues into architectural design. It has been mostly realized in the relation between the building and the climate conditions of its site, so as to guarantee adequate conditions of indoor comfort: in the history of architecture we can indeed trace many examples about the influences of climate conditions on the architectural form.

In the VI book of *De Architectura*, chapter 1, Vitruvius wrote that buildings "are properly designed, when due regard is had to the country and climate in which they are erected. For the method of building which is suited to Egypt would be very improper in Spain, and that in use in Pontus would be absurd at Rome: so in other parts of the world a style suitable to one climate, would be very unsuitable to another: for one part of the world is under the sun's course, another is distant from it, and another, between the two, is temperate. Since, therefore, from the position of the heaven in respect of the earth, from the inclination of the zodiac and from the sun's course, the earth varies in temperature in different parts, so the form of buildings must be varied according to the temperature of the place, and the various aspects of the heavens".

Till the Industrial Revolution, geographical context has therefore strongly had effects on the architectural response regarding to shape, materials and orientation of buildings: this is also evident in some spontaneous vernacu-



7. Different approaches to the theme of energy in architecture at the building scale lar architectures of the past [refer to images 8 and 9 (note **12**)].

The separation of the architectural project into aesthetic and scientific disciplines dates back to the XVIII century. During the Enlightenment, as a result of influences exercised by the development of natural sciences, various branches of knowledge which have always been necessary to define the architectural project have been categorized as "disciplines". By the assumption of this statute, they have therefore acquired the characteristic features of specialization and mutual separation: architects have more and more defended the autonomy of form (aesthetic) from the construction and environmental constraints (scientific) underlined by engineers, and vice versa. The whole meaning of the project is in this way reversed: instead of composing forms which are able to communicate environmental features, the shape is more and more independent from these inputs, so that the building doesn't represent anymore the contest from its formal features. With the Industrial Revolution new plants and technologies for buildings were indeed developed: as a consequence they enabled the progressive automation, full climate and lighting control inside buildings. The result has been a general tendency to uniformity of architectural language at the global scale, so a building with certain structural and material features of the envelope could indistinctly be located in different areas of the world, with totally different climatic and environmental features [refer to images 10 and 11 (note **13**)]. However, before the introduction of technological devices for climate control, the architectural knowledge and interpretation of places had always produced both the indoor temperature and humidity conditions inside buildings and the different cultural identities of places through the building's features. The development of air conditioning and environmental control through technological plants has quickly caused the shift of skills from architects to mechanical engineers: the knowledge of places in which the building is located has often become a mere collection of physical data which are just necessary to size a plant.
Today, due to the global energy crisis and environmental issues, the trend of bioclimatic architecture is more and more growing up and building is intended again as a dynamic system which is able to influence indoor thermal features. The term "bioclimatic architecture" has been reintroduced to define a specific design methodology which is able to use the contribution of local energies, in the full respect of local climates and ensuring the maintenance of thermal indoor comfort, just by using the potentialities of the environment in which the building is located. The bioclimatic ap-

8 Trulli in the region Puglia, photographer: E. Peressutti

9 Dammusi in Pantelleria, photographer: A. Pucci

10 OMA, Tv Office, Beijing 2012

11 Foster + Partners, Gherkin Building, London 2004 proach maximize the environmental effects of the structural components of buildings and minimize “power consuming” components. It relies “on strategies such as building orientation, daylighting, window shading and natural ventilation” (14).

We could summarize that forms of architecture are generally affected by the goal of energy efficiency in relation to local climate conditions and the functional program of a building is also affected by the building’s orientation and geographical location. However till now the functional program has been affected just by environmental issues related to climatic features of the site, while the relationship with energy networks has always been ignored.

2.2.2 Architecture and energy performance

Energy efficiency – using less energy for the same amount of work- is perhaps the most pervasive concept in the contemporary discourse of energy in architecture (15). As we have already stated, the issue of energy in relation to buildings includes many different meanings and it is developed according to different parameters and approaches, but in the last years we can notice that it has been mostly focused on definition and achievement of buildings’ energy performances, so as to meet minimum energy requirements given by international and national law. Particularly, the introduction of national and international regulations and minimum standards of energy performances pushed technological research to the identification of those materials for the building envelope with the lower transmittance values and to the improvement of efficiency of technological plants for heating and cooling’s control.

Efficiency of the envelope and technological plants inside buildings are obviously both essential aspects to reach international targets and energy standards. However, the risk of the only application of technological devices to achieve energy performances is to recognize a building as sustainable through the single elements that compose it, as if the quality of the single part could define the quality of its entirety. By single addition of individual technical solutions, it is maybe possible to get the maximum energy savings that we set, but we have probably denied spatial and compositional research. This kind of approach tends to emphasize research of the utility intended as the achievement of performances for energy efficiency, to push into the background the concept of beauty of the architectural form, intended in the Vitruvian sense of *venustas*.

Models based on the idea of sustainable development have mainly been fo-

cused on the idea of maximum efficiency. This concept has produced good results in energy savings together with levels of complexity, but it often has also generated a certain flattering of architectural languages.
Of course we can trace several virtuous examples of architectures in which technological elements for energy production are perfectly integrated to the building: in these examples the technological element is not only thought as a support to reach some given energy perfomances, but it is also part of the formal language of the building itself. However a general trend, which has in fact generated a sort of injury against the energy issue into architectural design, has been the one to act by summing technological elements to reach high performances, but without an appropriate attention to the formal research.   It becomes instead essential to start reasoning, alongside reflections upon technological performances of the envelope and building's devices, on what is the role of the architectural compositional research in relation to the energy issues. The role of energy efficiency in architectural discourse should not be considered just as a "question of quantities but also, and far more importantly, a question of qualitative states"(**16**). The duo energy/building should perhaps take the form of a deeper relationship in which qualitative aspects would be more and more involved.

2.2.3 Architecture and functional program

As analyzed in the previous paragraphs, relationship between the functional program of a building and energy issues has been mostly focused on buildings' orientation and internal organization due to the site's features.
However the functional program, which is able to affect the architectural form both in its spatial configuration and in the internal distribution, could also have effects on the management of energy flows. Especially, if we consider the building in its relation with the power grid, **functional program could have an important role** in the improvement of energy management during the 24 hours of a day. **Behavior of building's users** and the indoor activities are indeed able to affect trends of energy flows inside the building itself since they **influence energy usage during time**: but the presence of different users is influenced by the type of program inside the building. The functional program is able to generate very different living models and consequently new and different housing types. Thinking about a program that best fits to a smart energy management means therefore to reflect on building typologies and architectural forms.

2.3 Urban form and energy networks

In 2009, the research branch of the Office for Metropolitan Architecture, known as AMO, submitted a report to the European Climate Foundation titled "Eneropa", as part of the Foundation's "Roadmap2050: A Practical Guide for a Prosperous, Carbon-Free Europe": the proposal claims it would cut carbon emissions in Europe by 80% by 2050. Eneropa is an audacious design for Europe: AMO redraws the map of the continent according to methods of energy generation and what type of energy they would supply to the grid, so that North-West Europe becomes "Geothermalia", Mediterrenean area is "Solaria", UK is composed of "Tida States", while the Baltics become "Biomassburg and East Europe "Hydropia" (refer to images 12/13/14). What appears is that **the energy issue** is becoming so predominant to be able to **describe even new geographies**. The study indeed reveals the growing interest, also by the architects, in the new forms of energy production and in energy networks, which on the one hand are to be understood in a global and community sense (according to the international guidelines for a sustainable future development), but on the other hand will be more and more adapted to local and contingent conditions.
To some extent, the "AMO' s approach to complex environmental problems related to energy grids has been placed in historical perspective through recent examinations of some of the experimental practices of the 1960's and 1970's. Here as well, architectural proposals and projects operated as a discursive arena for wide-ranging explorations of emergent environmental knowledge"(**17**).
From the late 1940's a new design approach defined by Tafuri "international utopia" started to develop: from Europe to Japan architectural research began to focus its attention on rethinking of urban metropolis and several studies were conducted on the idea of the urban megastructure in relation to city networks and infrastructures. Archigram in Europe and Metabolists in Japan proposed over the years a wide range of design solutions for the contemporary and future City. What appears by their proposals is a renewed confidence in technology: architects at that time saw in technological innovations a new input for social transformations.
It is particularly in the work of Archigram that the most interesting references on the **concept of energy networks** in relation to urban design can be traced. Archigram is the name of an independent magazine which was published in London between 1961 and 1974. The name was the same of the informal collective of young architects which constituted the Archigram Architects between 1970 and 1975. The main members of this

group were Peter Cook, Warren Chalk, Ron Herron, Dennis Crompton, Michael Webb and David Greene. In the work of Archigram there is the explicit and intentional definition of an architectural thought related to the myth of advanced technology, industrial production, mass communication and the pop aesthetic. In R. Banham' s review of the work of Archigram (**18**) he underlined the importance of their projects as much for the technology on which they were predicated as for their new aesthetic qualities.

It should be underlined that Archigram' s research in turn was inspired by some previous design experiments of the avant-gardes. The work of Futurists, and particularly the collection "Tavole della Città Nuova" by Antonio Sant'Elia, was indeed surely a fundamental inspiration for the work of the Archigram Group. In 1914 Sant' Elia produced a series of drawings relating to his utopian vision of a completely industrialized and technologically advanced City (Città Nuova). Sant' Elia abolished the notion of the monolithic, free-standing building and integrated it into the idea of a complete urban machine. His drawings show future possible metropolis in which buildings are designed as nodes of a tentacle and integrated urban context (image 15).

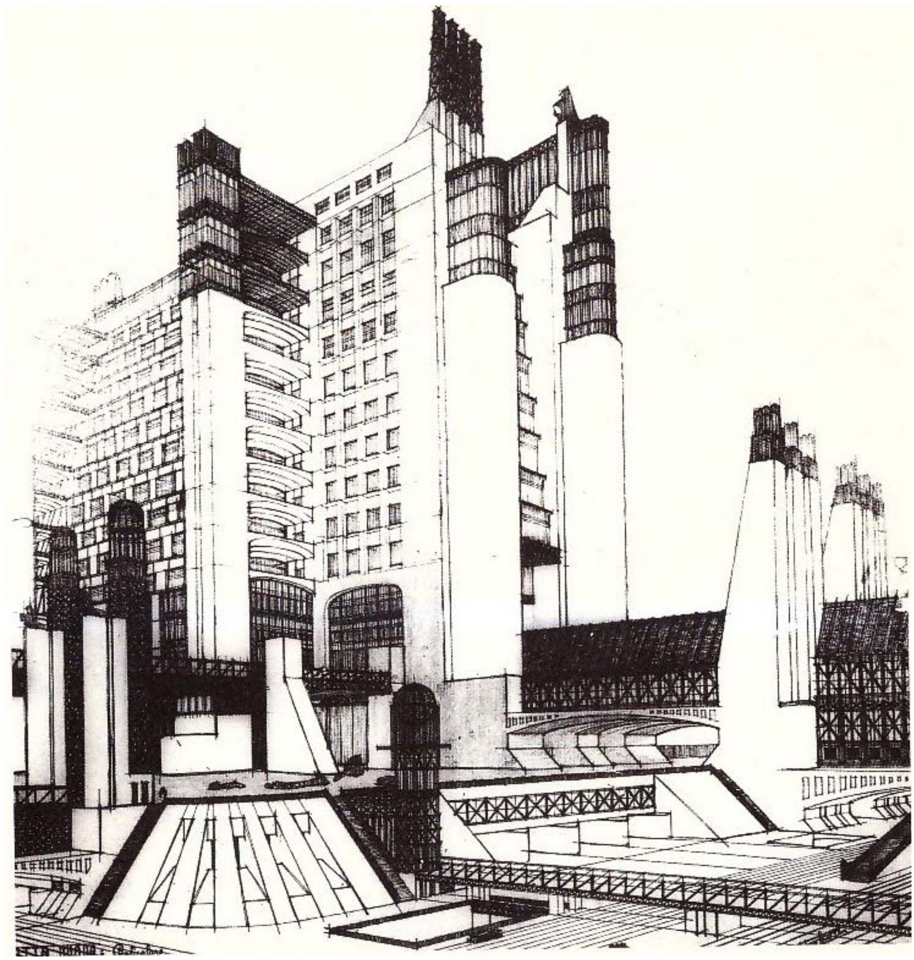
Some years after the publication of Sant' Elia's work, in 1927, Buckminster Fuller proposed a new idea of house in which all the plants and devices for energy supply play a fundamental role in the formal architectural composition of the building itself. The so called Multiple Deck-4D is designed as an air-transportable housing-block consisting of ten hexagonal floors arranged around a central big pillar, containing all the required plants and energy systems. The Multiple Deck-4D is a particularly interesting project because it deals with the relation between energy networks and architecture from a formal point of view of architectural composition (form is indeed affected by devices).

Some years later, mostly between 1936 and 1946, Buckminster Fuller proposed an equally interesting vision of a global energy grid throughout a series of world energy maps based on his Dymaxion Map. The map shows the world to be as a one-world island in a one-world ocean. In the map it is shown that the majority of people live in a relatively small area of the available surface of the Earth: however most of population, according to Buckminster Fuller's analysis, is not generally living where some of the best renewable energy resources naturally are. Thus, the need for the Global Energy Grid (image 16). In Buckminster Fuller's innovative idea a completed Global Energy Grid will encourage using renewable energy

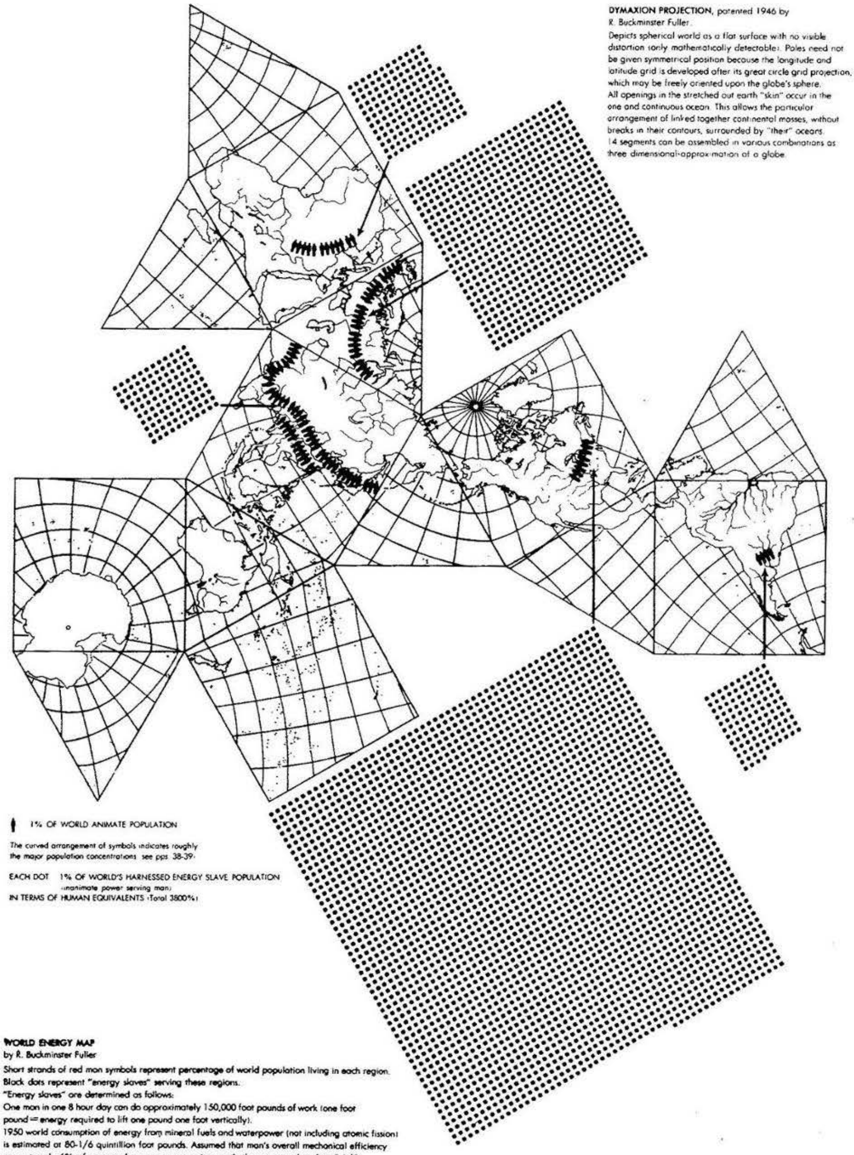
12/13/14. AMO redraws map of Europe by the type of energy source it is prevalent in the area. Figures 14 and 15 show a representation of Hydropia and Geothermalia


HYDROPIA


ENHANCED GEOTHERMALIA



15. Sant'Elia, La Città Nuova, 1914



WORLD ENERGY MAP
by R. Buckminster Fuller

Short strands of red man symbols represent percentage of world population living in each region.
Black dots represent "energy slaves" serving these regions.
"Energy slaves" are determined as follows:
One man in one 8 hour day can do approximately 150,000 foot pounds of work (one foot pound = energy required to lift one pound one foot vertically).
1950 world consumption of energy from mineral fuels and waterpower (not including atomic fission) is estimated at 80-1/6 quintillion foot pounds. Assumed that man's overall mechanical efficiency converts only 4% of consumed energy resources into work, the net annual profit is 3-1/5 quintillion foot pounds.
Dividing this figure by 37-1/2 million foot pounds, one year's (250 work days) energy output of one man, the result is 85-1/2 billion man year equivalents of work done by machines and structures. These equivalents we call "energy slaves" serving man.

$$\frac{\text{85-1/2 billion energy slaves}}{\text{2-1/4 billion world population}} = \text{38 energy slaves per capita}$$

Note

The atomic energy resource consumption during this period in various countries is not available but would probably tend to increase even further the present disparity of respective world energy advantages.
Also note that energy slaves are not confined to narrow range of physical conditions limiting man's activities for they can work "comfortably" anywhere between absolute zero and 5,000°F., at submicroscopic precision and at speed of 186,000 miles per second.

	A % OF WORLD POPULATION 1950	ENERGY SLAVES POPULATION 1950	% OF WORLD'S ENERGY SLAVES 1950	PROPORTIONAL % OF WORLD'S ENERGY SLAVES in terms of A and human equivalents as shown on map 1950	ENERGY SLAVES PER HUMANS PER AREA (in round numbers) 1950
ASIA	50	2,565,000,000	3	114	2
EUROPE	24	14,535,000,000	17	646	27
AFRICA AND MEDIT. WORLD	12	3,420,000,000	4	152	13
NORTH AMERICA	8	62,415,000,000	73	2774	347
SOUTH AMERICA	4	2,565,000,000	3	114	28
CENTRAL AMERICA	1	0	0	0	0
ALL OTHERS	1	0	0	0	0
	100%	85,500,000,000	100%	3800%	

16. Buckminster Fuller, World Energy Map, 1944 resources, such as hydroelectric, wind, solar, geothermal, biomass, tide, wave, and other non-polluting and natural, regenerative or inexhaustible, power solutions.

As stated, the Archigram group studied the work of Futurists and the futuristic proposals of Buckminster Fuller and they were surely inspired by them: in the years between 1960 and 1974 they created over 900 drawings showing different ideas of future possible cities. The main purpose of their work was to explore all the potentials for technology and engineering to reshape the urban environment.

Among their drawings one of the most fascinating is the Plug-in City by Peter Cook: the Plug-in City was the combination of a series of ideas that were worked upon by Archigram group between 1962 and 1964. Cook makes use of the term *plug*, hitherto only used in the architectural discipline in relation to electric plants and devices. A plug can be defined as a device which is able to establish the electric connection between conductors: the term therefore suggests the idea of urban elements placed inside a structural and electrical network. Peter Cook wrote that "the Plug-In City is set up by applying a large scale network-structure, containing access ways and essential services, to any terrain. Into this network are placed units which cater for all needs. These units are planned for obsolescence. The units are served and maneuvered by means of cranes operating from a railway at the apex of the structure. The interior contains several electronic and machine installations intended to replace present-day work operations"(**19**). The living unit itself becomes in the proposal a plug insubordinate to infrastructures for energy supply and distribution on a larger scale.

When Plug-In City was proposed in 1964, it offered a fascinating new approach to urbanism, **reversing traditional perceptions of infrastructure's role into the city** (**20**).

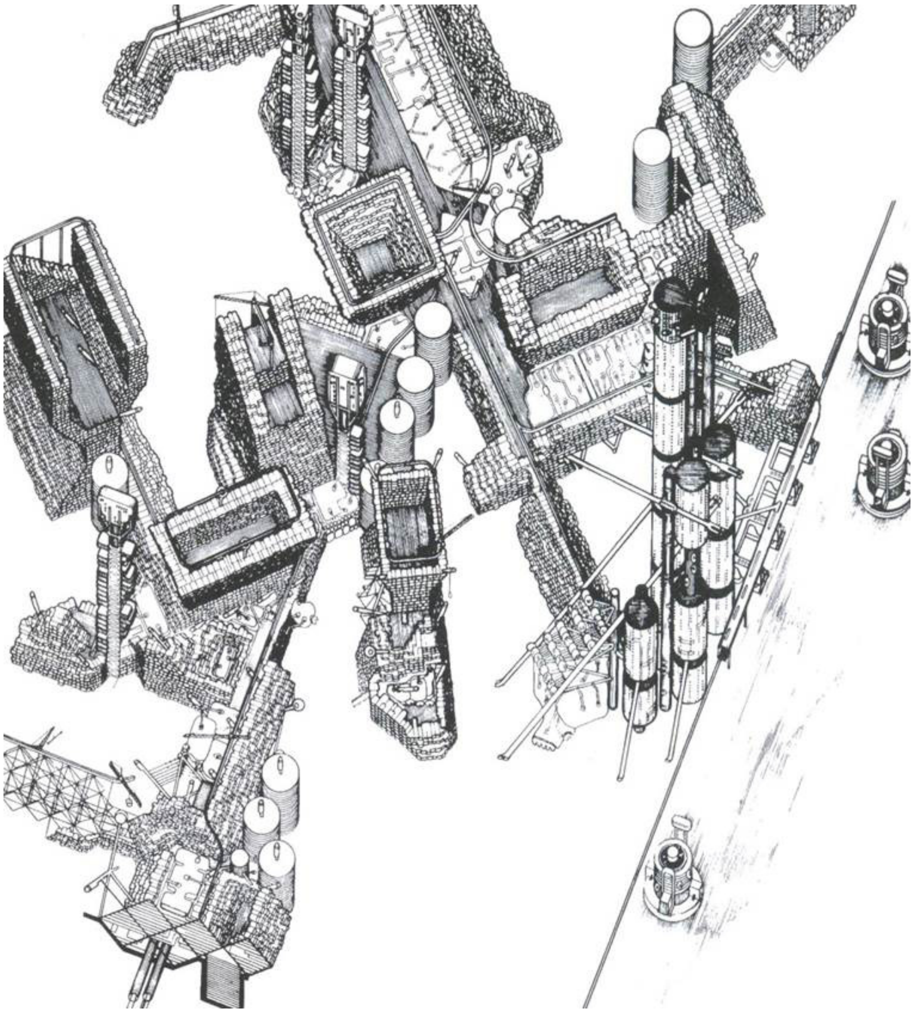
The Computer-City project by D. Crompton (1964) is a parallel study to Plug In City: "it suggests a system of continual sensing of requirements throughout the city using the electronic summoning potential"(**21**). Computer City is a network of flows- flows of traffic, goods, people, and above all information: it is a city controlled by electronic systems in which sensors become the pillars of all urban functions (**22**). Once again we can perceive the innovative nature of the work of Archigram: the Computer City appears in fact as a foreshadowing of contemporary informatics society set on internet networks.

If in some cases the radical proposals of these years became opportunities to experience new models of urbanity in total break with their contemporary city and in a close connection with new infrastructural networks, other hypotheses of those years focused on densification of the existing city through a sort of "duplication" of the city itself, with a new system overlying the existing one (23). It is also the case of some architectural experiments which have been collected in the book "La Cité de l'an 2000" by M. Ragon (image 19). Ragon collected in its book some illustrations of utopic cities by different architects of that time in which the idea of "network" is interpreted in different ways, such as "La Ville Climatisee" by P. Maymont, or "La Ville spatiale" by Yona Friedman. What is really interesting is, again, **the idea of cities as layers of different networks superimposed on one another**: this concept prefigures the model of networks as we figure now into the contemporary city: systems overlapping one another, "vehicles" of flows and information that connect buildings in a unique and alive urban system.

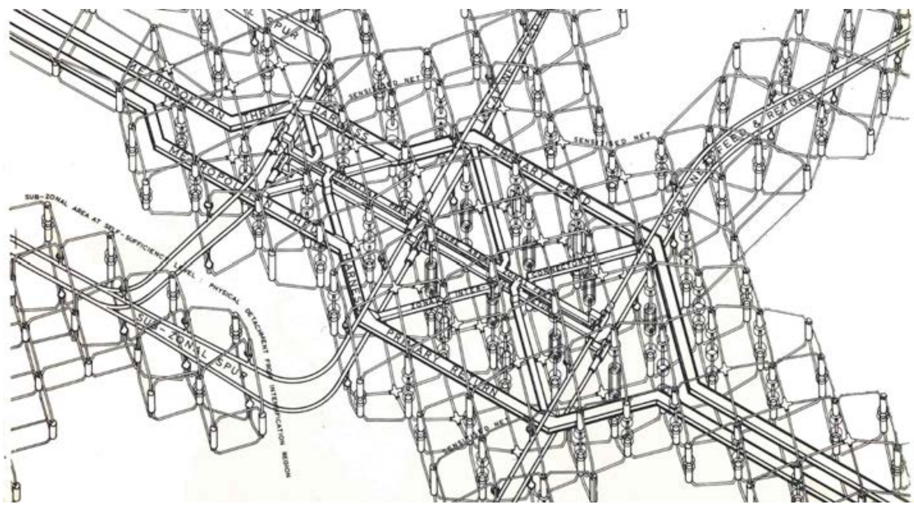
These utopic cities remained as formal experiments of urban models, but they often exhibited formal and technological intuitions of future developments: this is mainly evident in the work of Archigram. Archigram architects indeed didn't arrive at a workable architecture of technology since their drawings remained just as theoretical suggestions, but they had come up with an attractive set of proposals for what this type of architecture might look like (24). Their work remained utopian: as was written by Banham, Archigram "can't tell for certain whether Plug-in City can be made to work, but it can tell what it might look like"(25). We can however identify some key issues in which Archigram might be considered as precursors.

Firstly, in many of their urban proposals, buildings are designed as nodes of a complex system of technological networks: they become interchange points of flows into the city. This idea anticipates the contemporary concept of the Smart Grid. In the Smart Grid, as we are going to describe in the next chapter, buildings are indeed nodes and interchange elements of the multidirectional energy flows running into the grid itself. Both in the Archigram's design experiments and in the contemporary Smart Grid, buildings are not anymore passive elements, but active players into the complex energy system. Archigram have suggested a new idea of City in which technological networks act as modifiers of the urban form: they have in this way prefigured some key issues that are now appearing as crucial in the contemporary world.

The economist Jeremy Rifkin has recently defined five main pillars of what he defines as the "Third Industrial Revolution" contemporary time. The five pillars of this new global economy are *(1)* shifting to renewable energy; *(2)* transforming the building stock of every continent into green micro–



17. P. Cook, the Plug-In City, 1964



18. D. Crompton, the Computer City, 1964

19. D. Crompton, the Computer City, 1964

power plants to collect renewable energies on-site; *(3)* deploying hydrogen and other storage technologies in every building and throughout the infrastructure to store intermittent energies; *(4)* using Internet technology to transform the power grid of every continent into an energy internet that acts just like the Internet (when millions of buildings are generating a small amount of renewable energy locally, on-site, they can sell surplus green electricity back to the grid and share it with their continental neighbors); and *(5)* transitioning the transport fleet to electric plug-in and fuel cell vehicles that can buy and sell green electricity on a smart, continental, interactive power grid (**26**). The analysis of these five points shows the modernity of Archigram' s proposals: e.g. Computer City reflects a society based on information technology just like the contemporary society defined by Rifkin is based on internet networks. We can read in the Computer City the seeds of contemporary concept of Smart City. Contemporary Smart Cities have been indeed characterized and defined by a number of factors including sustainability, economic development and a high quality of life. Enhancing these factors can be achieved through infrastructure (physical capital), human capital, social capital and/or ICT infrastructure. A Smart City is then a contemporary city that uses information technology (IT) to manage all the main city functions and utilize energy and other resources efficiently (**27**), as the Plug-In City or the Computer City foreshadowed already in the Sixties.
From a contemporary perspective, the main limit in the work of Archigram is to consider energy sources as infinite. In their foreshadowing of future urban settlements, references to practices of energy saving to promote a flexible and cautious use of limited natural sources are indeed totally missing. It will be only with the energy crisis of the Seventies (1973 and 1979) that issues of sustainability and management of energy sources will begin to establish into architectural research.

Finally the growing interest in the relation between architecture and energy network is also clear into the section *Visions* of the exhibition *"Energy: architettura e reti del petrolio e del post-petrolio"* (MAXXI, Rome 2013): Visions is indeed dedicated to the possible influences of the new energy networks on living spaces' forms and layouts. Several studies conducted by a selection of architectural offices are showed into the exhibition: many of these are related to the theme of the relationship between contemporary energy grids and urban settlements; several scenarios of this relation between the grid and the city are collected in the exposition catalogue.

2.4 An overview on future design for energy

What appears by the historical overview about the duo energy/architecture is a general interest at the building scale on the achievement of energy performances by acting on the building's envelope and orientation, application of new and innovative technologies for energy production and introduction of performance energy devices for automation and control, to be located inside buildings. At the urban scale the utopian projects of Archigram have anticipated the contemporary interest of architects into possible urban spatial implications of technological grids: by their studies they often have brought forward development scenarios of contemporary cities. This growing interest in urban form and energy networks is evident in the architectural research conducted by some contemporary architects (refer to the previous paragraph): however at the moment they are still mainly research works without any applications on real design case studies.

The two above described approaches to the energy issue have often traveled on two parallel tracks, rarely materializing in formal experiments that combine together the interest on the complex distribution grid system and the achieving of energy standards in line with European and national directives.

For this reason, **the new challenge that this thesis will propose is the jointly reasoning on the two scales of the project** (urban scale of the energy grid - building scale): **the purpose is to improve management of energy flows in the bidirectional and complex relation energy grid/building**, by the adoption of a conscious architectural design. To do so, it is necessary to think more and more to the role of energy into design process: the energy issue should not be linked to the mere achievement of standards, but it should be inherent into the act of design itself. The main goal of this thesis will be therefore to understand the role of architectural design of residential buildings into the complex panorama of energy distribution grids, in order to define some design guidelines for architects valid as a sort of tool for architectural design. Particularly, the discussion will be conducted on the functional program of the building, so as to understand how much this may impact on the energy management of the building itself.

Regarding to the management of energy flows, is it better to design a building with the same kind of dwelling typology or different ones? Does the presence of collective spaces inside buildings have effects on energy management? What kind of technological devices should be integrated to the building? And how much space do these devices physically occupy in

the plan of a building? These are just some of the questions that will be examined in depth in the following chapters.
The idea that the architectural design could affect the relationship between the building and the grid could cause major changes in lifestyles and habits and housing models that recently have emerged in the contemporary world might be “re-confirmed” as efficient good prototypes even for the energy management. Architecture which is facing to the challenge of sustainability should therefore not just change in form and language: probably the biggest results in the energy management will come when it will also propose a new integration of lifestyles and a new relationship with living and working conditions of life.

Notes - Chapter 2

(1) MOE K., Convergence. An architectural agenda for energy, Routledge, Abingdon Oxon, 2013, p. 40

(2) MOE K., ibid, p.26

(3) The definition itself of sustainable development introduced in the "Report of the World Commission on Environment and Development: Our Common Future" (Burtland report) clarify the multidisciplinary nature of the concept – "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"

(4) PARIS S., *"Sostenibilità, tecnologia e qualità dell' architettura. Il mediterraneo"* in BAGNATO V., PARIS S. "Architettura e tecnologia. Lectures", DesignPress, Roma, 2010

(5) GREGOTTI V., Architettura, tecnica, finalità, Laterza, Roma-Bari, 2012

(6) GREGOTTI V., Ibid., text in the original language: *"Credo che, dal punto di vista dell' architettura, si possano schematicamente distinguere (sia pure con una artificiosa divisione) tre aspetti delle tecniche: 1. le tecniche materiali, 2. quelle dell' organizzazione e 3. quelle morfologiche. Le prime si riferiscono specificamente alla costruzione nei suoi diversi aspetti: strutturali, di scelta del modo di selezionare e lavorare i materiali, della loro messa in opera, dei sistemi di giunzione e sovrapposizione e dei loro dettagli relativi. Le seconde riguardano le dimensioni e le sequenze degli spazi abitabili, chiusi o aperti, i loro modi di costituirsi in organismo nello stesso tempo riconoscibile e disponibile agli usi, ma anche le tecniche in quanto modi di costituzione del progetto, individuazione di metodi e procedure delle gerarchie e dei sistemi di comunicazione tra progettista ed esecutore e, infine, le tecniche organizzative che attengono alla rispondenza tra programma e opera e al controllo produttivo del progetto. Le tecniche morfologiche riguardano, invece, i criteri e i modi di dar forma e misure ai materiali e di costituire fra tutte le parti l' unità (continua o discontinua che sia) dell' opera. Inoltre esse attengono ai modi di rappresentarsi dell' opera nella sua formazione e nel suo risultato. Il primo gruppo di tecniche- quelle materiali- ha a che vedere con la pratica e fa riferimento alle esperienze accumulate, alle abilità; il secondo – quelle dell' organizzazione – è piuttosto connesso all' idea di programma in quanto tecnica del fare sovente per fini definiti e in quanto possibilità combinatoria; il terzo gruppo – le tecniche morfologiche- è quello in cui la prassi diventa poiesis, tecniche volte a rendere massima la questione della finalità, una finalità senza finitezze temporali, anche se solo da una condizione precisa essa prende inizio e si attua per mezzo dell' opera compiuta."*

(7) The auditorium designed by E. Souto de Moura is conceived as an iconic sculpture, imaged and inspired on the concept of a "metal machine": all infrastructures and pipelines are indeed apparent and are part of the elevations. Technological apparatus contributes to the definition of the aesthetic of the building: materials, organizationals and morphological techniques are all involved into the design.

(8) The aesthetic of the Cultural Center of Viana de Castelo is the one of the machine. Its lower level is defined by an aluminium box hosting all the main activities, while huge aluminium pipes and services clad the upper walls of the building, so as to become

essential elements of the architectural language of the building itself.

(**9**) The concept of energy performance and quantitative indicators has been defined and perfected in a series of European directives and guidelines which have been promulgated since 2002. Particularly Directive 2002/91/CE on the energy performance of buildings fixed requirements about energy performances of both new and existing buildings. It defined and adopted a calculation method for energy certifications of buildings and it obliged Member States to legislate about energy efficiency and new national energy standards. Italy implemented the European Directive through the Legislative Degree 192/2005 and the following one 311/2006

(**10**) The "passive house" is a building with very low energy requirements (<15 kWh/sqm per year) which assures thermal comfort without any "conventional" heating system, but with the sum of passive heat contributions of solar radiation and heat produced by internal appliances and occupants

(**11**) CIORRA P., *"Fuel Architecture"*, in CIORRA P.(edited by), Energy: Architettura e reti del petrolio e del post-petrolio, Roma, MAXXI, 2013

(**12**) Trulli and dammusi are both Italian vernacular architectures which reflect principles of bioclimatic: the geographical context indeed strongly influences shape and materials adopted for their realization.
Trulli are realized with extremely thick stone walls to keep the building cooler during summer: the high thermal mass indeed mitigates the high excursion of the summer temperature. On the contrary, in winter, they protect from the cold by accumulating the heat supplied by a great fireplace. Houses are circular in plan as to minimize the amount of exterior wall that can be heated up from the sun. Openings are small and often located on a single facade where also the entrance is. Usually a tank of rainwater is located under the building.
Dammusi, the typical dwellings from Pantelleria (Sicilian island) are thought in order to maximize protection from the summer heat and the winds. The roof of a dammuso is made by a barrier vault externally waterproofed, and shaped to collect rainwater to be stored in an underground cistern. There is only one door to the dwelling and no windows except 2 or 3 small openings for the sole purpose of ventilation. Walls' thickness is between 80 cm and 2 m. They are made by an outer and inner wall of large dry-set stones and the central cavity is filled with smaller stones. This type of wall is particularly indicated in order to provide a good thermal insulation (GALLO C., SALA M., SAYIGH A: M.M., Architecture - comfort and energy, Pergamon, 1988)

(**13**) CCTV office designed by OMA and the Gherkin designed by Foster and Partners in London are both realized with a glass facade and structural steel. The used technology is really similar, but geographical context is different. This is possible because of the thermal control realized by plants and devices.

(**14**) BRAHAM W., WILLIS D., Architecture and Energy: performance and style, Routledge, Oxon, 2013

(**15**) MOE K., Ibid., p. 21

(**16**) MOE K., Ibid., p. 22

(**17**) BARBER A., *"Hubbert's Peak, Eneropa, and the Visualization of Renewable Energy"*, in Places Journal, MIT, 2013

(**18**) BANHAM R., *"A clip-on architecture"* in Design Quarterly 63, Walker Art Center, Minneapolis, 1965

(**19**) COOK P. (edited by), Archigram, Studio Vista London, 1972

(**20**) MERIN G., "AD Classics: The Plug-In City / Peter Cook, Archigram" 10 Jul 2013. ArchDaily

(**21**) LANGEVIN J., *"Reyner Banham"*, in Architectural Theory Review, 16: 1, 2 — 21, Routledge, 2011

(**22**) CALVO M. W., Archigram/ Metabolism – Utopie negli anni Sessanta, Clean Edizioni, Napoli, 2007

(**23**) REALE L., Densità città residenza: tecniche di densificazione e strategie antisprawl, Gangemi Editore, 2011

(**25**) BANHAM R., Op Cit., p- 32

(**26**) RIFKIN J., The Third Industrial Revolution, Palgrave MacMillan, 2013

(**27**) For further discussion on the concept of Smart City, refer to the website of European Union, ec.europa.eu

CHAPTER 3

FROM THE TRADITIONAL ELECTRIC MARKET TO THE SMART GRID MODEL

"You never change things by fighting the existing reality. To change something, build a new model that makes the existing model obsolete"

(Buckminster Fuller)

3.1 Development of Distributed Generation

The Distributed Generation (DG) concept has started to be developed in the last years in opposition to the traditional model of centralized energy production, thanks both to the **liberalization of the energy market** and the diffusion and **utilization of renewable sources**.
Until now the electricity supply structures have mainly been set on huge centralized power stations, in order to produce electricity to be distributed throughout the grid at an high voltage and in a monodirectional way. Nevertheless the electric market is nowadays moving to a new idea of energy production and distribution set on small to medium voltage production´s plants, which are mostly located as near as possible to the final users, reducing transmission costs and energy losses along the line. These smaller plants for the energy production basically use renewable energies and they are configured as small production units distributed throughout. Renewable energies are more widespread, so that "there is the possibility of harvesting or collecting them and then using or converting them directly there in the same place, or at least in the same area, where they will be used (…). This means that for covering requirements using renewable energies, a much shorter energy supply chain is needed, if any at all"(**1**).
A unique, comprehensive and generally accepted definition of Distributed Generation has not still been provided, but it is possible to refer to different explanations given by some of the main institutional bodies related to the politics and to the energy market´s field. What appears is that current definitions are actually set on different parameters, such as the voltage´s measures, the technology used or the type of connection (**2**). We could however refer to Distributed Generation when we are considering small to medium sized plants designed to respond to the needs of local users, physically located close to the plants themselves (**3**). DG is therefore a conceptual new paradigm in which demand and supply are much more closely related than in the past. According to ENEA (the Italian National Agency for New Technologies, Energy and Sustainable Economic Development), Distributed Generation is a set of generation plants distributed in a certain territory and with a power output of less than 10 MVA (**4**).

As a consequence of this upcoming changing in the energy grid, a new political, economic and cultural freedom from fossil fuels, based on decentralization of energy sources and production, could be pursued in the future. A new vision of production and usage of renewable energies could indeed cause a more **democratic** distribution of power and would promote

new social and territorial organizations. These new social organizations based on a not more centralized production and consumption of energy would favor development of enlarged societies compared to current political communities and a broader sharing between individuals, society and territory would be produced (**5**). Renewable energies have the potential to be shared as much as information on the internet network. The same design principles, the same smart technologies that made possible the spread of Internet are used to reconfigure the global electric grids, so that individuals can produce renewable energy and share it just like now everyone can produce and share information: but this is obviously possible if an appropriate technology for the energy sharing (an appropriate energy grid) is provided.

The DG system, set on renewables and local energy control, accords to be a more energy efficient model compared to the traditional and centralized one. Its main strengths are therefore here below pointed out:

a- The advantage of using alternative sources directly from Nature, with a consequent reduction of fuels' usage.

b- The possibility to reduce losses along the distribution line since local energy production can significantly reduce waste by lessening dependence on the infrastructure of large power plants and distribution systems. Pollution related to current energy production and usage could be consequently significantly reduced (**6**).

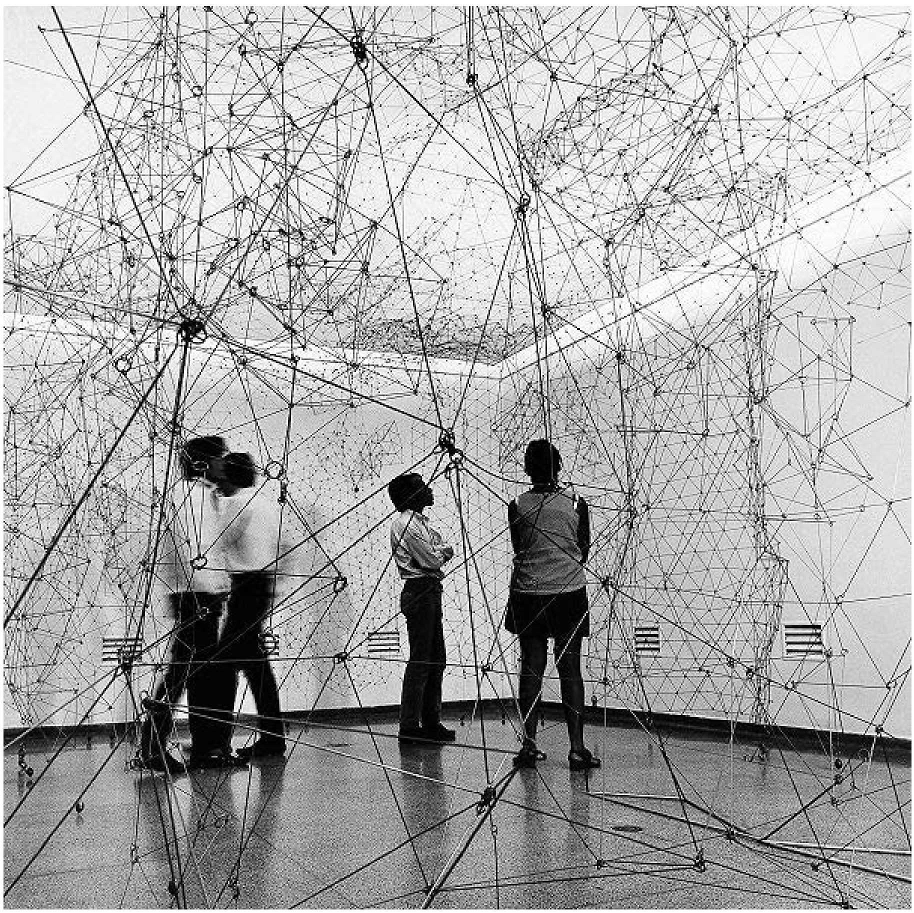
c- The possibility to involve customers in the whole process, e.g. by producing electricity for their own consumption or even by entering it directly into the electric market, in a more active and multidirectional approach, in which consumers are also producers (a new word has been introduced to describe this new type of users, the *"prosumers"*)

d- Possibility to locally store electricity, heating and cooling to eventually level out peak powers.

The traditional and centralized production and distribution system has been mainly based on a top-down approach, the DG is on the contrary a bottom-up system considering the single unit at first to "build up" the whole energy infrastructure.

3.2 The Smart Grid conceptual model

As stated in the previous paragraph, the traditional electric system based on one way flow and centralized production of energy is today in a time of transition, mainly because of the diffusion of renewable energies which introduced unpredictability into the system and also because of liberalization of the energy market.



20. GEGO, Reticulárea, 1969, Museo de Bellas Artes, Caracas

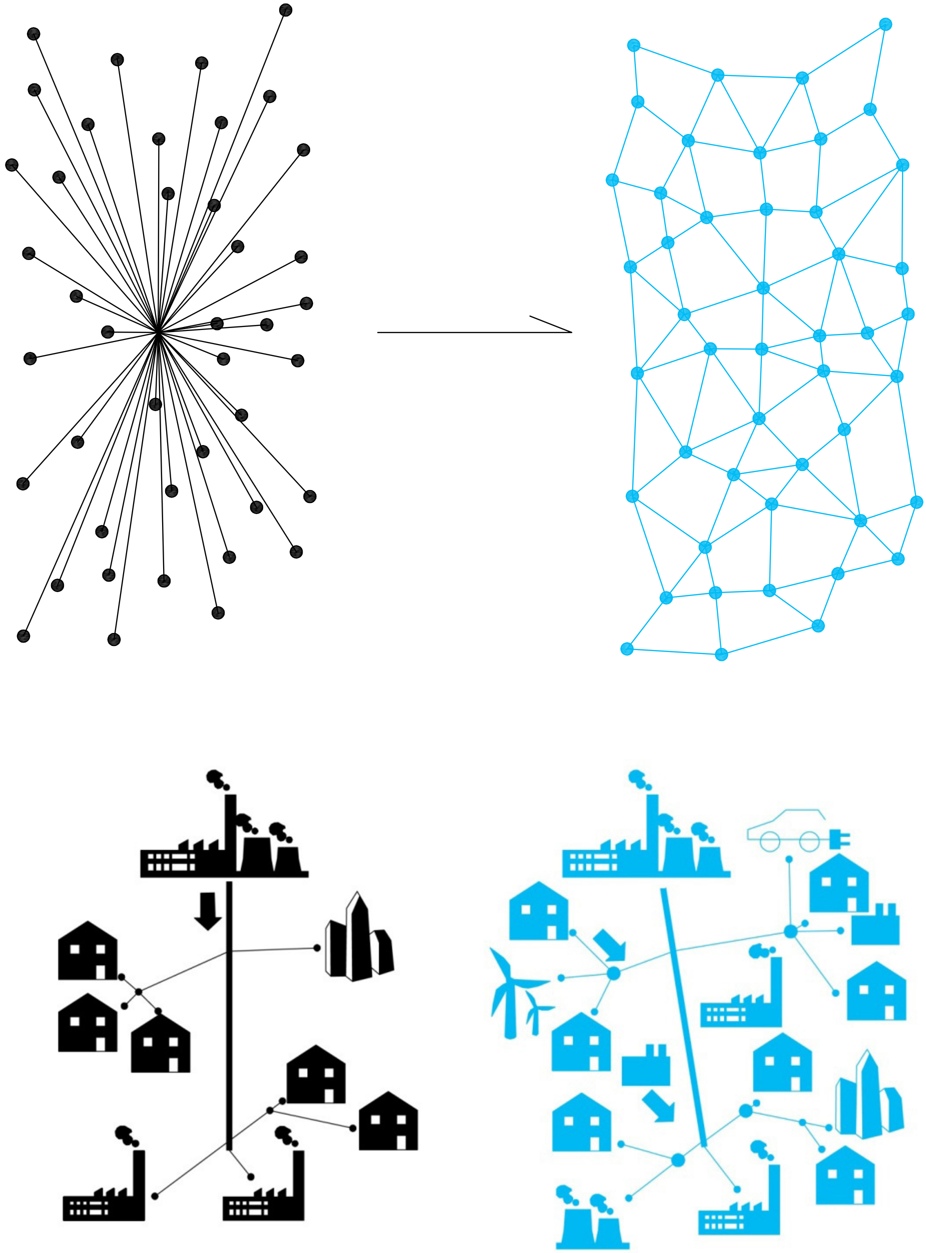
It is therefore not anymore possible to think about a mono directional energy distribution system set on a huge power plant for the production of energy: this is mainly because of environmental problems related to fossil fuels' depletion and ecological damage produced by them over time. System's configuration development is occurring towards a more flexible and efficient load management: following the liberalization of the electricity market, the Distributed Generation paradigm seems to be as the future power paradigm because of economic, environmental and social benefits. In the DG the maximization of on-site RES and the adoption of adequate technologies and practices create a stronger connection between energy demand and supply with respect to load dispatch and control strategies (7).

The transition to the Distributed Generation paradigm seems to have started but there are several barriers to be removed to develop it potentially. Firstly, the network connections should be improved to be able to computationally control bi-directional energy flows, control multiple energy entry points and optimize the load management in a context of unpredictability and strong discontinuity (due to the nature itself of renewable energy sources) (**8**). The Distributed Generation needs therefore to be supported by a new multidirectional and "active" power grid, commonly defined as "Smart Grid". The Smart Grid responds to the DG needs and it is based on the combination between centralized and distributed generation, liberalized market, use of renewable energy sources, real-time pricing due to energy fluctuations into the market and net metering, regulatory and social issues, ICT technologies for the automation and control. Particularly Smart Grids will be centered on smart meters (Advanced Metering Infrastructure), data privacy issues, policies and regulations promoting distributed generation programs. Actually the Smart Grids´ concept is beginning to be applied and a number of smart grid pilot projects is increasing rapidly.

3.2.1 Definition of Smart Grid

As in the case of DG, even the "Smart Grid" concept has been defined in many different ways from politics and energy institutions. Here the following some of the most common and used definitions are reported.

The IEC (International Electrotechnical Commission) defines the Smart Grid as *"the concept of modernizing the electric grid. The Smart Grid comprises everything related to the electric system in between any point of generation and any point of consumption. Through the addition of Smart Grid tech-*



21. Grid modernization from the centralized model to the Smart Grid´s one based on on-site energy production, flexibility and multidirectional flows (**10**)

nologies the grid becomes more flexible, interactive and is able to provide real time feedback"(**9**).The IEC´s definition mainly points the importance of having a flexible and multidirectional structure to support the unpredictability of renewable sources and energy production. This is possible thanks to the ICT technologies.
According to the European Smart Grids Technology Platform *"a Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies"*(**11**).
The ERGEG (European Regulators Group for Electricity and Gas) uses the European Smart Grids Technology Platforms definition: in the document "Position Paper on Smart Grids" they also focus on the importance of the users in to the Smart Grid´s system (**12**).
The International Energy Agency defines a Smart Grid as *"an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users. Smart grids co-ordinate the needs and capabilities of all generators, grid operators, end- users and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimizing costs and environmental impacts while maximizing system reliability, resilience and stability"* (**13**). Both the last two definitions emphasize the new condition of users connected to the Smart Grid: they are not anymore passive receivers of electricity from the grid, but on the contrary they become active and empowered actors of energy interchanges.

3.2.2 Features of the Smart Grid

Whereas the different definitions, here below the main features of a Smart Grid are summarized:
a- Combination of Technologies: A Smart Grid is the set of an informational and an electricity distribution network. Smart Grid is the tool which allows the deployment and integration of Distributed Generation into the current energy market: it is a complex model set on different types of technologies.
b- Real-time action: A Smart Grid has to be enable to locally manage any surplus energy in order to distribute it in contiguous areas in which some deficits could have been occurred. This means that a Smart Grid should provide a real-time balance of supply and demand of energy with a new and active approach.
c- Management of the energy loads: As a consequence a Smart Grid has to

manage energy loads to and from the DG system
d- Automation and control: In order to provide a real-time energy balance, the Smart Grid has to be observable and automated, based on information Technologies.
e- Active participation: The Smart Grid allows customers to actively participate in the electricity market, even by the application of opportune price fluctuations according to the grid itself needs. Central to the promise of the Smart Grid concept is indeed its "ability to match new forms of demand and supply through involving users in new initiatives in which use of electricity is made more responsive to production conditions, reducing the need to reinforce the grid to handle the moments of the day/year with highest peak demand" (**14**).
f- Integration: It has to be able to integrate its features to the centralized existing grid in order to support its operation.

3.2.3 European and National requirements related to GD and Smart Grids

As already stated, according to the Climate and Energy Package European Member States should reach by 2020 three main goals: they should reduce 20% greenhouse gas emissions from 1990 levels, they should increase 20% of EU energy consumption produced from renewable sources and finally they might improve 20% energy efficiency. These aforementioned targets don't directly refer to DG and Smart Grids, but however they encourage and promote the use of renewable sources and development of new advanced technologies for energy efficiency.
What appears is that legislations and rules about Distributed Generation and Smart Grids are still in progress since the change is occurring currently in these last years.
Directive 2009/28/CE encourages MS to apply a renewable energy policy: at point 1 is indeed stated that
"The control of European energy consumption and the increased use of energy from renewable sources, together with energy savings and increased energy efficiency, constitute important parts of the package of measures needed to reduce greenhouse gas emissions and comply with the Kyoto Protocol to the United Nations Framework Convention on Climate Change, and with further Community and international greenhouse gas emission reduction commitments beyond 2012. Those factors also have an important part to play in promoting the security of energy supply, promoting technological development and innovation and providing opportunities for employment and regional development, espe-

cially in rural and isolated areas."

Directive 2009/72/CE states common rules for the internal market in electricity related to the generation, transmission, distribution and supply of energy. At point 27of Directive 2009/72/CE is written that
"Member States should encourage the modernization of distribution networks, such as through the introduction of smart grids, which should be built in a way that encourages decentralized generation and energy efficiency"
Between 2009 and 2011 EU published three annual documents titled Mandate M490 for Smart Grids (2011), Mandate M468 for electric vehicles (2010) and Mandate M411 for smart meters (2009): they all disclose the growing interest for this new paradigm of energy production and distribution. Development of Smart Grids is then stimulated by European Union: new international research programs (**15**) have been launched and new pilot projects are monitored with great attention.

The Commission recommendation 2014/724/EU are related to the Data Protection Impact Assessment Template for Smart Grid and Smart Metering Systems. At point 1 EU commission states that
"Smart grids are an enabler for implementing key energy policies. In the 2030 policy framework context, smart grids, as the backbone of the future decarbonised power system, are recognised as a facilitator for the energy infrastructure's transformation in order to accommodate higher shares of variable renewable energy, improve energy efficiency and ensure security of supply. Smart grids provide an opportunity to boost EU technology providers' competitiveness, as well as a platform for traditional energy companies and new market entrants to develop innovative energy services and products in grid infrastructure and related information and communications technology (ICT), home automation and appliances".
Smart Grids are therefore here considered as means for economic and environmental development of European States.
In Italy a legislation specifically dedicated to DG and Smart Grids does not exist yet, even if the Autorità per l' Energia Elettrica ed il Gas is actually carrying out market analysis and studies concerning Distributed Generation. For this reason at the moment the current regulatory framework related to the traditional energy grid is applied equally to DG too (**16**).

3.3 Smart Grid and buildings: an overview

"There is a considerable difference between buildings and other objects in daily use. They already fulfill the requirements for the use of renewable energy sources. As a rule they are connected with the ground and are so near to the surface that they can benefit from the earth´s even temperature level or from geothermal heat from deeper strata. They stand in an unimpeded airflow and can take advantage of differences in pressure and wind energy. They are exposed to daylight and can therefore tap directly into the main energy source available to us – the sun. Depending on location, further renewable energy sources are available: groundwater and rivers, biomass and biogas, to name but a few." (**17**)

Buildings are the largest consumers of energy in Europe accounting for nearly 40% of energy total consumption (**18**). Because of their vital role in the world total energy consumption, efficiency in the use of energy and resources has become an essential key quality indication for a building. Buildings are obviously directly connected to the electric grid as the largest energy consumers and they are also starting to be active subjects into the electricity market, even because renewable energies are more and more integrated to them.

Energy efficiency in buildings is a complex and multidisciplinary subject since many parameters are directly or indirectly involved on it. A "sustainable" performance is indeed determined through an assessment of various environmental performance criteria and features such as urban space and infrastructure, building envelope, building services, construction and materials (**19**). Energy efficiency in buildings is nowadays a global challenge so as "the final generic goals are to allow buildings to achieve high-performance sustainability, minimize environmental impact, and create a safe, healthy, comfortable and energy-efficient place" (**20**).

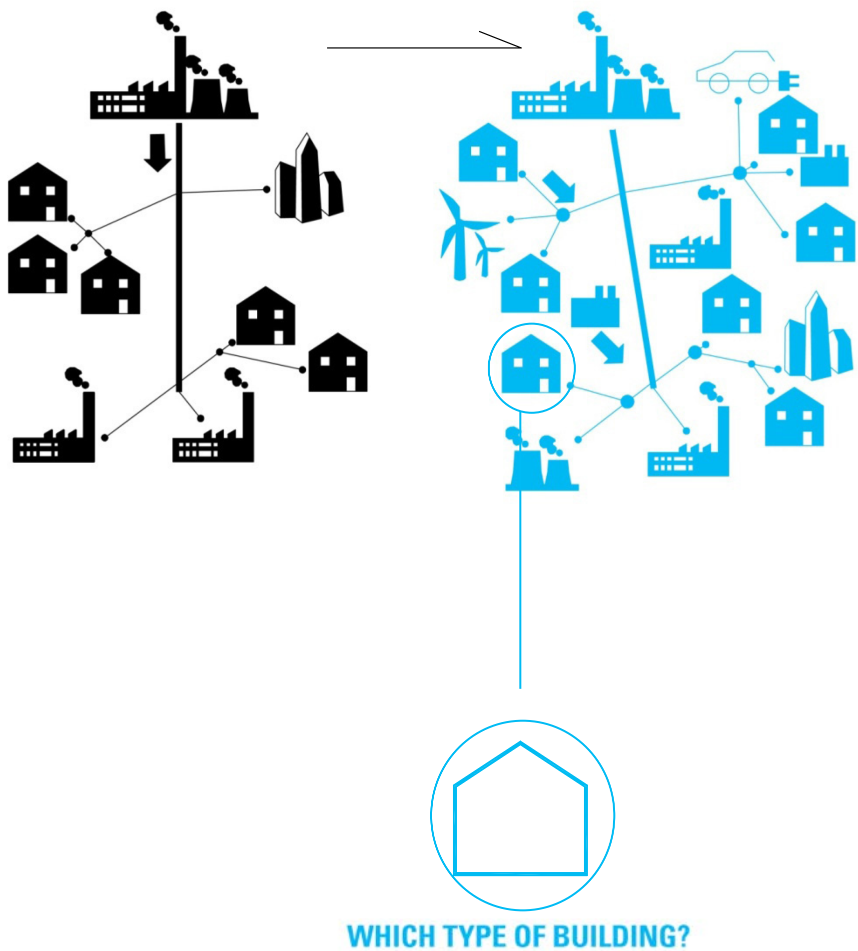
Within the complex issue of energy efficiency in buildings, the present research aims to focus on a more specific goal regarding to the relation between energy and buildings: **the spatial consequences of the new Smart Grids´ paradigm for energy production and distribution**.

The main preliminary hypothesis of this work is that buildings should not be just energy efficient units, but in the close future they will be also active leading actors in the flexible and multidirectional Smart Grid energy distribution model, so that "the issue of mismatch between instantaneous demand and supply of energy will be one of those issues that are crucial in the design"(**21**).

As stated in the previous paragraphs, a Smart Grid provides flexibility to the electric system in order to properly respond to customers´ inputs and unexpected peak energy demands. To better integrate buildings into the Smart Grid, they should be able to modulate their energy usage so as to ensure flexibility and reliability to the whole grid. **Buildings** should act at the same time **as energy producers, storages and smart users**: it means they should ask for energy when the market price is lower because of the low general demand on the grid, while they should manage to input energy into the system while it is overloaded. At times when energy is generated surplus to its occupants´ immediate demands, energy is supplied by the grid and if the dwelling is unable to generate sufficient energy for autonomous operation, energy is received back from the grid (**22**). It is therefore a further definition of the nZEBs which have been introduced by the Directive2010/31/EU (refer to paragraph 1.1.2): they will be no longer the passive terminal of an electric grid, but active actors, injecting or withdrawing energy.
Relation between buildings and the grid appears to this end as a complex problem not concerning anymore just electric and automatic engineers alone: on the contrary buildings should be designed and operated in such a way as to take into account this issue from the first steps of the architectural design. Since it is based on an active approach, "the design and operation of a ZEB is something very different from the design and operation of a Passive House, for example, where only the energy needs for heating, cooling, ventilation, domestic hot water production and lighting are considered and minimized" (**23**).

3.3.1 Net ZEB

In the Chapter 1 of this work a definition of nearly zero energy building (nZEB) has been provided. The main purpose of a nZEB is to optimize the energy performance to ideally achieve the condition of the ZEB (Zero Energy Building), characterized by total independence from fossil fuels.
The Net ZEB further completes the definition of Zero Energy Building: the term Net ZEB can indeed be used to refer to buildings that are connected to the energy infrastructure, while the term ZEB is more general.
In order to define a Net Zero Energy Building, it is important to focus on the building systems´ boundaries at which to compare energy flows in and out the system. Physical boundaries can encompass a single building or a cluster of buildings: their definition allows to determine whether renewable resources are "on-site" or "off-site". Balance boundaries determine



22. The sketch intends to underline the close and bidirectional interrelationship it has to occur between Smart Grid and buildings. Particularly buildings should be designed since the earliest steps of design as active actors interfacing to the energy grid

indeed which energy usages (e.g. heating, cooling, ventilation, hot water, lighting, appliances) are included in the balance. The physical "edge" of an energy system becomes extremely important to manage energy flows in and out. The Net ZEB should reach the condition of energy balance: only energy flows that cross the system boundary are considered for the Net ZEB balance.
Buildings analyzed in the following paragraphs of this work will be Net ZEBs, since the whole research is set to the identification of architectural guidelines for residential buildings being able to smartly interact with the electric grid.

3.3.2 Expected features for a Net ZEB
The main expected features of Net ZEB buildings interacting with the Smart Grid are here below pointed out:
a- Capability of loads' modulation
b- Flexibility
c- Independency
d- Reliability
Until now the issue of Smart Grid has mainly been studied from the installations and plants´ point of view with a special attention on ICT technologies, so as to maximize a real-time feedback on supply and demand. This is what European Commission points out defining Smart Buildings as "buildings empowered by ICT (Information and Communication Technologies) in the context of the merging ubiquitous computing and the internet of things: the generalization in instrumenting buildings with sensors, actuators, micro-chips, micro- and nano-embedded systems will allow to collect, filter and produce more and more information locally, to be further consolidated and managed globally according to business functions and services" (**24**).
While the importance of information technologies in the design of a "Smart Building" is universally recognized, building design itself and formal characters of buildings are probably still not enough included in the whole designing process from the first steps. Nevertheless there are many advantages related to a conscious architectural design: this is particularly evident from the analysis of the whole existing Italian building heritage. Nowadays one of the main and problematic issues in energy efficiency of buildings is indeed related to retrofitting: the majority of existing buildings has been built before the introduction of energy standards so that it is particularly complicated to respond to the new energy requirements and

international targets. A conscious design would avoid subsequent works of renovation which are often expensive and difficult to realize.
The issue of smart grid integration into building environment is still largely unexplored: it would be on the contrary more and more challenging and even urgent **to identify possible architectural implications on the residential design due to the new energy distribution paradigm**.

Notes - Chapter 3

(1) SCHEER H., *"Energy change"* in HEGGER, FUCHS, STARK, ZEUMER, Energy Manual – Sustainable Architecture, Birkhauser, Edition Detail, Munich, 2008, p. 15

(2) PERNECHELE M., TANSINI A., TARDIVO A., *"Il nuovo paradigma della generazione distribuita di energia: opportunità e limiti allo sviluppo delle smart grid"*, master degree thesis, Politecnico di Milano, Facoltà di Ingegneria dei Sistemi, Corso di Laurea Specialistica in Ingegneria Gestionale, Milano, a.a. 2009/2010

(3) MANFREN M., *"Sistemi ad alta efficienza per la generazione distribuita a scala urbana"*, PhD thesis, supervisor: BUTERA F., CHIESA G., CAPUTO P., Politecnico di Milano, Dipartimento BEST Scienza e Tecnologie dell' Ambiente Costruito, 2009

(4) BERTINI I., DI PIETRA B., GRADITI G., Quaderno - L' efficienza nel settore delle reti energetiche, ENEA Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile, Roma 2011

(5) MAZZARI L., Design per l' energia – strumenti e linguaggi per una produzione diffusa, Alinea Editrice, Firenze, 2011

(6) MARSDEN J. *"Distributed Generation Systems: A New Paradigm for Sustainable Energy"*, paper presented at the 2011 IEEE Green Technologies conference, April 14-15, 2011, Baton Rouge LA

(7) MANFREN, M., CAPUTO, P.,COSTA, G., *"Paradigm shift in urban energy systems through distributed generation: methods and models"*, in Applied Energy n. 88, 2001, pp. 1032- 1048

(8) www.energystrategy.it, Politecnico di Milano

(9) www.iec.ch

(10) The image of the models of centralized and distributed networks at the top of the figure is excerpted from the book: HAFNER, K., LYON, M., Where Wizards Stay Up Late – The Origins of the Internet, Simon & Shuster, 1996

(11) AA.VV., Smart Grid SRA 2035, Strategic Research Agenda, Update of the Smart Grids SRA 2007 for the needs by the year 2035, European Technology Platform Smart Grids, 2012

(12) We can read in to the document that *"many parties have published definitions; some focusing on the technologies that might be deployed in a smart grid and others on the services that a smart grid can offer to its users. ERGEG has chosen the latter approach for its definition on the basis that it represents the users of networks."*(in "Position Paper on Smart Grids", p. 19)

(13)www.iea.org

(14) POWELLS, G., BULKELEY, H., BELL, S., JUDSON, E., *"Peak electricity demand and the flexibility of everyday life"*, in GEOFORUM, Volume 55, August 2014, pp. 43 - 52

(15) Among European research programs, it should be noted the Electricity Grid European Industrial Initiative, a 9-year European research, development and demonstration program to accelerate innovation and the development of the electricity networks of the future in Europe. The Smart Grids Task Force (SGTF) was instead set up by the

European Commission (EC) at the end of 2009. The SGTF reached a consensus over the last two years on policy and regulatory directions for the deployment of Smart Grids: it has issued key recommendations for standardization, consumer data privacy and security.

(**16**) PERNECHELE M., TANSINI A., TARDIVO A., Op. Cit.

(**17**) HEGGER M., *"Preface"* in HEGGER, FUCHS, STARK, ZEUMER, Energy Manual – Sustainable Architecture, Birkhauser, Edition Detail, Munich, 2008, p. 6

(**18**) KRANZL L., ATANASIU B., BONETA M., BURGER V., KENKMANN T., MULLER A., TOLEIKYTE A., PAGLIANO L., PIETROBON M., ARMANI R., nZEB Renovation in the building stock: policies, impact and economics, paper presented at the WSED World Sustainable Energy Days 2014, Wels, Austria, 25-28 February 2014

(**19**) HEGGER, op. Cit.

(**20**) REN J., "High-Performance Building Design and Decision-Making Support for Architects in the Early Design Phases", Licentiate Thesis in Building Service and Energy Systems, KYH University, Architecture and the Built Environment, Stockholm, 2013

(**21**) BUTERA F. M., *"Zero-energy buildings: the challenges"*, in Advances in Building Energy Research n. 7, 2013, pp. 51-65

(**22**) NEWTON P. W., TUCKER S.N., Hybrid buildings: pathways for greenhouse gas mitigation in the housing sector, SWINBURNE Institute for Social Research, Swisburne University of Technology Melbourne, 2009

(**23**) BUTERA F.M., Op. Cit.

(**24**) http://ec.europa.eu/

SECTION II

EXPERIMENTAL APPROACH

CAP. 4

ARCHITECTURAL DESIGN AND ENERGY MANAGEMENT

“A space large enough to take the banquet, elephants or go karts. Ways of adapting from chamber music to ice hockey. An architecture that is made of the event, rather than the envelope. So why not forget the envelope?”

(Archigram, Peter Cook, the MonteCarlo Project)

4.1 Defining architectural strategies: an introduction

What distinguishes sustainable buildings from "normal" buildings? One could argue as follows: architecture is sustainable when it is something other than "mere" building, that is, when it has special design qualities, is technically up to date and socially compatible. Creating a technically optimal building that fails to satisfy the aesthetics, design and societal requirements is simply not enough. Architecture is always linked to the cultural identify of a society – it is, one might say, society´s mirror image. Sustainable buildings contain aspects of architecture that are closely linked to the ethics of our creative work. (**1**)

During 2010 Domusweb, in cooperation with ENEA, opened a section on its website titled "Forms of Energy". The section is being dedicated to architectures and urban developments in which design and energy blend together in a unique and related view. One of the main ideas behind the project is that it is even more necessary to provide a concrete architectural form to energy: the **possibility of integration between a formal research and energy efficiency**, architectural quality and technical research is investigated by analyzing several contemporary design projects.

NZEB, and particularly netZEB, are today a really interesting field of investigation and a new and strong link between energy and architectural form should be found to reach those ambitious goals of zero energy stated into the definition itself of nZEBs. For this reason "the challenge today is to think about buildings, and landscapes they belong to, according to new categories referring to energy issues. It is even more necessary to conceive new elements and production spaces which are no longer those we are used to from the tradition"(**2**).

Concerning the relation between form of buildings and energy, the expected target of this research is to underline some architectural design strategies at the different scales of the architectural project so as to design residential buildings being able to modulate and manage energy loads in a flexible and multidirectional way. The purpose is **to define architectural guidelines to design residential buildings as efficient actors of the Smart Grid's market**.

Because of the complexity of both the energy system and the contemporary urban condition, the involved design scales are the ones from the building to the city. The following analysis assumes that buildings interacting with the Smart Grid should meet the energy features which are listed at the end of the previous chapter (capability of loads' modulation, flexibility, independence, reliability). The work aims to identify architectural features

which respond to the above mentioned energy features, so as to define implications of the new energy system on the architectural form.
Analysis is carried on by the development of an applied case study, which is firstly analyzed in its state of art and then redesigned in order to improve its energy management during the 24 hours.

4.2 Modulation of energy loads: an hypothesis on the involved parameters

One of the assumptions underlying this work is that potentially there could be a strong correlation between architectural design and daily energy management of a building. However this relationship has not yet been formalized and it still has to be implemented in the design process, so as to exploit energy potentials that underlie the architectural composition.
The expected purposes for a building interacting with the Smart Grid are the ones identified at the end of the previous chapter (capability of loads' modulation, flexibility, independence and reliability): they are listed in Column 1 of the following table as the **main goals** to be reached or at least favored through a conscious architectural design.
Column 2 identifies those parameters which could have impacts on the energy management of the building, so as to reach the features of Column 1. They represent the **preliminary hypothesis** of this work, to be proved through the application on the case study.
Finally, Column 3 is currently unfilled: it should show the **architectural features** that buildings should have in order to reach purposes of Column 1, but it could be filled just after a literature review and the application of the assumptions of this work (Column 2) on the case study. The main goal of this Chapter is therefore to define those architectural features which are actually unfilled at Column 3 of the following table: these are the features a building should have in order to be as much as possible integrated to the Smart Grid.
Following paragraphs are dedicated to an analysis of all the parameters of Column 2: firstly a review on the knowledge of the state of art is conducted, then parameters of Column 2 are inserted one by one into the building of the case study, in order to test individually their effects on the global energy management of the building itself. Effects of the introduction of these parameters in the re-design of the building are quantitatively analyzed through a software for energy simulation.
In the next Chapter (Chapter 5) same reasoning is conducted at the scale of the urban neighborhood, in order to fix analogies and differences of

PURPOSES	HYPOTHESIS	EXPERIMENTAL DESIGN
Expected features for a NetZEB	**They could be favored by...**	**Which kind of design?**
Capability of loads' modulation	Mixed users (4.2.1) Different models of consumption (4.2.2)	?
Flexibility	Temporal flexibility (4.2.3) - *In relation to withdrawals* - *In relation to energy use*	?
Independence	Energetic self-sufficiency (4.2.4)	?
Reliability		?

23. The Table identifies main purposes to be reached by buildings interacting to the Smart Grid and hypothesis of the research work to reach these purposes. Column 3 is still unfilled, since it should summarizes architectural design features which should favor the achieving of purposes listed at Column 1. At the end of Chapter 4 the Table will be again represented with the identified results building and urban scale in relation to the energy management issue.

4.2.1. Mixed users

Building users´ behavior is a very important data to be known for the design of energy efficient buildings: "when optimizing the design of a low energy building, it is of great importance to know what amount of household electricity is likely to be used and how it varies over the year and during the day in order to understand the internal load pattern". (**3**)

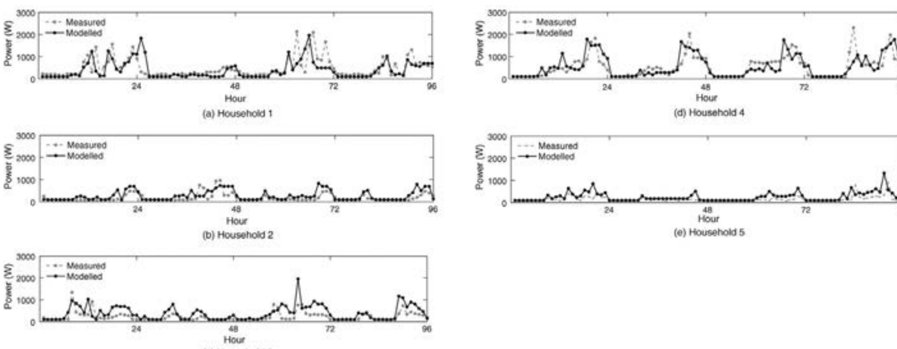
It has been proved by several studies that "societal energy consumption and related emissions are not only influenced by technical efficiency but also by **lifestyles and sociocultural factors** e.g. household size and composition or greying of society"(**4**). The pattern of electricity usage in an individual domestic dwelling is indeed highly dependent upon the activities of the occupants and their associated use of electrical appliances: that is why creating a relationship between energy use and occupant activity is particularly important in the study of the demand side management, including flexible demand (**5**).

Different users live into the building in different hours and with different habits: by the **knowledge of their usage habits** a lot of advantages could be gained relating to energy flexibility: one of the main features of the Smart Grid is indeed temporal flexibility in the loads´ flowing and **one of the main goals is uniformity of loads** that during time effect on the electric grid, which could be both reached by the coexistence of users with different social attitudes and habits. By the coexistence of different users, it is indeed easier to avoid peak demands.

Theoretically the same type of user has got about the same type of energy needs so that by the presence of different users energy request is more constant and continuous during the day.

By introducing mixité, "active occupancy" of the inhabitants tends to vary during time, reflecting the natural behavior of people going about their daily life (**6**).

The temporal relation between a worker and his/her own dwelling is really different from the temporal relation between a couple of elderly people and their own place: this has got reflections on the **load energy curve**. If we compare the load curves of the inhabitants of a hybrid building to define their average load curve, it will appear that peaks are reduced in favor of a more constant energy usage over time. For this reason "detailed load profiles for domestic energy use are important as input to simulations of small-scale energy systems such as distributed electricity"(7).

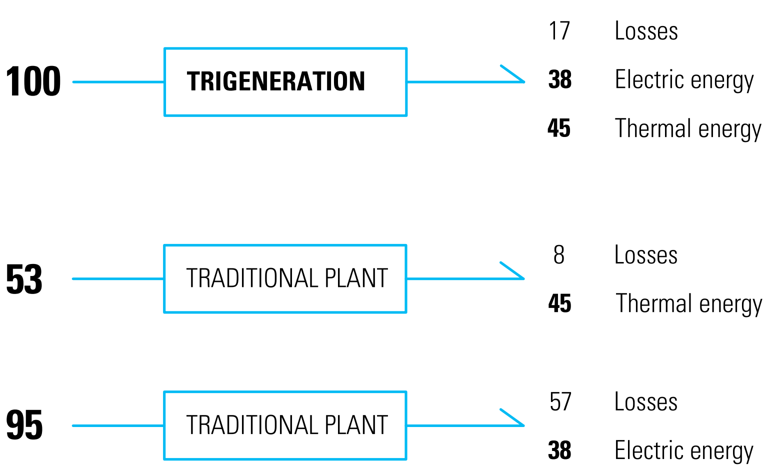


24. The study conducted by WIDEN, J., LUNDH, M., VASSILEVA, I., DAHLQUIST, E., ELLEGARD, K., WACKELGARD, E. has got the purpose to develop a model that can be used for determination of households´ energy use through collection of time-use data and for prediction of changes in future energy use through behavioral change. The households have been selected between Swedish population to cover ages between 10 and 97 years (total number of analyzed people: 431). In the picture 5 different types of households have been selected: according to activities and lifestyles the load curve is different during time for the 5 inhabitants

By the analysis of literature review, it appears that mixed users help to maintain the load energy curve **more constant over time**. This has got the direct consequence of a better energy management of flows, so as to avoid or at least to reduce unexpected peak demands of energy.
Mixed users are the typical inhabitants of a hybrid building type: multi functionality indeed favors mixité of different users. Since the building is able to reply to different needs, it can be more affordable for different types of users (single workers, families, young couples, elderly people etc…) so as even energy behaviors tend to increase than those of a traditional residential building. Collective and public activities inside the building are able to attract different types of people with different housing needs and habits. At the same time, mixed users´ presence influence architectural design: dwellings' variety in size and typology are indeed a good response to favor the coexistence of different city users.

4.2.2. Different models of consumption

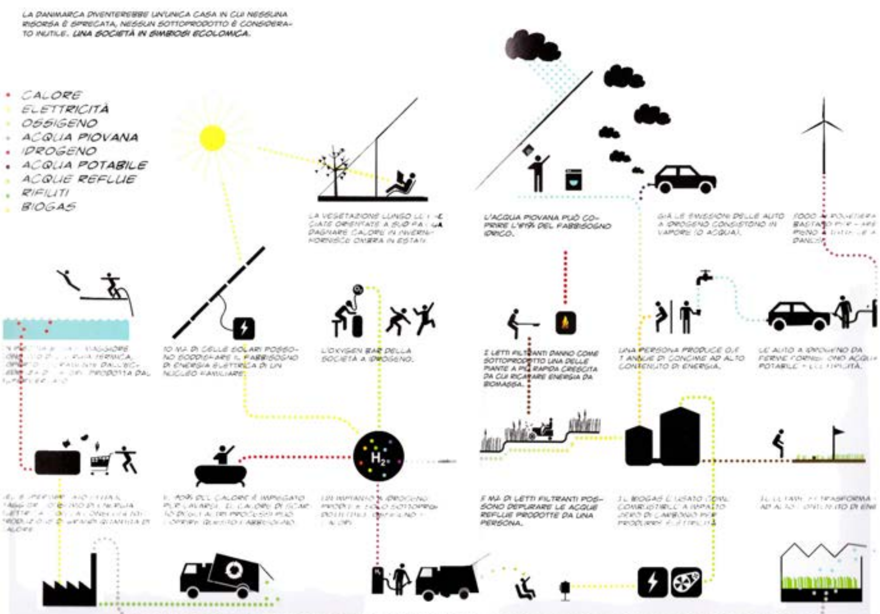
The idea that coupling of energetically complementary spaces could favor the on-site energy usage is made possible thanks to the diffusion of technologies of combined energy production such as cogeneration and trigeneration.
Cogeneration provides simultaneous production of electricity and heat from a single source (either fossil or renewable) by a single and integrated system. Resulting efficiency can be even higher than 90% and savings of primary energy can be 25-30% compared to traditional separate production. Trigeneration is instead the technology which in a single process



25. Comparison of the primary energy usage in a traditional plant and in a trigeneration one

combines the production of electrical, thermal and cooling energy starting from a single source of primary energy.
If we compare this type of energy production with a traditional one providing same amount of electricity and thermal energy, we could get:
a- Cost savings, due to the reduced consume of fuels
b- Reduction of the environmental problems, due to decrease of emissions and of residual heat
c- Decrease of losses in transmission and distribution of energy along the electricity line because of the "in loco" consumption of the produced energy.
Cogeneration and trigeneration are obviously more effective if spaces that are served by electricity, heating and cooling are close each other and close to the production plant. In this way energy dissipations along the line are avoided and compensations of different types of energy are locally managed. By mixing different functions it is possible to combine together different spaces with different consumption models, in order to achieve a certain level of complementarity between demand and supply of energy. **Complementarity** could be obtained by coupling spaces having different heat needs. For this reason a new and more flexible energy model could be based on **hybridization** of residential, public, working and commercial spaces with totally opposite needs. This complementarity of spaces would tend to reduce dependency from the grid since, as we have seen, **two spaces with different energy behaviors could partly compensate for each other energy needs through the use of appropriate technologies**.
This principle of energy compensation is slowly starting to be considered in contemporary architectures and urban complexes. It is e.g. illustrated in one of the architectural projects of the section "Forms of Energy", in Domusweb, the headquarters of Meters/ Bonwe designed by Vudafieri Severino Partners, Consalez Rossi Architetti Associati and Enrico Scaramellini (with the expert advice of Prof. A. Rogora, Politecnico di Milano). In the project it is possible to observe a "proposal for a system that balances energy use between the different functions in the urban complex (offices and services) and their schedules of operation. Even though from this standpoint the project is at the preliminary stage, it is very interesting that thought is being directed at the issue since the differences and the complementarities of the energy requirements of different functions can enable significant savings within an integrated project. For example, offices, cafeterias and restaurants work on different schedules (and therefore different heating and cooling needs) while a pool and a supermarket have needs that

could be usefully coupled by using appropriate systems solutions insofar as the first requires more heat and the second more refrigeration (for which, as we know, energy is dissipated in the form of heat). There is a shift in the logic here: from the design of local solutions to the design of an **integrated system** which produces optimal overall performance”(**8**).
The same idea is proposed by Pepe Barbieri in his essay “Figure ed energia” (**9**). Talking about the necessity of renovation for some of the buildings in Tor Bella Monaca area (Rome), the author theorizes a system of energy offsettings based on **energy combination** (between waste and resources).
Also, particularly interesting is the study conducted by BIG Architects about an ecological society in which wastes of a certain system become the gains of another one (**10**). Here again the concept of energy compensation is theorized in a diagram in which spaces which need heat are coupled with others whch need cooling (refer to image 25).
A new approach is therefore readable in the three previous examples: a **functional mix is considered as an opportunity to couple spaces which are complementary from the point of view of their energy needs** so as to produce a sort of compensation between the two adjacent spaces.
As an example of this approach, we could try to think about two “complementary” spaces coupled together. Supermarkets are between the most energy-intensive types of commercial spaces. Refrigeration is the main component of their electric usage, accounting for half or more of the store total. In order to achieve more reliability for the energy system a good design strategy could be to couple this type of space with a one producing heat, in order to get a thermodýnamic exchange. The proposal by Vudafieri Severino Partners, Consalez Rossi Architetti Associati and Enrico Scaramellini is based on this concept, e.g. by coupling supermarkets and swimming pools for thermal exchanges.
Same reasoning made at the building scale could furthermore be referred to the district level. A mix of generation systems and a mix of utilities are today more and more considered as the best configuration model for energy efficiency at the district level. Districts could indeed be designed in such a way as to favor as much as possible an energy complementarity between buildings. In this way the whole neighborhood could energetically “behave” with the same principles of a hybrid building. Energetic complementarity at the urban scale will be more deeply analyzed in the next chapter.



26. BIG Architects, Study of a society in ecological and energy harmony through the application of a model of energy compensation between spaces

4.2.3. Temporal flexibility

Temporal flexibility in the use of spaces would help to manage part of the energy flows according to the real-time needs of the energy network, so as to guarantee the highest level of flexibility in relation to the fluctuation of energy flows into the grid.

Considering electricity loads, they consist of **fixed building loads** and **controllable building loads**. The fixed household loads are the ones which the household members are not prepared to postpone (they are also defined as "critical demand"). The controllable household loads are on the contrary the ones which the household members are prepared to postpone in time (e.g. use of washing machines and dryers, charging of electric vehicles…). The main impact on the improvement of temporal flexibility in the energy usage can be obviously achieved by actions on controllable loads, postponing or anticipating the controllable loads using an energy management system in the household (**11**). Another way to act on controllable loads is to make their usage collective and centralized in the control, so as it becomes easier to shift them over time. Generally, temporal flexibility in energy management of loads requires **advanced control systems**, which would be able to favor the postponing or anticipation of energy usage during time. Support of technologies for automation and control is therefore necessary to make the building as flexible as possible.

A flexible use of energy can be related to the time period in which energy is absorbed by the network or to usage of energy during time.

Regarding to the withdrawal of energy, it can be taken from the network when the cost is lower and the grid is undercharged to use it lately in time, when the grid is already overloaded. If we consider public or commercial spaces, this shifting of the withdrawals could greatly affect the overall load. Shifting of the withdrawal is made possible by technologies for energy storage, that will be more deeply analyzed in the following paragraph. An easy example of what has been explained could be related to the cooling of a small supermarket inside a residential building. Supermarkets are among the largest users of energy, since their refrigerators need energy to work. To improve energy management, they could purchase energy when it is cheaper (e.g. night periods) to reach a lower temperature of that one required at that moment, in order to release cold during the day, when energy costs more and the request on the grid is higher.

Temporal flexibility in the energy usage could be instead partially be affected by the introduction of some collective spaces inside buildings. By

the shifting of some private spaces into collective ones, it is indeed more easily possible to control and manage their usage over time, in order to better adapt the building to the flexible and real-time electric grid needs.
Today more and more contemporary architectural research is focusing on definition of those forms of collective living responding to the big issues of land usage, traffic and pollution and radical changing in working habits. Collective spaces inside buildings are indeed considered as a good response to the big issue of land usage since, by their introduction, it is possible to gain space otherwise subtracted to agricultural land. Moreover, this type of layout based on collectivization of certain functions, has got effects on cost savings for the inhabitants, because of the consequent reduction of dwellings´ size. The shift towards collectivization of certain functions has moreover surely strong social implications because it has got a direct impact on human habits. The new type of collective services inside residential mixed use buildings can be defined as "relational services" because of the "new intensity of interpersonal relations required to enable such solutions to operate (…) Relational services are a particular kind of collaborative service in which participants need not only to be operationally active and collaborative, but also well-inclined and willing to relate with others in a personal manner"(**12**). There are many current research studies on the social consequences of this new "culture of sharing": there is indeed still in many cases "a certain level of resistance in some social groups regarding sharing, partly because it involves relationship, individualism, collective rules and mandatory interaction between individuals, as well as a weak sense of ownership"(**13**). As pointed out above, the new culture of sharing helps to save energy, favors economic savings and can be useful to create more social interaction, but at the same time it needs to be supported by policies to be more easily accepted by inhabitants: if the value of relational services is recognized (in improving sustainable lifestyles, promoting new welfare models and save and manage energy), it is necessary to create the basis for its consolidation and diffusion (**14**).
In some kind of special residences (e.g. student residences, elderly people residences, temporary housing…) the level of collectivization can be even higher then collective housing for permanent inhabitants, so as the energy shifting control during time may be even more substantial. This type of buildings lend themselves well to control of energy loads just because the greater collectivization of some functions.
The main purpose to be demonstrated by the case study proposed in this Chapter is that loads produced by collective spaces are quite consistent on

the total amount of loads affecting a building, and they could be moreover more easily shiftable during time than those of a traditional residential building, in cases of emergency of the electric grid. To do that, in paragraph 4.3.3.4 a general calculation about the percentage of energy which could be modulated by the introduction of collective spaces is calculated, throughout a series of practical examples. These values can be compared with the total amount of energy used by the R5 building, so as to understand which is the incidence of the architectural design on the total amount of energy.

4.2.4. Independence and self-sufficiency

As already stated, more and more buildings should be able to resemble energy units so as to be as independent as possible from the electric grid. Energy independence and self-sufficiency could correspond and be favored by an equivalent functional condition of self-sufficiency: as well as the building is independent from the functional point of view, at the same type this feature could reflect in an energy independence, so as the building tends to take the role of the City itself, becoming as a sort of City into the City.

The situation of energetic self-sufficiency is technically made possible by the introduction of energy storages inside the building: for this reason storages should be included in the design of buildings since the early stages of the preliminary design. Accumulation of energy consists of its storage in such a way that it can be retrieved at a later time for the use: by the introduction of energy storages, buildings could simultaneously produce, store and use energy locally, without any "support" from the grid. They would become able to interact with the Smart Grid when it would be necessary, by **withdrawing energy from the grid when the general demand is lower and entering energy into the grid when it is undercharged and the demand is higher**.

4.2.4.1 Technologies for energy storage as part of the architectural design

Besides considerations on the functional program of the building, it is also essential to reason on the role of an adequate technological and plant support to be integrated into the building since the earliest steps of the architectural design. Particularly, integration and use of storage systems would help to maximize temporal flexibility in the energy usage, so as to avoid energy overloads on the grid. Storage of energy can be considered as one

of the essential and imperative technologies of a building interacting with a Smart Grid: energy storages play indeed a vital role in the improvement of flexibility and efficiency of energy systems.
The introduction of multi-hour electricity pricing has increased enormously interest in energy storages systems. New pricing indeed economically favors offtakes from the grid at night or at other times when there is a low overall load on the distribution network. On the contrary offtakes during times of overload are penalized. In this way the system is moving towards a model based on translation of energy withdrawals from the critical period of request to the most favorable from an economic point of view. For the above mentioned reason, it becomes more and more important to develop and use technologies being able of storing the withdrawn energy for later use when demand on the network is higher and the cost increases. The energy storage becomes even more urgent with the increasing development of renewable energy sources. The production of energy from renewable sources is indeed characterized by unfavorable intermittency of supply because of changings in atmospheric conditions. Generally speaking, the energy supply cannot be constant since energy reserves depend on the season, the time of day, and climacteric conditions. Technologies for storage become critically important for any intermittent source of energy because otherwise intermittency precludes to these sources to be the only ones for the total amount of supply of the utilities (**15**). **By the use of technologies for energy storage, systems of energy production from renewable sources could instead become almost autonomous**, without the constant need of energy produced from the use of traditional fossil fuels. Finally, storage systems may also play a crucial role for the recovery of wasted energy produced by different types of processes (e.g. industrial ones), so as to store the discarded energy to use it lately in time when there is demand.
Storage systems have therefore a dual function: if we are considering conventional energies they can be helpful to compensate for temporary declines in energy production, always ensuring the expected level of demand. They also allow to minimize economic costs by withdraw of energy from the grid when it is more convenient in time according to that idea of temporal flexibility at the base of the Smart Grid concept. On the other hand, if energy is produced by renewables, energy storage systems provide added value by making the offered energy always predictable and available.
Energy storage can be thermal or electric. Energy technologies differ one from another according to the purpose they have to reach (type of stored energy, time of storage, economic availability..). Here below a quick over-

view of the main technologies for thermal and electric storage is presented.

4.2.4.2 Thermal energy storages (TES)

There are three main types of thermal energy storages:
a- Sensible TES
b- Latent TES
c- Thermochemical TES

The choice between these three types depends mainly on the period of storage required (diurnal, weekly, seasonal), the economic feasibility, the operating conditions. The choice of the used material for the energy storage also depends on several factors such as the necessary time period for the energy storage (e.g. diurnal or seasonal), the cost and availability of the material itself. In general, best materials are those characterized by a low cost and a good thermal capacity factor (**16**). Materials with a wide variation of internal energy per unit volume are usually preferred because the space required is minimized. The most commonly used material is **water** because it responds to the main basic features described above, also being capable to adapt for both sensible and latent storage systems. Water has also the advantage that it can be used in its liquid state so that produced heat can be easily transferred through pumping systems (**17**).

In thermal energy storage systems heat/cold is transferred to the accumulator during the charging period and it is released at a later time during the discharging period (**18**). The entire process is mainly based on three steps: the charging, storing and discharging. The main features which characterize a TES are:
a- The duration (the time energy can be stored without too high losses)
b- The density (the amount of stored energy per unit volume)
c- The efficiency (the ratio between the extracted energy during discharge and the stored energy during charging)

A good storage system should have a high density, long life and should minimize thermal losses. Sensible thermal storages refer to the energy systems that store thermal energy without phase change. In the sensitive storage systems thermal energy is stored by exploiting the change of temperature induced in the adopted material (among the most common: water, air, oil, rocks, bricks, sand…). The amount of stored energy in these systems is proportional to the difference of temperature between the initial phase and the final one.

Unlike sensible TES, latent ones exploit the latent heat of the material during a phase change transition, mostly isothermally (this means without significant changes of the temperature inside). The simplest latent system is the one based on the phase change of water from liquid to solid scale. Materials used for latent storages are commonly defined PCM (Phase Change Materials): they are materials in which the phase change transition takes place very slowly. PCM absorb/release heat at an almost constant temperature: they can store at a constant temperature up to 14 times more heat than a sensible TES. The phase change materials may exploit the following transformations of state: solid-solid (from a type of crystallization to another), liquid gas and solid-liquid. The high density storage of PCM (it can reach the value of 100 kW/sqm) and the almost no change in temperature makes this type of storage very interesting for the development of future technologies. The potential stored energy can be hot or cold and it can be derived from a wide variety of processes.

In Italy the main energy usages in the last decades are registered during the hot season so as summer is the most critical period for the electric system. Due to this growing tendency, storage of cold is currently a topic of great interest. Through the cold storage system a gap in time between the production of cold by refrigerating machine and its use (e.g. for air conditioning) is introduced. Particularly the decoupling of production from cold usage responds to the need for flexibility due to the multi-hour charging. This difference of temperature can be of a few hours (daily storage system) or even months (seasonal storage system)(**19**).

Storage of cooling e.g. could be realized by exploiting sensible heat of cooling at the liquid state (sensible TES) or its latent heat in the state transition from solid to liquid state (latent TES). Storage capacity required for the two systems is very different. Storage by water is indeed usually characterized by a difference in work temperature of 10 degrees: for each cubic meter of water is indeed possible to store a maximum of 41860 kJ (to be reduced about 25% because of the difference in internal temperature). It can therefore be considered a final accumulation of 30 000 kJ/m^3. In ice storage systems, since the latent heat of solidification is equal to 333 kJ/kg, it is necessary to add this value to the previous sensible heat of accumulation. Therefore the theoretical capacity in this second situation is about 340 000 kJ/m^3 that, whereas a loss of 25%, is reduced to about 250 000 kJ/m^3, a 8 times higher level than that one obtained by simple accumulation of water.

4.2.4.3 Electrical storages

Storage of electricity is quite difficult since the electricity is not easily storable except in small quantities. However electricity is the most noble form of energy so that electrical storages are one of the most studied technologies to be improved in the next future. The main system for electrical energy storage is the battery, an electrochemical storage device.

One of the most promising and studied technologies of electric battery is the one associated to vehicles. Currently electric vehicles (EV) work with batteries with a capacity ranging from 8 kWh to 200 kWh: this kind of powers would be able to supply more than two apartments for several days. A vehicle is on average parked for more than 80% of its time and its displacements are mostly reduced to the way and way-back from home to work. For this reasons electric cars could be considered not just as transports, but even as active elements being able to play an essential role in the management of power and electricity. An EV, once connected to the electric grid, could become an active element of the system, providing power during times of peak demands (draining the battery) and absorbing the surplus energy produced during times with lower demand (charging the battery) (**20**). This is surely possible just by the introduction of Smart Grids and the use of "smart" charging stations in order to real-time monitor the needs of the electric grid and consequently manage the whole process of charge/discharge of the battery. It appears that the new distribution paradigm involves architectural design, but even infrastructures and transportation systems, changing the urban structure of contemporary cities.

The new role of EV in the complex system of Smart Grids will have direct consequences in the whole process of architectural design of buildings: e.g. a new focus to the inclusion of spaces for recharging and parking of cars (such as underground car parking) will become increasingly necessary.

4.3 Case study. R5 building in Tor Bella Monaca

The main purpose of this work is to underline which are potentialities of architectural design for a better energy management of the building in relation to the Smart Grid. In order to verify the hypothesis discussed in paragraph 4.2, a case study is here below developed. An existing building is indeed analyzed in its current configuration and in a new design operated on the building itself. In this way a comparative and quantitative analysis between two different situations (the present situation of R5 building in Rome and a new design for the building itself) is carried on. Particularly, the assumed parameters of paragraph 4.2 are one by one introduced in the

new design of the building, so as to verify their relation with architectural design features and their effects on the global energy management of the building, compared to the present existing building.
In paragraph 4.3.2 a description and analysis on the current situation of the building is conducted, by an inspection of the area, the reference to the existing literature about the neighborhood and an energy simulation.
In paragraph 4.3.3 the building is then re-designed: one at a time the identified parameters are inserted into the new design and their effects are qualitatively and quantitatively analyzed. A new energy simulation is indeed conducted on the new building.
The main purpose of this section is to highlight any differences in energy management during the 24 hours of two typical days (winter and summer conditions) of the state of art and re-designed building, so as to test any different behavior of buildings with different layouts.

4.3.1 Building simulation as a quantitative tool of evaluation

Energy consumption modeling of buildings seeks to quantify energy requirements as a function of input parameters (**21**). Techniques which are used to model residential energy consumption can be grouped into two categories, *"top-down"* and *"bottom-up"*. The terminology relates to the hierarchical position of data inputs as compared to the housing sector as a whole. *Top-dow*n models utilize the estimate of total residential sector energy consumption and other pertinent variables to attribute the energy consumption to characteristics of the entire housing sector. In contrast, *bottom-up* models calculate the energy consumption of individual or groups of houses and then extrapolate these results to represent the region and nation (**22**). In the following study the used energy consumption modeling is a bottom-up one, set on a software for building simulation.
Building simulation is a powerful tool to study energy performance and thermal comfort during the building's life-cycle. Softwares for energy simulations are based on mathematical and thermodynamic algorithms that are used to calculate the energy performance. Extremely relevant for the practical use of those tools is the graphical user interface, which is often set on CAD applications (**23**). Today more than 400 hundred building software tools for evaluating energy efficiency, renewable energies and sustainability in buildings are listed into the Building Energy Software Tools Directory by the US Department of Energy.
The one selected for the following simulation is Design Builder: it is a user interface of the Energy Plus dynamic thermal simulation engine. En-

ergy Plus is the official building simulation program of the United States Department of Energy, promoted through the Building and Technology Program of the Energy Efficiency and Renewable Energy Office.
Through the “Simulation” tool of Design Builder an analysis in dynamic mode can be conducted (**24**): in this way it is possible to observe the growth, inside more or less extensive intervals, of all the thermal variables which affect the energy behavior of the building.
A model can be defined as a reproduction of reality: a system is extrapolated from the real contest to be inserted in a simulated one. The purpose is to recreate same characters and factors, even if obviously characterized by a certain level of approximation. Through an energy audit the building is reproduced by considering several factors such as architectural design, urban location, orientation, building’s envelope and plants (**25**). Simulation results are as accurate as the provided input data for the simulation itself (e.g. climatic data, building geometry, plants and devices, building envelope…). It is however “crucial to understand that there are differences between a building model that was created by an architect and a building model needed for energy simulation. The latter (…) is basically a simplified view of the architectural building. One of the difference is that architectural spaces can tipically be aggregated into thermal spaces (…). This conjunction or division of architectural spaces is based on the thermal perspective where spaces with the same or very similar thermal characteristics and control patterns are combined into one” (**26**).
For the energy use the model takes into account:
- Thermal contributions due to solar radiation on glass and opaque surfaces, presence of people and artificial lighting.
- Heat dispersion through the envelope and ventilation of the rooms
- Heating or cooling power supplied by the plants
- Plants’ efficiency

Since building simulation is a quantitative tool to test energy efficiency, it can´t obviously be considered as an instrument of design, but it is here used as a tool, so as to check the real incidence of the architectural design on energy usage and management.

4.3.2 The R5 building in Tor Bella Monaca: the current situation

The following building simulation is based on an existing building, named R5 and located in Tor Bella Monaca neighborhood in Rome.
Tor Bella Monaca is a suburb in the south-east edge of Rome: it was realized between 1981 and 1983 as a council housing district. It is constituted

of different building typologies and it currently hosts almost 28000 inhabitants. Regarding to the climatic data of the area, degree days are 1415 and the climatic zone is the D one. Total amount of heating days is fixed to 166. General climate data are immediately recognized by the software used for the simulation, while monthly average temperature have been changed according to the ones indicated in UNI 10349.

Tor Bella Monaca neighborhood has been recently the focus of a research program between several Italian universities (**27**): the main purpose of this research was to define urban and architectural strategies to improve the neighborhood, which is actually problematic to manage because of architectural and social problems. Most of the buildings show indeed a high level of deterioration of materials and poor maintenance.

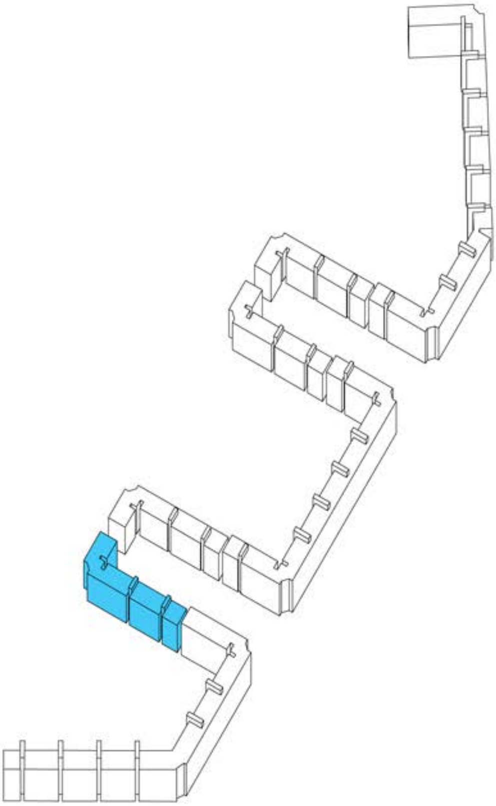
4.3.2.1 R5 features

R5 is located at the north- east edge of Tor Bella Monaca, one side facing on Agro Romano (Roman countryside) and the other one facing on the city. It is actually one of the most problematic buildings of the suburb, both from the social and architectural point of view. It has been realized between 1981 and 1983 and the Project Director was Arch. P. Barucci: he was head of a team composed both of architects and engineers (**28**).

It is a long linear building constituted of a series of courtyards, alternatively facing on east and west: its linear length is 1100 meters. It is a 7/8 story building with an underground level and it is 24,50 meters high (in the 8 story blocks). It is constituted of 1264 apartments: the typical floor hosts 3 main dwelling types plus corner apartments (three more typologies) with a total floor area included between 45 and 70 sqm per unit. The main structure is made of concrete tunnels: the distance between structural walls is 5,70 meters and the building's depth is 12,55 meters (**29**).

The façade is made of sandwich concrete prefabricated panels. Regarding to the insulation it has been considered that the building has been built after the Law n. 373/1976 (**30**) which introduced thermal insulation into the buildings. For this reason it is hypothesized a sandwich package with a 5 cm layer of insulation inside.

R5 building has been chosen for the current research because of its features. It is indeed a residential building hosting almost 3900 inhabitants: this means that energy usage is rather significant even at the district scale. Moreover it actually presents a mono functional layout without any other public, collective or private activity hosted inside and based on just six types of dwelling units, all with a medium size between 45 and 70 sqm.



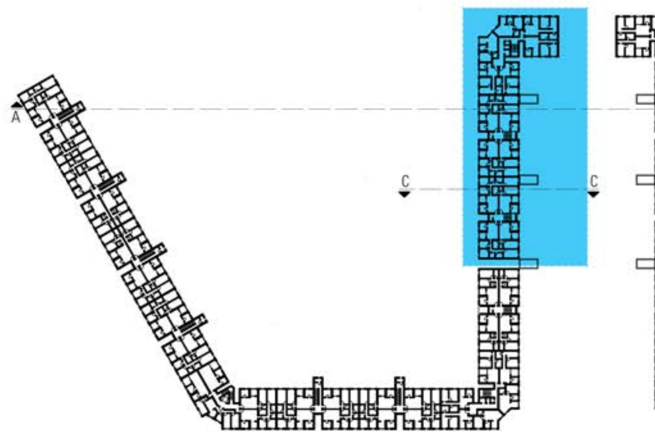
Year: 1981-1983

Coordination:	arch. P. Barucci arch. M. Casanova arch. E. Piroddi arch. D. Ianni arch. A. Bentivegna arch. M. Cascarano ing. F. Romanelli ing. F. Santolini
Number of dwellings:	1264
Number of inhabitants:	3929
Dwellings per floor:	158

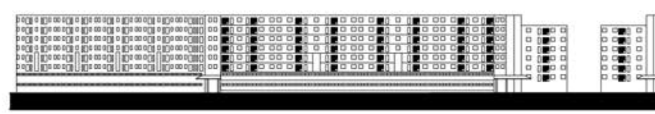
27. DRAWING 1
R5 building in Tor Bella Monaca. The research work fo cus on Block 2 of the R5 building, which is represente in Drawing 1

R5 BUILDING, TOR BELLA MONACA

Section AA

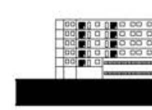


Plan of a typical floor



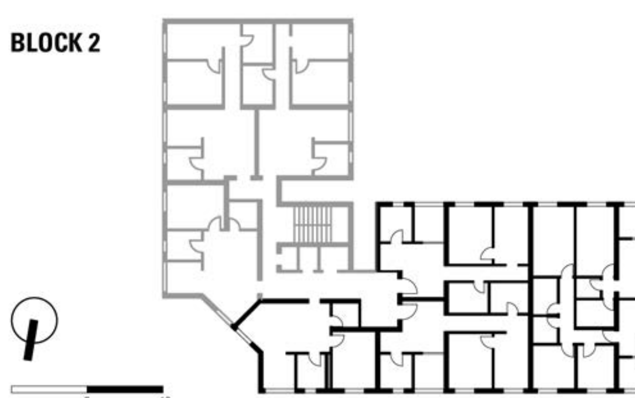
West facade

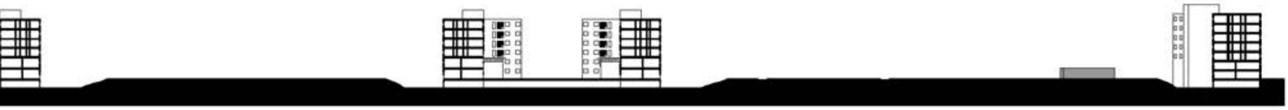
Section CC

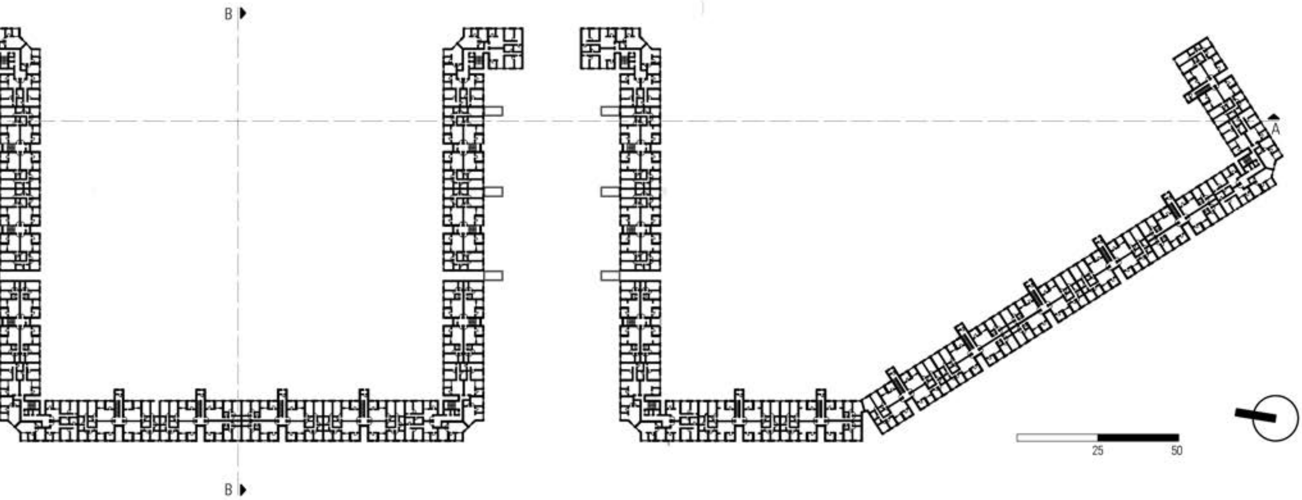


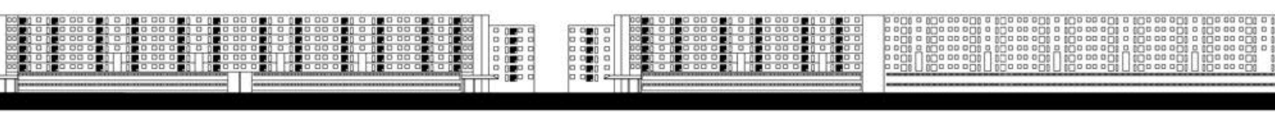
Section BB

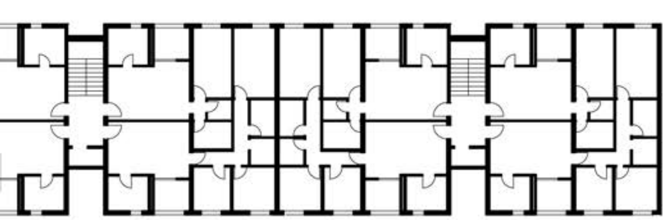
BLOCK 2

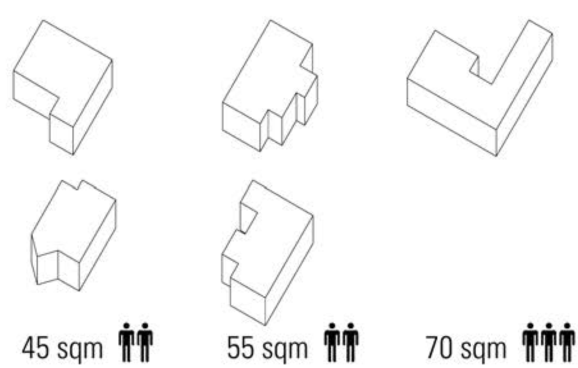





B
A
25
50
B






45 sqm
55 sqm
70 sqm

For this reason it could be easily made a comparison between the existing situation (prototype of a mono functional layout) and a new architectural design based on a more flexible and hybrid layout.

General data

Year of construction	1981-1983
Number of floors	7
Residential Gross Floor Area (m^2)	6036
Parking Gros Floor Area (m^2)	1006
Net area per floor (m^2)	830
Net residential area (m^2)	4980
Function	Dwellings + underground parking
Percentage of transparency (walls)	23%
Percentage of transparency (loggias)	77%

Envelope and structure

Structure	Tunnel structure
Envelope	Sandwich panel
Sandwich panel	Concrete reinforced cm 8 Insulation (foam slag) cm 3 Concrete reinforced cm 8 Plaster (dense) cm 1.5
Transmittance of the sandwich panel (W/mq x K)	2.6
Glass (windows)	Sgl Clr 3 mm
Transmittance of the glass (W/mq x K)	5.9

Heating and cooling

Heating set point temperature	20
Cooling set point temperature	24
Heated - Fuel	Natural Gas
Cooled - Fuel	Electricity from Grid
Ventilation	Natural

28. One of the north façades of the R5 building, facing to the east courtyard

29. The prefabricated façade of the R5 building, made of sandwich concrete panels

4.3.2.2 Energy simulation of the state of art

Energy simulation has been conducted by inserting assumed usage profiles for the building. Usage profiles are hypothesized in relation to dwellings' size and data related to categories of users living into the building.

The simulated data are the ones both related to the yearly consumption of the building and the hourly consumption during a typical winter day and a typical summer day. Because of the complexity of building simulation, the case studio is applied on one of the five blocks which compose the whole building, Block 2 (which is coloured in Figure 27). The Block has been chosen since it is one of the most problematic because of its orientation: it indeed hosts some apartments just facing to the north and some others just facing to the south.

In the table here below, data related to building usage and the results of building simulation are listed (refer to Image 30 for the graphs).

Usage profiles	
Occupancy profile	7:30-9:00 100%
	17:00-19:00 70%
	19:00-23:00 100%
ACS usage profile	7:30-9:30
	19:30-22:30
Heating usage profile	Jan-Apr and Nov-Dec
	6:00-13.00
	16:00-23:00
Cooling usage profile	Jun- Aug 8:00-20:00
	May- Sep 10:00-16.00

Simulation results	
Global heating (kWh)	521 223
Heating per heated building area (kWh/sqm)	105
Global cooling (kWh)	179 578
Cooling per cooled building area (kWh/sqm)	36
ACS/ electricity (kWh)	152 302
ACS per building area (kWh/sqm)	31
Lighting (kWh)	130 836
Lighting per building area (kWh/sqm)	26
Computer and devices (kWh)	108 946
Computer and devices per building area (kWh/sqm)	22

4.3.3 The R5 building in Tor Bella Monaca: a new design

The R5 building is re-designed with a new functional hybrid layout. Levels of functional complexity are gradually added to the existing layout, currently based on the repetition of three dwelling typologies of medium size (their surface is respectively 45, 60 and 70 sqm), so as to test one by one the effects on the energy management of the building.

Here below the main steps of the study are pointed out:

a- In paragraph 4.3.3.2 a diversification of dwelling types will be proposed, so as to favor the settlement of mixed inhabitants with different housing needs and habits. However, the building presents at this step still a mono functional residential layout.

b- Subsequently the functional program of the building is partially changed, with new levels of complexity. The first two floors of the building are indeed redesigned to host public and collective functions: the effects of this new functional layout are analyzed in paragraphs 4.3.3.3 and 4.3.3.4.

c- Finally, energy storage systems are integrated within the building (paragraph 4.3.3.5): they are dimensioned in order to provide a general idea of their impact on the overall dimensions of the building.

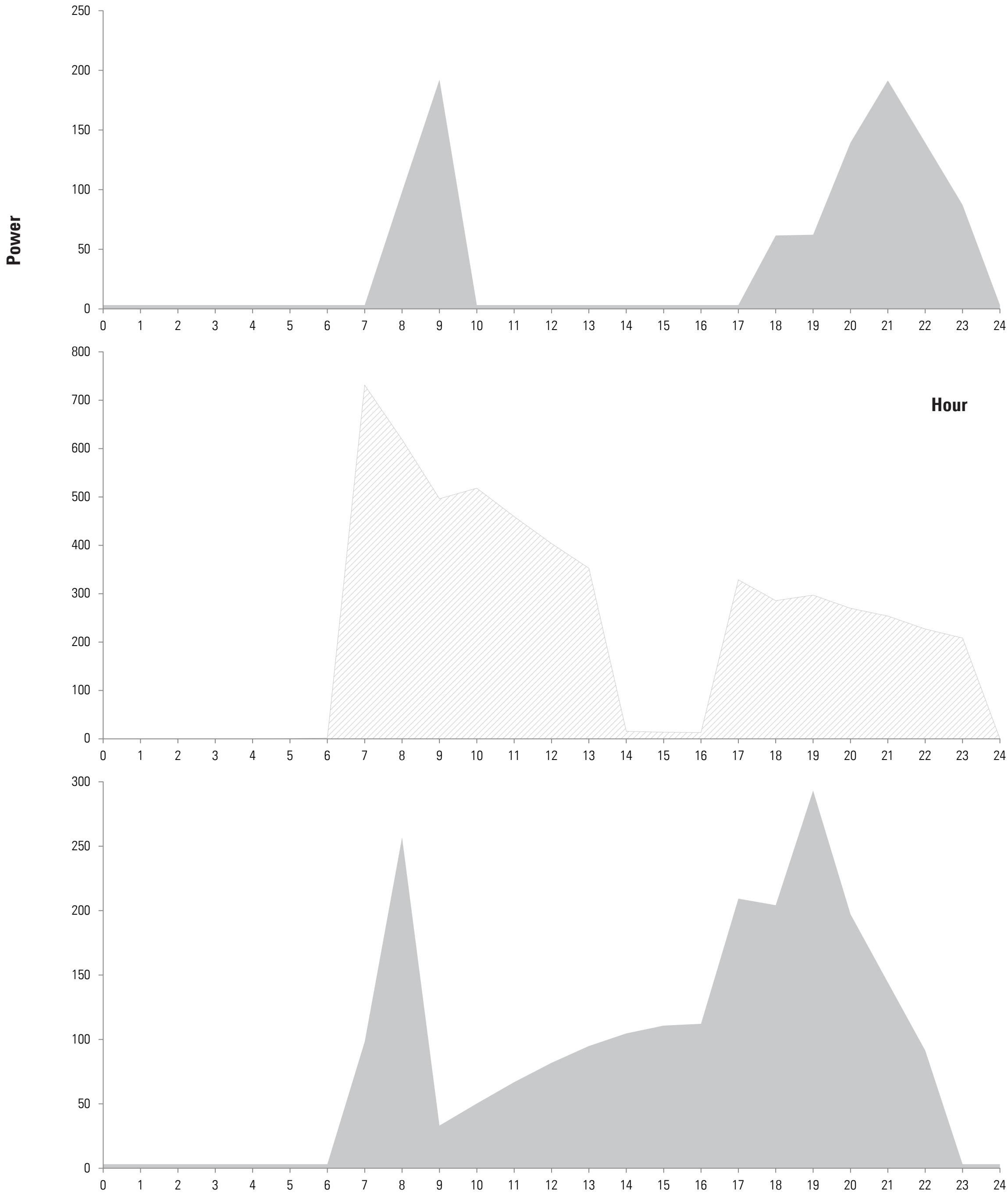
4.3.3.1 Parameters

In order to better understand and read results that will be obtained from the energy simulation, it is essential to fix those parameters of the building that are made vary in the R5 new design, and those which remain fixed respect to the starting condition (state of art). In this way parameters which are modifying the energy flows in the design during the 24 hours are immediately recognizable.

Climatic data are the same in the two phases of the study, since the building is the same in the two steps of the study, even if with a different functional layout. Moreover, the following design doesn't involve building envelope, which is therefore considered as a fixed parameter in the two layouts (state of art and design). Plants and devices are the same in the first phases of the simulation (referring to paragraphs 6.3.2), while a trigeneration plant is inserted in the second stages of the study (referring to paragraph 6.3.3).

Conversely, the building program and the organization of dwellings inside the residential building are considered as variable parameters.

From a point of view of energy simulation the building is divided into "thermal zones" which correspond to spatial elements with the same type of energy behavior (**31**).



30. Used power for gas and electricity consumption in the R5 building / state of art

a. Electricity / 1st January
b. Gas / 1st January
c. Electricity / 15th July

4.3.3.2 Mixed users

First variation to be introduced is related to dwellings' design. The statement to be proved and discussed is that presence of mixed users helps to minimize peak loads during the day: in this way the grid would not be overloaded and demand of energy would be more distributed throughout the day.

A conscious design could favor mixité by the introduction of different dwelling sizes. By differentiation of housing types both a differentiation of the general energy needs and business hours is introduced. What is interesting to check is a possible reduction of the peak load on the network: in this way the building does not burden on the network with concentrated electrical requests which would be difficult to sustain.

The building has been then re-designed with a more various layout. The layout has already been defined by the authoress of this work into the master degree: *"Abitare il margine urbano: progetto di rigenerazione architettonica a Tor Bella Monaca"*. Apartments have been re-designed in order to:

a- Improve mixite by the introduction of more dwelling typologies

b- Avoid apartments which are just north-facing. In order to improve shores at the north side, some small projecting volumes have been designed, so as to open small windows even at east and west. However, in order to not affect energy usage with the variation of percentage in the surface of openings, total percentage of surfaces is left the same of the present R5 building.

Particularly, the new dwelling types to be designed are here below pointed out:

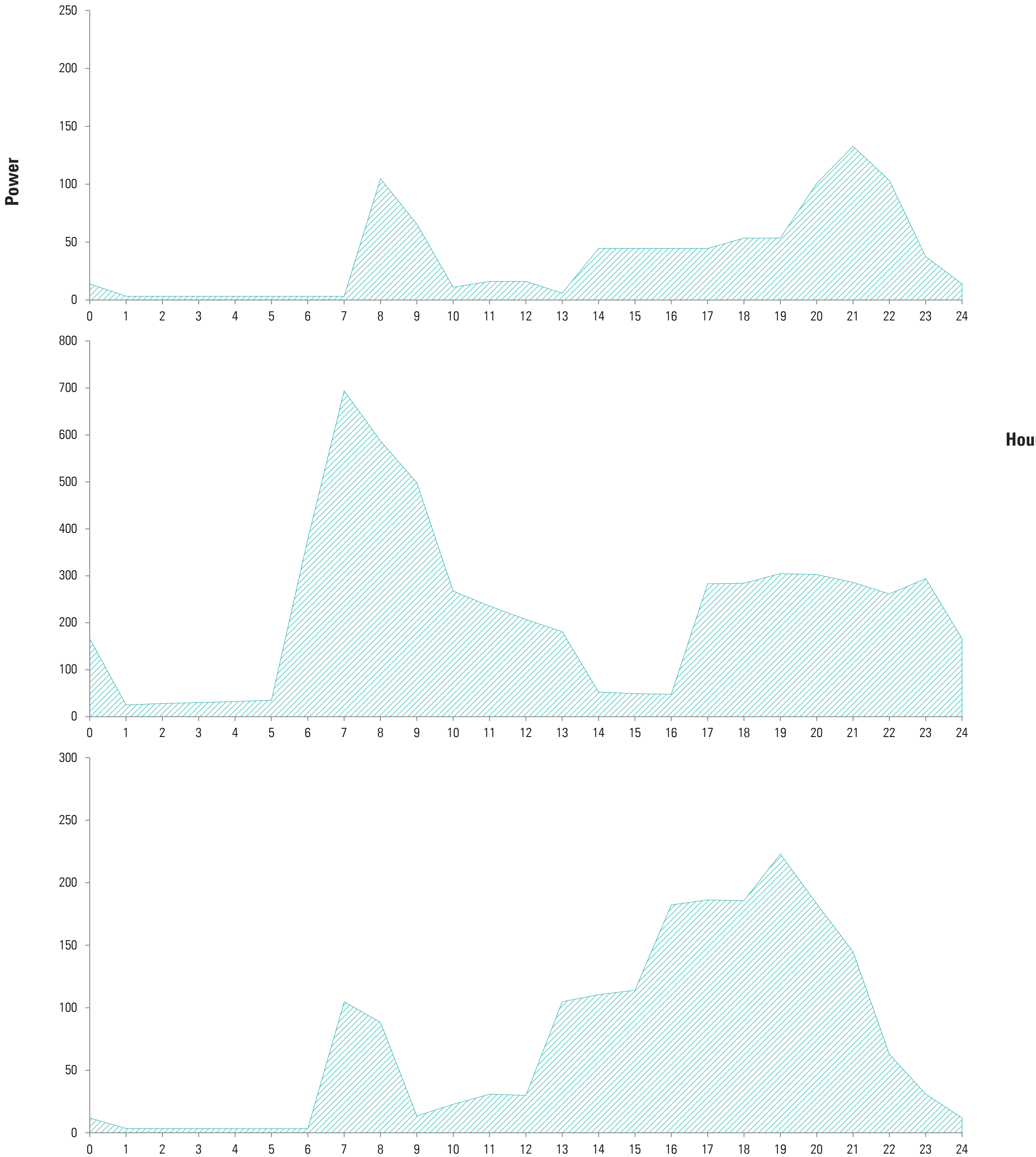
- 35 sqm apartments- one single person (9) – 18%
- 55 sqm apartments- elderly coupe (12) – 23%
- 65 sqm apartments- workers/small family (9) – 18%
- 75 sqm apartments- workers/small family (3) – 6%
- 90 sqm apartments- family (15) – 29%
- 100 sqm apartments- family (3) – 6%

For each type of inhabitant a corresponding profile of usage has been defined according to its hypothesized needs and a building simulation has then been conducted. Usage data are hypothesized according to the hypothetical inhabitants of the designed dwelling typologies: an existing research study on housing usage profiles in relation to the "social" type of user in the Italian context has not indeed be found, so that inhabitants behavior has been hypothesized referring to their hypothetical family liv-

ing into the dwelling typology. Used profiles are reported at page 124.
Here below the results about fuel totals consumption in the state of art and in the design solution have been reported together in order to be compared, both in a typical winter day (1st January) and in a summer one (15th July). Gas amount is the one which is used for heating, while electricity consumptions includes general lighting, computer and equipment, cooling systems and water heating.
The obtained results are particularly interesting: while in the new designed solution there is not a considerable reduction of the total gas and electricity consumptions during the 24 hours, there is instead a better management of energy loads over the 24 hours. By keeping the overall number of operating hours more or less constant in the winter and summer profiles the absolute value of consumption can't indeed obviously break down, but energy request to the grid is more distributed over time because of the presence of mixed users with different habits and needs. It follows that the standard deviation (**32**) of the function in the design case, compared to the situation of the state of art, is reduced. Standard deviations for the three reported case studies (gas consumption at 1st January and electricity consumption at 1st January and 15th July) have been calculated and reported at Image 32.
As stated in the Chapter III, one of the main features of the Smart Grid is the capability to manage energy flows, so as to maximize global efficiency of the network and minimize energy peak loads on the grid. In paragraph 3.3.2 the expected features of a Net ZEB had been pointed out. By the introduction of mixed dwellings inside the building we can state that capability of loads modulation during the 24 hours has been increased. Also, reliability of the building-system in its relation with the electric grid is higher because peak loads and requests to the grid are consistently reduced.

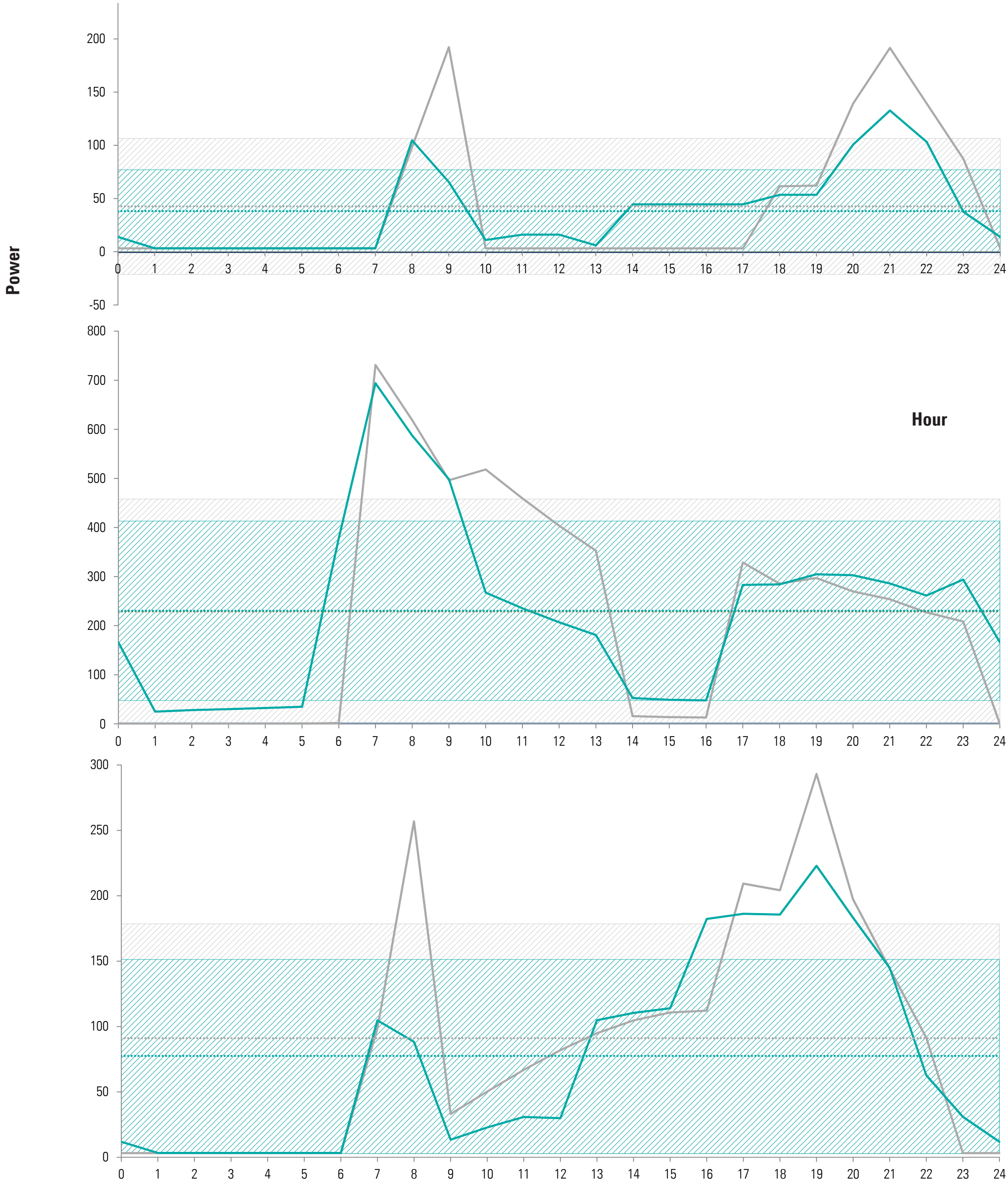
	Usage Profile
Type a. 35 mq	
Occupancy	19:30- 23:00
ACS	7:00-8:00 & 19:30-21:30
Heating	Nov-Apr 5:00-9:00 & 16:00-24:00
Cooling	May-Sept 16:00-24:00
Type b. 55 mq	
Occupancy	9:00-22:00
ACS	9:30-12:00 &19:00-20:30
Heating	Nov-Apr 6:00-23:00
Cooling	May and Sept 10:00-16:00 Jun-Aug 8:00-20:00
Type c. 65 mq	
Occupancy	7:30-9:00 17:00-23:00 (70%)
ACS	7:00-8:00 & 19:30-21:30
Heating	Nov-Apr 5:00-9:00 & 16:00-24:00
Cooling	May-Sept 16:00-24:00
Type d. 75 mq	
Occupancy	7:30-9:00 13:00-22:00 (50%)
ACS	7:00-8:00 & 19:30-21:30
Heating	Nov-Apr 5:00-9:00 & 16:00-24:00
Cooling	May-Sept 16:00-24:00
Type e. and f. 90 mq	
Occupancy	7:30-9:00 13:00-22:00 (70%)
ACS	7:00-8:00 19:30-23:30
Heating	Nov-Apr 6:00-13:00 & 16:00-23:00
Cooling	May and Sept 12:00-18:00 Jun-Aug 8:00-20:00

	Usage Profile
Type g. 100 mq	
Occupancy	7:30-9:00 13:00-22:00 (70%)
ACS	7:00-8:00 19:30-23:30
Heating	Nov-Apr 6:00-13:00 & 16:00-23:00
Cooling	May and Sept 12:00-18:00 Jun-Aug 8:00-20:00



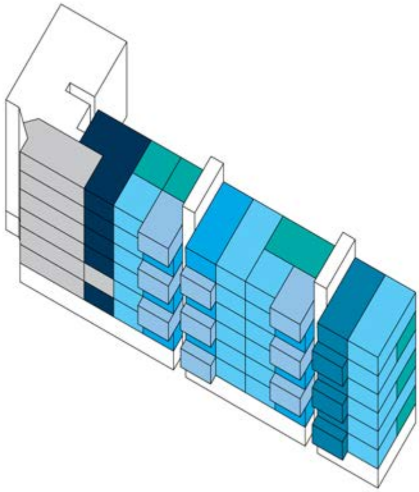
31. Used power for gas and electricity consumption in the R5 building / new design

a. Electricity / 1st January
b. Gas / 1st January
c. Electricity / 15th July

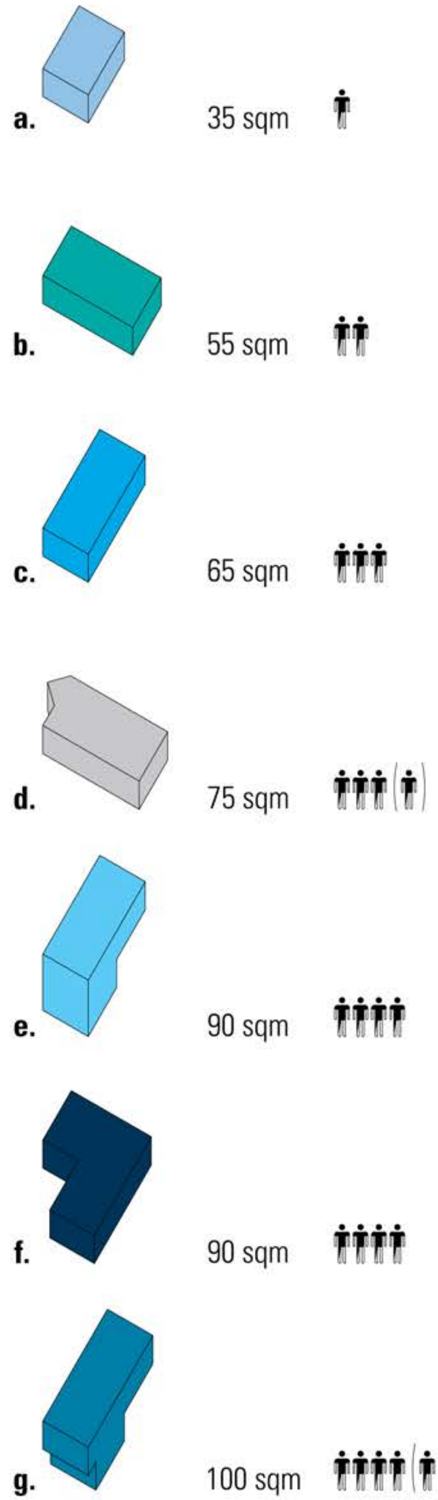


32. Curves of the daily consumption of gas and electricity of the state of art and new design.
Standard deviation of the two curves is compared in the 3 cases: what emerge is that standard deviation of the new design is always smaller. It means that peak loads are overall reduced

a. Electricity / 1st January
b. Gas / 1st January
c. Electricity / 15th July

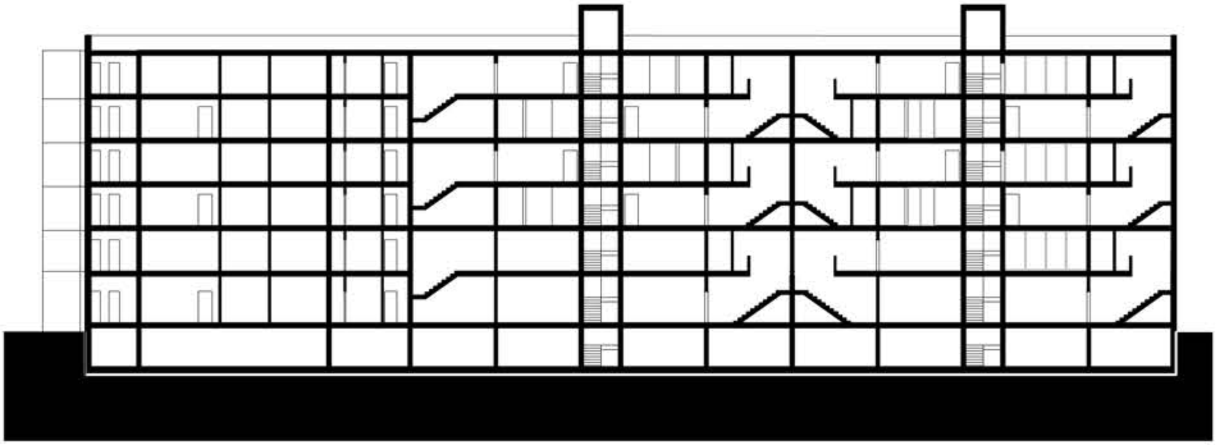


Number of apartments per typology

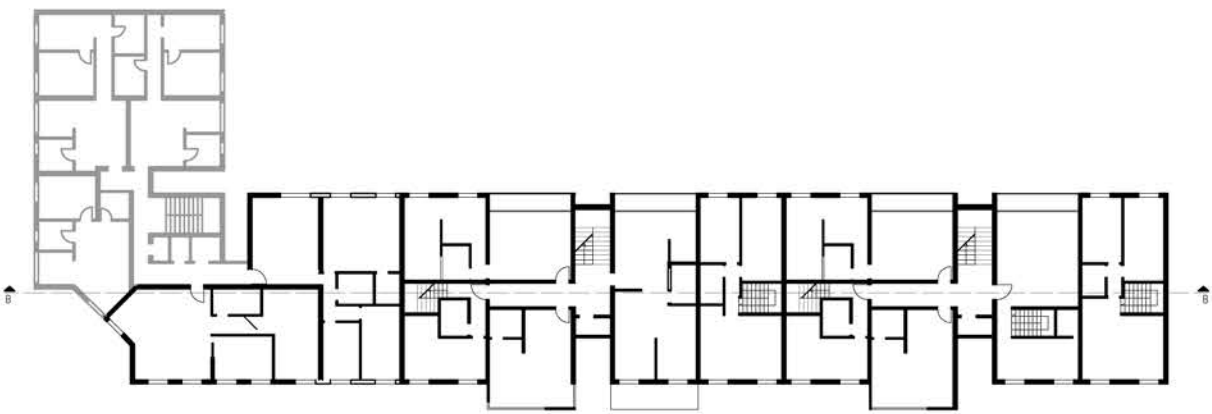


33. DRAWING 2

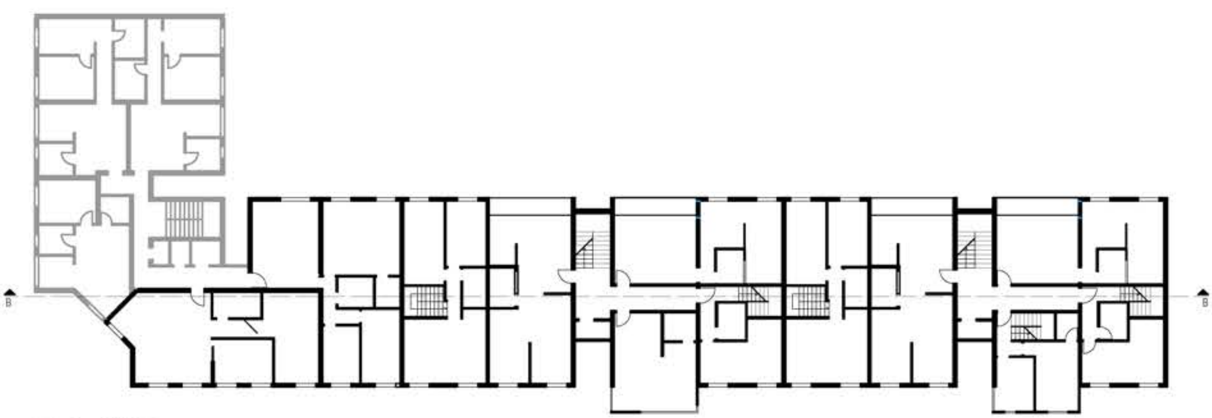
Plans and section of the new dwelling typologies. Bot to get also one-room apartments and to increase geo graphical orientations and number of views some pro jections are designed on the north facadeof the builc ing. By the new design 7 dwelling tpologies are inserte into the building, so as to improve mixité and user behaviors inside the building



Section BB



Second, fourth and six floors



Third and fifth floors

4.3.3.3 Different models of consumption

Through the first step of design (paragraph 4.3.3.2) peak loads have been reduced and use of energy has been rationalized during the 24 hours, both in a typical summer day and in a winter one. Load curves present however, inevitably, peaks which correspond to times of peak usage of, respectively, thermal and electric used energy. What is sought by the following architectural design is a further rationalization of the energy use, supported by the insertion of a cogeneration plant plus an absorption chiller, in order to get a trigeneration plant. The idea to be tested is that, by inserting **spaces** which are **complementary** from an energy point of view, **losses of a user could become the gains, in term of energy, of another user**, according to a real compensation mechanism. This would obviously improve building's independence from the grid, since part of the losses are used to get new energy, which is therefore not requested to the main grid. The building is therefore redesigned by inserting collective and public activities at the first two levels (ground floor and first floor).

By the introduction of new functions inside the building, inevitably the amount of used energy from the building during the 24 hours increases, so it would not have any sense to compare load curves with the ones of the existing building (as we have done in the previous paragraph). For example, if we imagine to insert commercial (small retail food with refrigeration machines) or functions for the public (spaces for sports, nurseries, etc…), the global energy consumption obviously grows up since they are more energy-intensive activities. What is analyzed isn't thus the overall energy consumption, which is inevitably higher, but the **system of energy compensation** between spaces with different functions and the **consequent use of energy on site**, immediately close to the plant.

Here the following first two levels of the building are redesigned, inserting some collective and public functions which need cooling and others which need heating. Particularly, inserted spaces are:

- *Offices and small stores* (for a total surface of 135 sqm)
- *Supermarket* (for a total surface of 265 sqm)
- *Cafeteria* (for a total surface of 265 sqm)
- *Gym* (for a total surface area of 195 sqm)
- *Laundry* (for a total surface area of 65 sqm)
- *Common rooms and game rooms* (for a total surface area of 130 sqm)

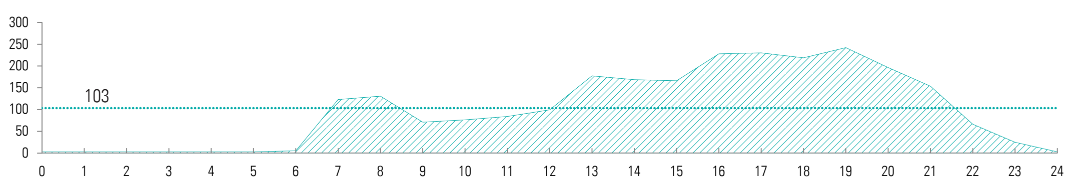
An energy simulation with Design Builder is than conducted, so as to get peak loads of requested power for gas and electricity. Particularly, the sizing of the plant is carried out on the electric usage of a representative day, 15th

July, which is considered as one of the most electrically energy-consuming days of the year: gas turbines which have been chosen to size the plant modulate their speed of rotation based on the required electrical power of that day. Thermal energy is then a by-product of the process of production of electrical energy. In Image 34 the load curve of used electric power at 15th July is showed, and the average line is also indicated. The average value of electric power corresponds to the value 103 kW: it is the one used to size the plant. The cogeneration plant is composed of a couple of gas turbines driven by peak loads, which correspond to a model currently available in the market: each turbine has got a power of 65 kW. The couple of turbines has been chosen because they give the possibility to modulate from 0 to 100% the energy load in relation to real-time demand and they can cover the identified average used power. They also have the advantage of being usable for an high percentage of time: they could indeed be used for 8000 hours/year. Plant is also composed by an absorption chiller (lithium bromide) which has the task of transforming thermal energy as heat into cooling: the maximum power of the absorption chiller is 107 kW.
The building is compared, in its energy usage, with the R5 monofunctional existing day. What appears is that, through a multifunctional layout with energy-complementary spaces inside, thermal energy, produced as a waste of electricity production, could be entirely be used both as heating and cooling, since there are spaces which need heating as well as spaces which need cooling. Conversely, in the monofunctional building part of the thermal energy would be irretrievably lost, since it would be a surplus of heating which could not be used: it would not be indeed all transformed into cooling, because of the capacity of the absorption chiller.
If we imagine to operate the plant for the maximum of possible working hours, that is 8000 hours/year, it follows that energy used for cooling production would be:

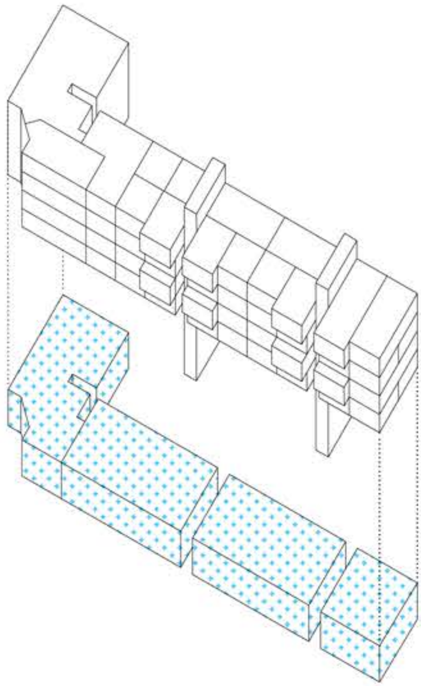
107 kW x 8000 h = 856 000 kWh
and energy for heating production would be
130 kW x 8000 h = 1 040 000 kWh.

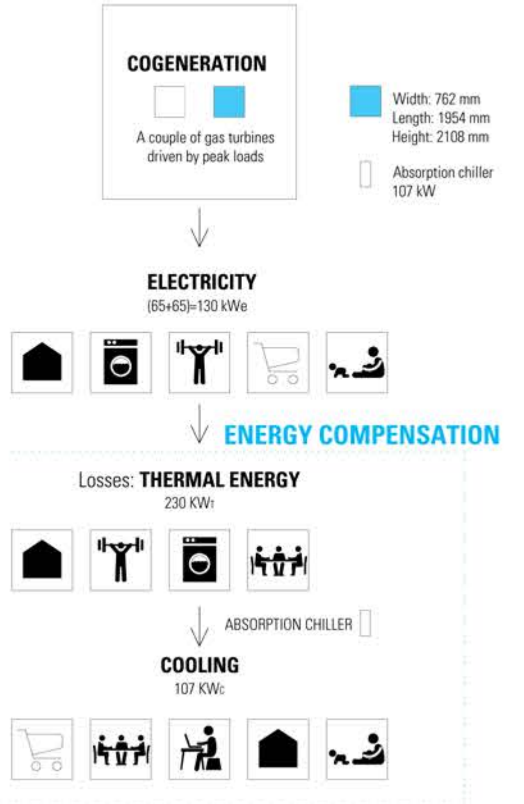
It appears, therefore, that the order of magnitude of considered energy is high and possible savings dictated by the coupling of energy complementary spaces is remarkable. The coupling of spaces with different energy needs is therefore useful if it is thought together with a plant with cogeneration + absorption chiller: if spaces would be far away each other this

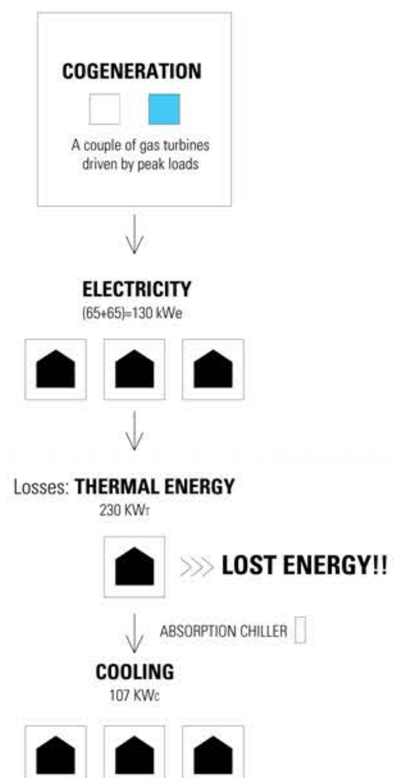
type of efficient production would be surely less useful, since energy losses along the line to reach the various spaces would improve. If psaces are far away each other the other solution would be to think about two different plants (one for the cooling and the other one for heating), but they would be surely less efficient (refer to paragraph 4.2.2, Image 25). Moreover, the described approach appears as extremely sustainable, since wastes become gains, in a sort of closed "ecological" cycle.
In order to better understand the best location for the trigeneration plant, some points should be taken into account:
- Fuels are a transportable energy source (even if sometimes it could be economically or energetically not convenient)
- Electricity is a transportable energy vector
- Heat is not transportable (except for small distances)
For these reasons, the trigeneration plant should be located as much as possible close to the thermal users. The plant is therefore located into the building at the underground level.



34. Graph of the power load curve of electricity consumption at 15th July

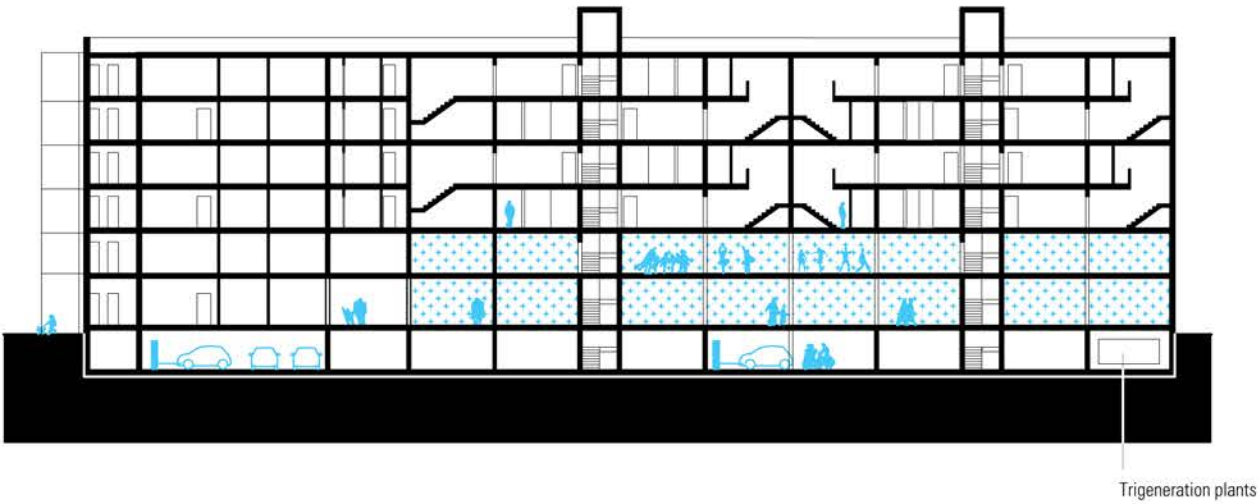




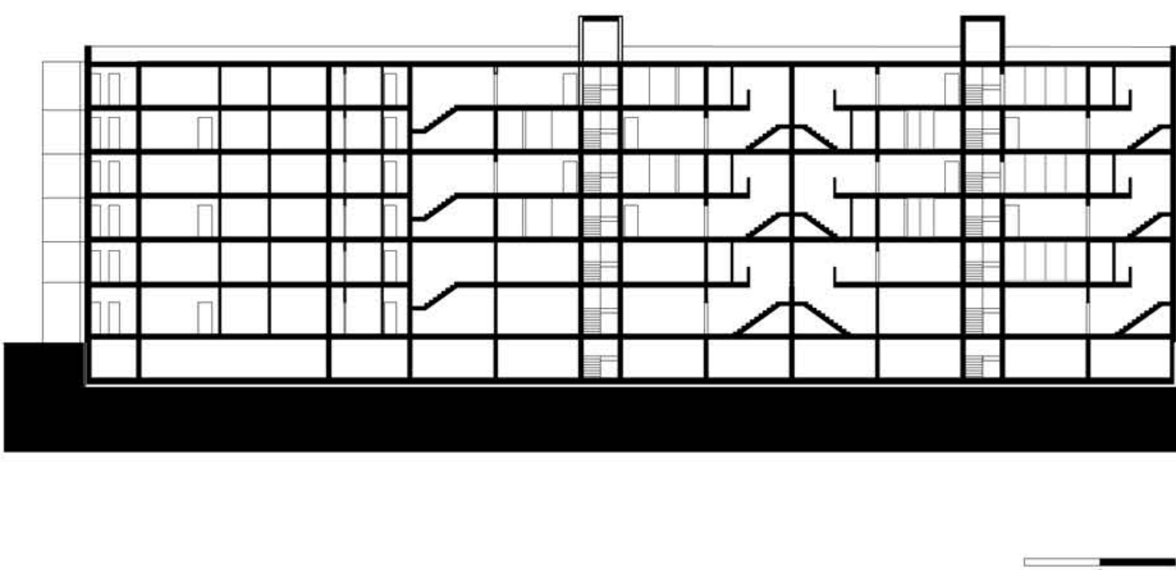


35. DRAWING 3
Plans of the ground floor and first floor / Section of the new re-designed building (above) and of the existing one (below). Functioning of the building with a trigeneration system (cogeneration + absorption chiller) is showed both in the new design and in the state of art.
At the top of the drawing trigeneration is applied to the building that has been re-designed with public and collective functions inside: particularly, the use of energy at 15th July is here represented. A couple of gas turbines selected from the real market is inserted into the example, so as to provide plausible numerical values of the amount of involved energy. Through an energy compensation between "complementary" spaces thermal energy, which is produced as a waste of electricity production, is entirely used, splitted between heating (used for production of hot water into dwellings, gym, laundry and cafeteria) and cooling (used into the supermarket and for the air conditioning of different spaces).
Under the re-designed building, the present monofunctional residential building is instead represented: again the usage of energy at 15th July is shown. What appears is that most of the thermal energy would be lost, since the global use of energy is uniform in all the areas of the building

NEW DESIGN



MONOFUNCTIONAL RESIDENTIAL LAYOUT



4.3.3.4 Temporal flexibility

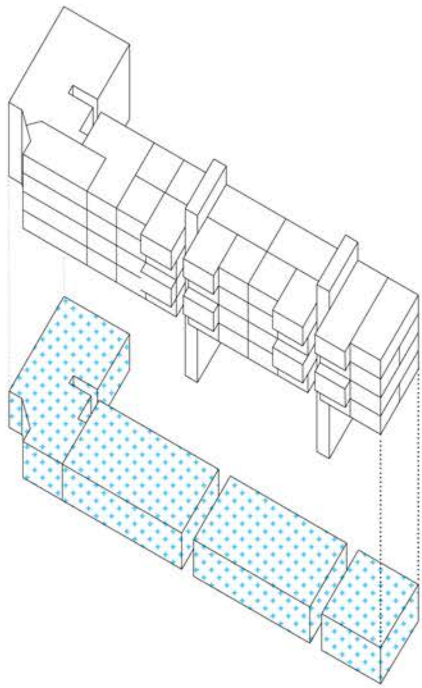
As already stated at paragraph 4.2.3, electricity loads consist of fixed building loads and **controllable building loads**, which are the ones that building's users are prepared to postpone over time. Temporal flexibility in the energy usage necessarily concerns controllable building loads: if they correspond to activities and spaces which are made collective through architectural design, control on this energy usage is made more possible, so that spaces could eventually function in relation to the real-time functioning of the grid.

In a hybrid layout collective functions are often integrated inside the building. Residents have indeed the possibility of using common facilities which could be multiple according to the needs and to the specific layout (e.g. dining rooms, community kitchens, lounges, meeting rooms, laundries, recreation facilities, libraries, workshops, or childcare areas).

In the new design for the R5 building, public spaces are inserted at the ground floor, while some common facilities for the inhabitants are located at the first floor, such as a common laundry and common rooms. In order to give a general idea of the amount of energy which could be managed by a correct use of these spaces over time, a general calculation is made for a specific case, the electricity use in a common laundry: this is made in order to have a general idea of what could be the percentage of flexible loads on the total energy flows of the building. What emerge by a rough calculation is that electric energy used for the laundry corresponds to a 7% of the global yearly electric energy used from the building. It means that the request of this percentage of energy could be eventually shifted over time according to the real-time needs of the grid.

Calculation on the global energy consumption conducted by the use of Design Builder on the collective building didn't consider any charging column for electric vehicles, so as to simplify the already complex calculation. However, the inclusion of charging columns for electric vehicles at the underground level of the building could represent both an additional element for regeneration of the building and an even more profitable interaction with the "smart" electric grid. Charging could indeed work as an on/off functioning, according to the real-time needs of the grid, increasing the interaction between the building-system and the network-system.

A calculation of electric consumption for the charging of 100 electric vehicles is therefore showed as an example (Drawing 3).



36. DRAWING 4

Calculation of the used energy in a representative new collective space inside the building (the laundry) is conducted, in order to have a general idea of "manageable" energy due to the introduction of collective areas inside the R5.

Also, the introduction of charging of electric vehicles for sustainable mobility could be integrated into the new active building in the existing parking area at the underground level, so as to manage this charging as a part of the bidirectional relation building/grid in the management of energy flows. The underground level become in this way as a sort of "technical basement" for the building

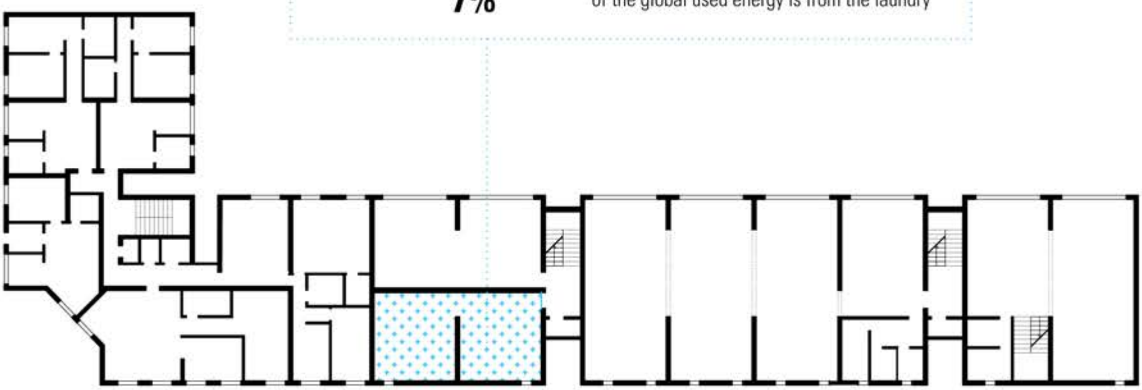
LAUNDRY

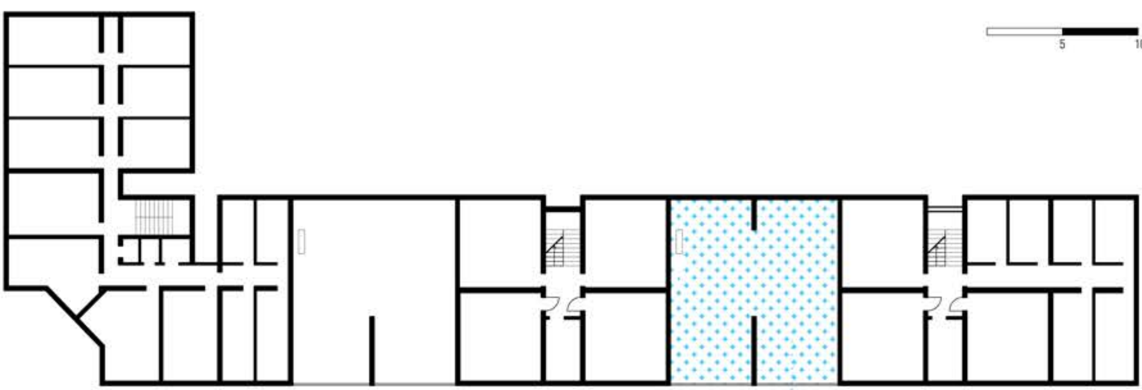
Energy use per washing cycle (at hal load 40-60 degrees): 0.41-0.65 kWh
Energy use per drying cycle: 1.61 kWh
Number of washing cycles in a day: 60 (laundry opened 5 hours per day, 3 machines)
Number of drying cycles in a day: 60 (laundry opened 5 hours per day, 3 machines)

612 280 kW Electricity used in a year from the building

46 866 kW Electricity used in a year from the laundry

7% of the global used energy is from the laundry





CHARGING OF 100 ELECTRIC VEHICLES

Hypothesis: lithium battery - 3.7 V and 5 Ah
Each cell contains an energy equal to 3.7 x 5=18.5 kWh
We suppose that a car has got 60 cells: 18.5 Wh x 60=1.11 kWh
We suppose to have 100 cars in the garage which are charged during the night: 111 kWh
We suppose that every car has to be charged for 60% of the total:

111 kWh x 0.6= **66 kWh**

4.3.3.5 Independence and self-sufficiency

One of the main goal to be reached by future buildings interacting with the electric grid is self-sufficiency. Buildings should be able to ask for energy when the grid is under loaded, while they should be able to be independent or even to input produced or stored energy into the grid if it needs. Self-sufficiency could be favored by the introduction of RESS (Residential Energy Storage Systems) inside buildings.

As already discussed in paragraph 4.3.4, the size of a storage depends on both the type of storage itself and the total amount of energy which has to be stored. In the new design of R5, **new thermal energy storages** are located inside the building. The chosen type of technology is the one based on **water storage**: water has indeed the advantage of being a low-cost and always available material with a high specific heat.

In order to size the plant, we can imagine to set a difference of temperature of 10 K for the stored water (e.g. from 5 °C to 15 °C). Since specific heat of water is equal to 4,187 kJ/(kg .K), the amount of heat that can be stored in 1m³ of water (1000 kg) is 41 870 kJ, which is equal to 11,6 kWh/m³.

Energy storage can be then partial or total (Image 37). The partial one is obtained by using machines that work 24 hours per day, so that they can storage energy in the nighttime and they can compensate for the daytime requests both with the previously stored energy and with the working machine. On the contrary the total accumulation is expected that the machine works only at night when the price of energy is lower (**33**).

The chosen technology for the R5 building is the partial accumulation. Calculation is conducted for the considered winter day (1st January). The average value of the daily energy consumption is multiplied by the number of hours of a day 24.

The obtained value is then divided by the amount of energy that can be stored in 1m³ of water to obtain the value of the necessary volume to store the right quantity of water.

208 kW = average value of the daily winter consumption (1st January).

We dimension storages in order to cover 60% of the amount of the average value:

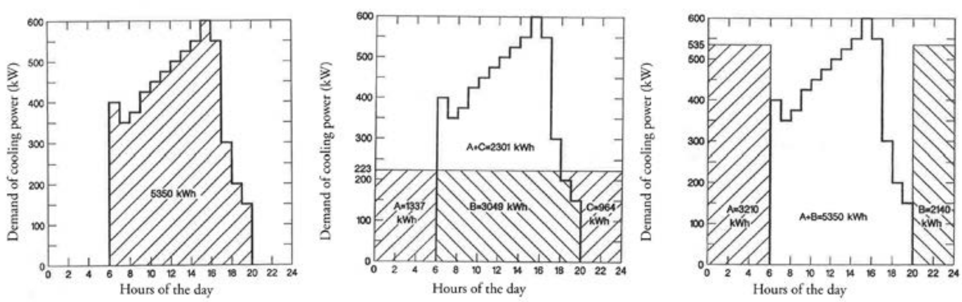
208 kW x 0,6 = 125 kW

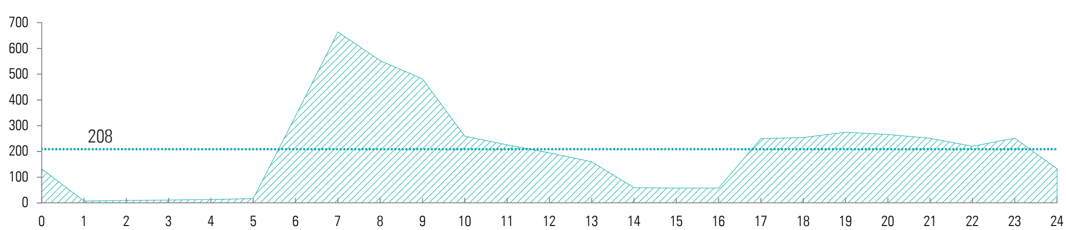
125 kW x 24h = 3000 kWh

3000 kWh / (11,6 kWh/m³) = 259 m³

259 m³/ 2.4 m = 107 sqm

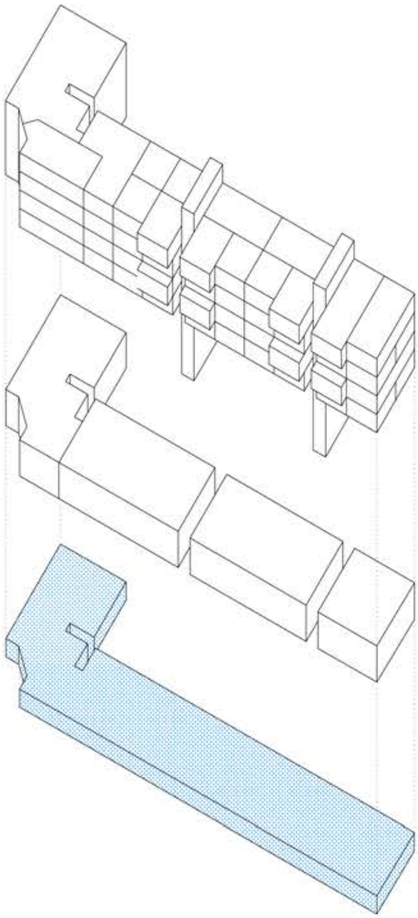
Usually thermal storages are located **in the basement of the building** for structural reasons related to the weight of the storages.



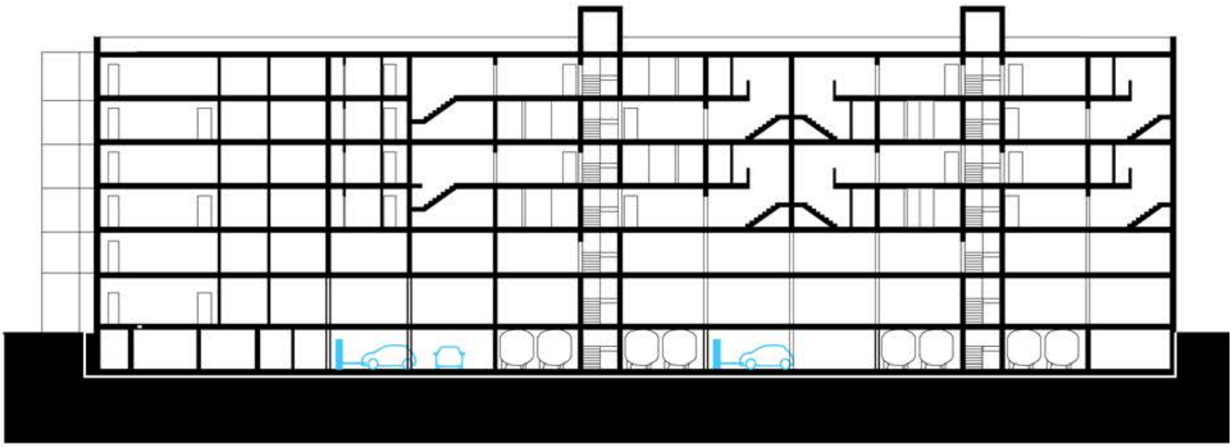


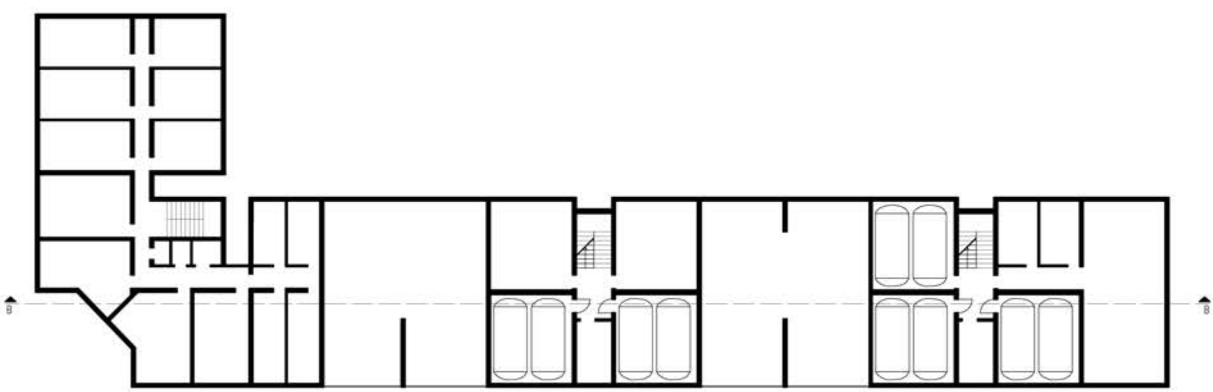
37. In the first Image a load curve of power use of a building is shown. Image 2 and 3 represent the functioning of two different technologies for energy storage: Image 2 represents a partial storage, while Image 3 a total accumulation of energy during the night

38. Power used for gas production at 1st January. The average value is equal to 208 kW



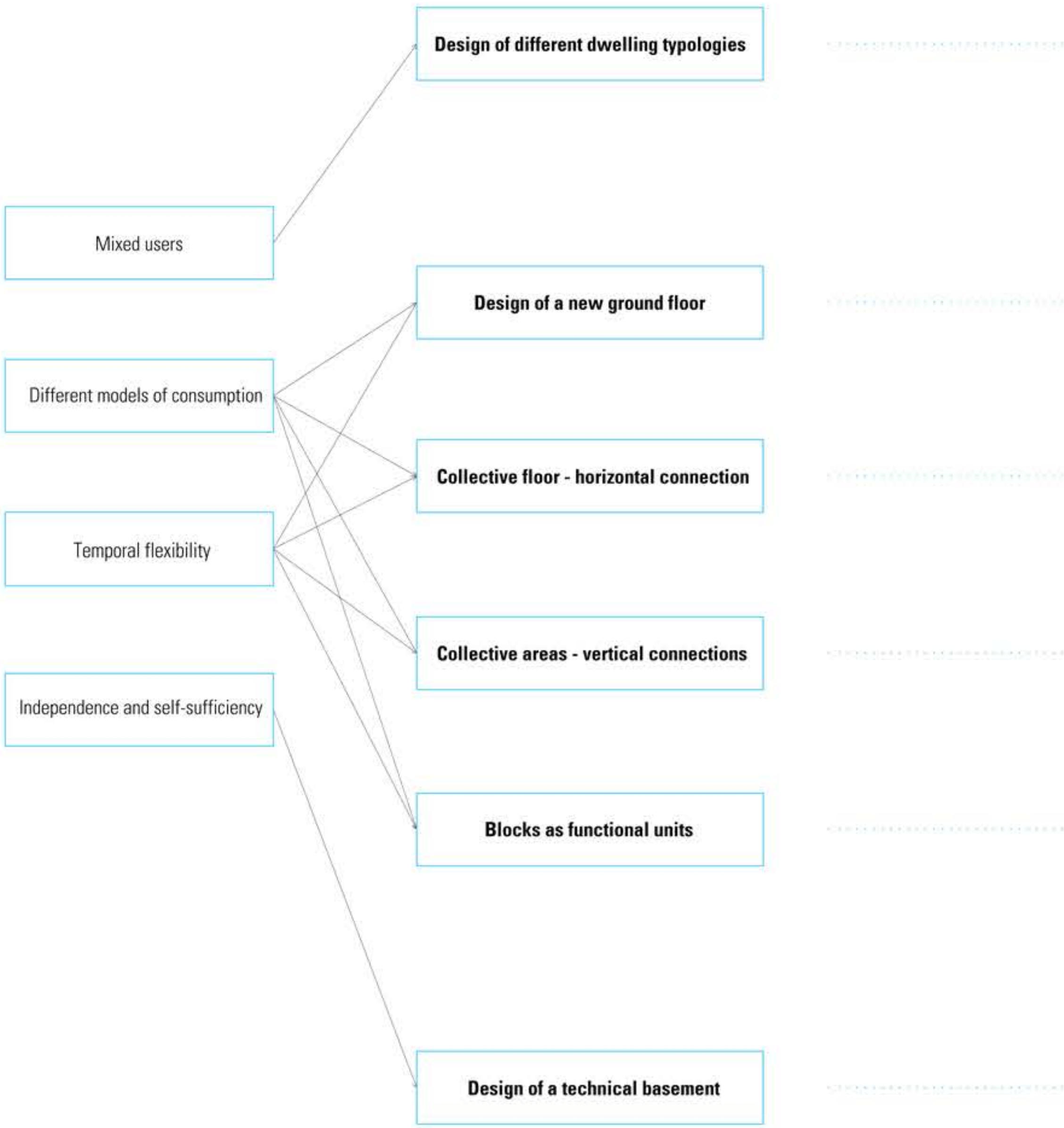
39. DRAWING 5
The dimensioned storage systems are located at the underground level of the building. Every water tank has got a volume of 19,4 m^3, so that 10 tanks are necessary to cover the requested heat storage



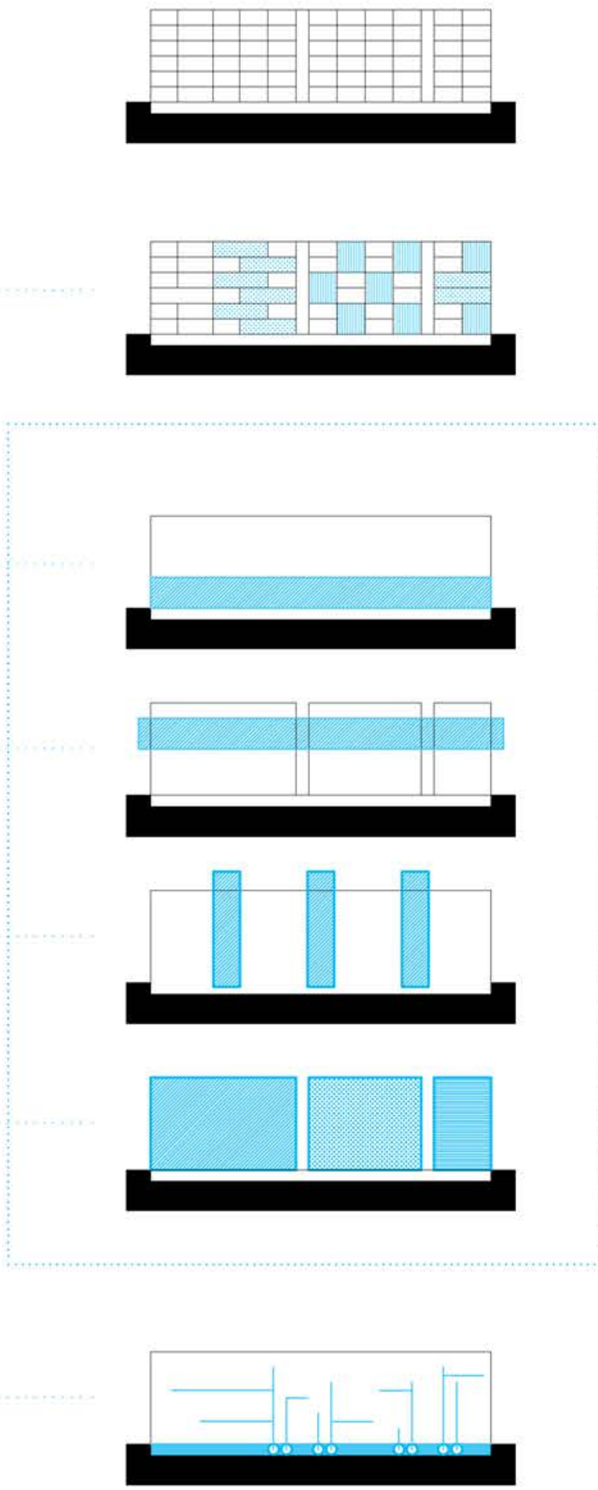

B
B

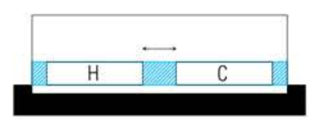
4.3.4 Conclusions

We can conclude that architectural forms could influence the energy management of a building and particularly **hybridization of the architectural design** towards more flexible layouts could have good effects on the energy management, so as to obtain a more dynamic and flexible interchange between the electric grid and the building itself. What emerge is that the **role of the functional program** becomes crucial in the global energy behavior of the building.
Particularly, the Table introduced at paragraph 4.2 at the beginning of this Chapter is here the following proposed again, so as to fill even its third column that was still missing.
We have tested that presence of mixed users is favored by a certain **variety in dwelling typologies**, both in size and in their internal organization.
Different models of energy usage are possible if the building has hog a certain level of **multifunctionality**: in this way is indeed possible to couple together spaces that at the same time need respectively heat and cold. By the **collectivization** of some areas it is also easier the control of the use of spaces and consequently the control of energy usage over time.
Finally we have underlined that a building should be as much as possible **independent** from the grid: this is both encouraged by the presence of storage systems and by a functional program which is the most complete and dense one. That is why the condition of self-sufficiency is favored by a dense program and a strong formal identity of the building itself.
Variety in dwellings' typologies, multifunctionality, temporal flexibility in the use of spaces, identity and density are all features of a hybrid building type. Hybrid typology therefore appears as one of the most indicated one for the global energy management of the building interconnected with the Grid.
The reached conclusions become as important starting point of the architectural project both **in the new design** of residential buildings and also **in the architectural refurbishment and regeneration** of the existing building heritage. Here the following some design strategies to be applied both on existing buildings and on new ones are defined through graphical diagrams in the forms of simplified sections.



41. DRAWING 6
Architectural design strategies





Coupling of heating and cooling

PURPOSES	HYPOTHESIS	EXPERIMENTAL DESIGN
Expected features for a NetZEB	**They could be favored by...**	**Which kind of design?**
Capability of loads' modulation	Mixed users (4.2.1) Different models of consumption (4.2.2)	VARIETY IN DWELING TYPOLOGIES MULTIFUNCTIONALITY
Flexibility	Temporal flexibility (4.2.3) - *In relation to withdrawals* - *In relation to energy use*	FLEXIBILITY IN THE USE OF SPACES
Independence	Energetic self-sufficiency (4.2.4)	IDENTITY
Reliability		DENSITY

40. The Table proposed at paragraph 4.2 of this Chapter is now fully filled. Third Column summarizes architectural features a building should have to favor the global energy management in its relation with the Grid. What emerge is that a hybrid layout is particularly indicated to favor management of energy flows of the building

4.4 The hybrid building concept

"The hybrid building is a specimen of opportunity which has the mixed use gene in its code. It turns against the combination of the usual programs and bases its whole raison d' entre on the unexpected mixing of functions. The hybrid is the consequence of a rant against tradition, it sticks two fingers up at typology. It is an opportunist building, which makes the most out of its multiple skills, a key player which revitalizes the urban scene and saves space. The hybrid scheme proposes crossed fertilization environments, where known genotypes are mixed and new genetic alliances are created. This way the personality of the hybrid emerges, as a celebration of complexity. Hybridization is associated with a certain form of grandeur, of gigantism, as mixing imposes grandesse. The hybrid surpasses the domains of architecture and settles into the urban scale. It is an artefact able to exercise centripetal force, a colossus counteracting the evil forces of dispersion. The intimacy of private life and the sociability of public life dwell within the hybrid and produce constant activity, making it a building working full time. It is not a disciplinary prototype but a concentration of interests, based not on tradition but rather on the future and the survival of which hinges on consensus". (**34**)

The term "hybrid" is entered today in the everyday language in very different and heterogeneous fields. It is indeed frequently used to identify innovative and new models and types based on coexistence of different elements in several disciplines and cultural areas. Regarding to the field of architecture, one of the most important critical contributions in the formalization of the term "hybrid" in relation to buildings is the catalog edited by Joseph Fenton in 1985, "Hybrid buildings". Although his contribution has been almost exclusively related to the North American context, Fenton laid the base for the definition of those general features of the hybrid building which can be considered universally valid. In recent years researches by "a+t architecture publishers"(**35**) have implemented the definition of hybrid buildings through several publications with the collection of case studies, the definition of main features of hybrid buildings and analysis of their potential in relation to the combination of different functional programs.

A hybrid building is based on the coexistence, in the same structure, of different functions and programs interacting each other, often with a consequent alteration of types of the individual canonical uses. As stated by Fenton, "the hybrid building, at its largest scale, become a **City within a City**. A single structure on a single urban block could become the life nucleus and sole support of the people within" (**36**).

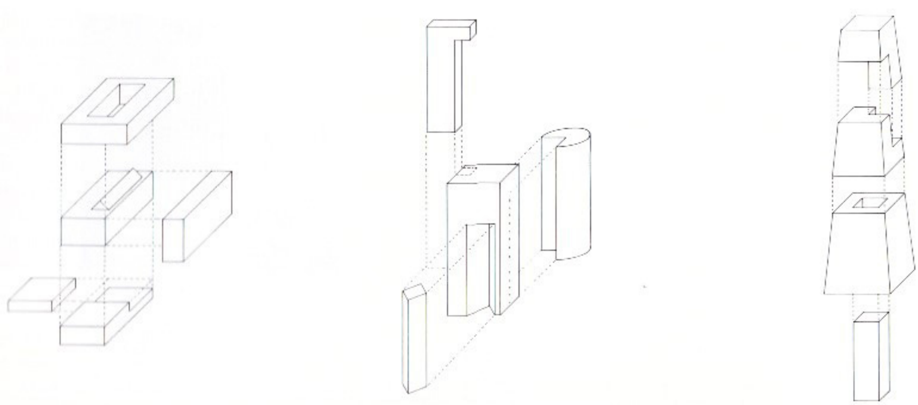
Multi functionality is the peculiar feature of the hybrid building: programs can incorporate different categories of uses according to specific requirements, such as residential, working, leisure, commercial, productive or social functions. Due to the usual complexity and completeness of the functional program, **self-sufficiency** is another typical feature of the hybrid building. The functional self-sufficiency often corresponds to a strong formal identity, so as the building appears as a sort of "icon" into the urban layout. That is the reason why some examples of contemporary hybrid buildings show a monumental character due to the building´s strong identity within the urban pattern. Moreover, dense environments with land use limitations are usually good conditions to encourage hybrid situations. Mixed use is indeed usually closely linked to increased density, which allows for more compact development. Moreover a hybrid building can usually easily be reconfigured in different layouts. This is mainly because it is designed since the first steps as a complex structure being able to adapt to inhabitants´ changing needs and habits. Flexibility provides to implement life strategies over time by dialing the "service package" that best meets populations´ actual needs. **Flexibility** can be intended as spatial (possibility of different architectural layouts) and temporal (by the collectivization of certain functions some spaces can be set to be used in certain periods of time during the day). Temporal flexibility is the one which is able to affect the global energy management of the building, as discussed in paragraphs 4.2 and 4.3.

Today the hybrid building concept looks like as extremely investigated and it represents a great potentiality for the future development of cities: because of the hyper-urbanization of contemporary cities and progressive waste of agricultural and natural land, hybrid buildings could indeed "act as **catalyst incubators** for new and experimental architectural types"(**37**).

In the "Hybrid buildings" Architecture Pamphlet n.11 (**38**) hybrid buildings are analyzed considering their history, program and architectural form. In the following paragraphs the same type of classification is conducted.

4.4.1 History

The concept of hybridity passes through history of architecture and has always had a significant role, even if it was firstly formalized by Fenton just in 1985. The combination of multiple functions within a single structure is indeed a recurrent layout throughout history: the inhabited bridge or the medieval house over the store are just a few of the many examples that we can trace.



42. Forms of hybridity

However, "history of hybrids begins at the end of the 19th century, when the dense city started to accept the overlapping of functions as inevitable" (**39**). At that time, in North American metropolis both the disproportionate increase of the price of land and the rigidity of the urban weft favored the development of new architectural typologies based on verticalism, as a way to concentrate several functions in a limited land area. The new hybrid building differed from a multi-use building by scale and form. Scale was usually the one determined by the dimensions of a city block into the pattern grid (**40**), while the form could be variable, even if it started from the beginning to be characterized by compactness and a certain monumentality. The hybrid building was born as a result of the Contemporary Culture. Its conceptualization and the subsequent spread at the end of the Nineteenth Century were even possible thanks to technological innovations such as structural framing, the elevator, the electrical wiring, central heating and ventilation system (**41**).
Since the Twenties of the XX century the Modern Movement introduced the idea of the Functional City: the Charter of Athens (1933), in the paragraph titled "Dwelling", point 15, marked the definition between workplace, housing and leisure spaces. Each zone of the city was organized and optimized by specific standards related to density, building types and minimum services, and it had to be connected to functionally different areas so as to optimize the overall productivity. This new idea of city was therefore at odds with the mixed-use building's concept. The City of Zoning could easily be represented by plan: this representation is indeed able to show different functions it was composed of.
Even if there have been crucial experimentations of buildings in which other functions and services were coupled to the residential one (the Unité d' Habitation by Le Corbusier is the most known and determinant example) the rationalist city has been mainly based on the concept of zoning. However since the Seventies and mostly during the Eighties the zoning started to be criticized in favor of a more complex and stratified layout. It seemed indeed that zoning could not meet anymore the needs of the contemporary society: the traditional Town Planning Act, implementation tool of the zoning (the so called PRG in Italy), appeared to be excessively rigid and not enough flexible to encourage processes of social, economic and environmental transformation according to the new principles of sustainability starting to be developed. Zoning was accused of having guided spatial fragmentation, social segregation and urban sprawl. A new return to mixitè based on the model of the historic city spread in response to the crisis of zoning. First the experimental and utopian research conducted by

Archigram, then the radical architecture of Superstudio with Continuous Movement and Archizoom with No-Stop City contributed to the overcoming of the functional city to more hybrid forms of living.
The recent process of computerization of the society has also encouraged return to mixitè in the urban pattern: the contemporary city of the Information Age can be considered as the city of mixitè since it tends to regroup, overlap and interweave functions which are no longer strictly bonded to a specific location. The hybrid building itself is a product of the Information Age because the Information City makes everything available anytime and everywhere: we can indeed work at any time and everywhere and this is possible because of development of information. We can simultaneously work and leisure, produce and consume. If the car was the instrument of the Industrialized City to move throughout different areas, computer allows us to be almost ubiquitous. Space and time are then reconfigured into a new completely production system, so that "the fundamental web of relationships among homes, workplaces, and sources of everyday supplies and services — the very glue that holds cities together — may now be formed in new and unorthodox ways"(42). Hybrid building is the product of the City of Layers in opposition to "ghettoization" so as it can easily be represented by the use of architectural sections. Stratification of different layers suggests the development of complex sections: section becomes the most effective instrument of architectural representation (43).

4.4.2 Program

The basic principle behind the concept of the hybrid building is the mixitè. A hybrid residential building is characterized by a mixed-use development: it means a combination of residential, commercial and cultural uses, where those functions are physically and functionally integrated. The program can assume a variety of possibilities, even if "two basic categories of program are readily identifiable: the thematic program, and the disparate program. Both are based on the combination and interaction of the programmatic parts. Thematic combination cultivate the dependency between parts and encourage the interaction of elements. Disparate combinations allow pieces to exist in a mutual, (…) emphasizing the fragmented, almost schizophrenic aspect of society and of the period" (44).
Usually thematic combinations tend to emphasize a singleness of function between the various ones inserted into the building. Buildings we are considering in this study are characterized by a thematic program and the main functions is the residential one.

The pamphlet of Fenton has been the first theoretical contribution to establish a disciplinary autonomy of the hybrid building, until that moment generally categorized as mixed use building. However mixed use is a necessary but not sufficient condition to define a hybrid. A hybrid building is indeed characterized by a certain level of openness to the city: social exchanges are favored and functional integration between its parts is enhanced.

4.4.3 Form

Hybrid buildings can assume different architectural forms and layouts: "the resultant forms are as numerous as the potential combinations of programs. The functions which comprise the program of a hybrid building may be expressed or repressed. These functions may be stacked vertically, grafted horizontally, or, as in some instances, internally engulfed within the exterior membrane of the building"(**45**). Aurora Fernandez Per (**46**) introduces an interesting distinction between hybrid buildings and social condensers, regarded as "predecessors" of the hybrids. First identified difference is in the context: while hybrid buildings belong to highly urbanized contexts, the social condenser typically reflects a suburban condition. Moreover social condenser is typically a residential building with a service program associated to dwellings, while hybrid buildings include a diversity of uses, even including residential: not necessarily the residential one is the predominant function. Their attitude to the city is also different: while the social condenser mainly guarantees an exclusive use of the service program by residents, the hybrid is opened to the city. The analysis of social condensers and hybrid buildings is particularly interesting since it introduces formal features to define these typologies. However in many cases it is extremely difficult to make a strict distinction between these two building types, since many contemporary examples show some typical features of both the hybrid building and the social condenser, as they are identified by the a+t publication.

4.4.4 Hybrid buildings: some references

Some case studies of existing hybrid buildings which potentially could have a good response in their relation with an hypothetical Smart Grid have been collected in a representative filing. Those case studies have been organized in a table, with the main information of the buildings and a re-drawing of both a representative plan and section. This is made so as to easily compare buildings' typologies, dimensions and functional programs. Particularly, as we have stated, the section is the most effective instrument

of representation of the hybrid condition: in the table sections are therefore coloured, so as to underline main functions inside buildings. The used scale for representations are 1:5000 for master plans (with the exception of the Corviale, which is represented at 1: 20000) and 1:5000 and 1:2000 for representation of plans and sections.
There are many possible classifications which can be done about hybrid buildings, e.g. according to the building´s typology, the functions inside, the year of construction, or the geographical area. Here below examples of hybrid buildings with a predominant residential use are analyzed. In the range of existing worldwide projects in which the theme of the hybrid building has been developed, buildings chosen for this short section have been selected since they are considered as particularly innovative or representative of the hybrid typology.
Firstly the Unité d' Habitation and then the Corviale are indeed milestones in the experimental design of the building as a "social condenser" of activities. Fifty years later Le Corbusier's experience, Steven Holl addresses the issue of the hybrid building in several of his projects and he appears so interested to the "hybrid concept" to declare it even in the name of one of his most known projects (Linked Hybrid): his practical and theoretical research on the topic (refer to bibliography) deserves to be mentioned.
Another important field of investigation on the hybrid architecture is surely belonging to the Dutch cultural panorama. During the Nineties Dutch architects, encouraged by national policies, developed and experimented the theme of housing design and dwelling typology: the results were many and different, but among them we can identify interesting studies on the "urban hybrid container" (e.g. the Whale or the Silodam). More recently Rem Koolhaas provided also his interpretation of the hybrid type by the development of its vertical city in Rotterdam. Finally a residential building for particular social users has been inserted: the student house designed by Lundgaard and Tranberg Architects is an interesting example of a research on the typology, so as to guarantee coexistence of dwellings and collective and public activities inside the building.

43. Hybrid building: some references (look at the following page)

- Hotel
- Dwellings
- Collective functions
- Public functions
- Offices
- Car parking

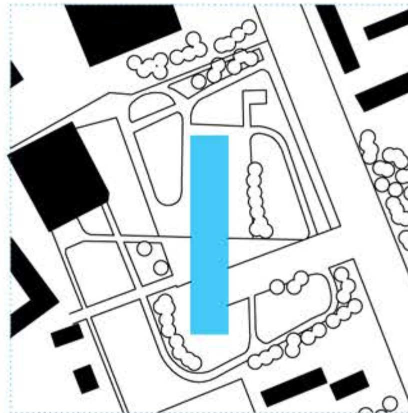
UNITE' D'HABITATION

ARCHITECT: Le Corbusier

LOCATION: Marseille (France)

DATE: 1947-1952

FUNCTIONAL PROGRAM: 337 apartments, restaurant, gym, laundry, kindergarden, hotel, office, biblioteque, shops



1:5000

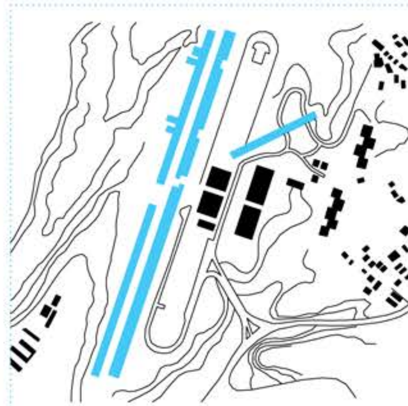
CORVIALE

ARCHITECT: Mario Fiorentino

LOCATION: Rome (Italy)

DATE: 1972-1974

FUNCTIONAL PROGRAM: 1200 apartments, offices, surgeries, retail, elderly house, supermarket, social activities



1:20 000

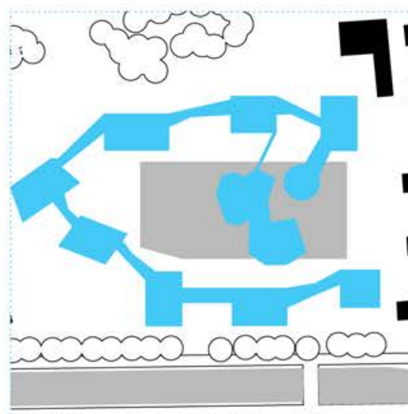
LINKED HYBRID

ARCHITECT: Steven Holl

LOCATION: Beijing (China)

DATE: 2003-2009

FUNCTIONAL PROGRAM: 644 dwellings, public green space, commercial zones, hotel, cinematique, kindergarden, school, underground parking



1:5000

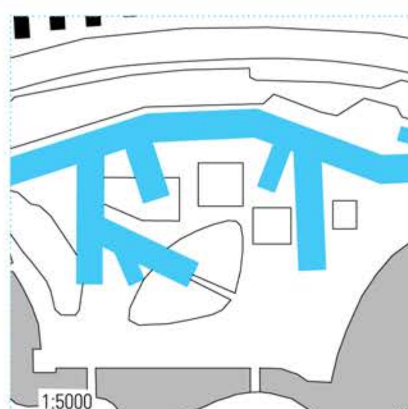
VANKE CENTER

ARCHITECT: Steven Holl

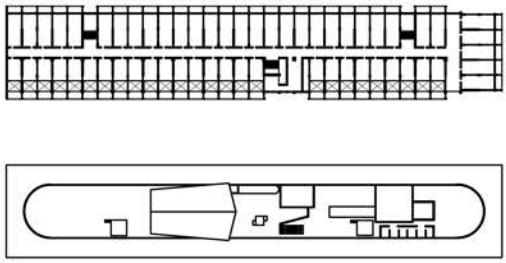
LOCATION: Shenzhen (China)

DATE: 2006-2009

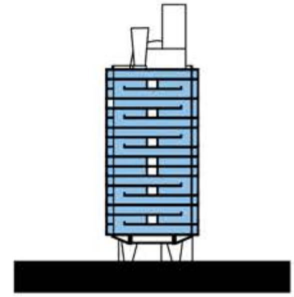
FUNCTIONAL PROGRAM: dwellings, offices, hotel, conference center, spa, restaurant, common areas, car parking



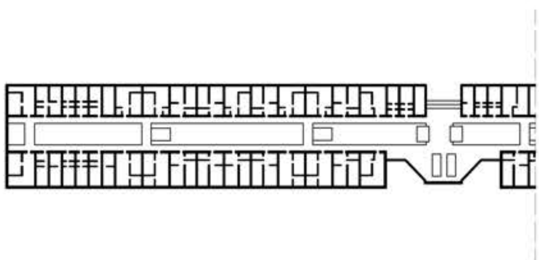
1:5000



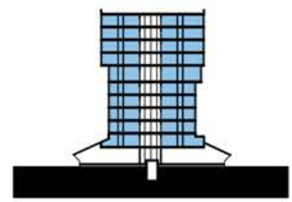
1:2000



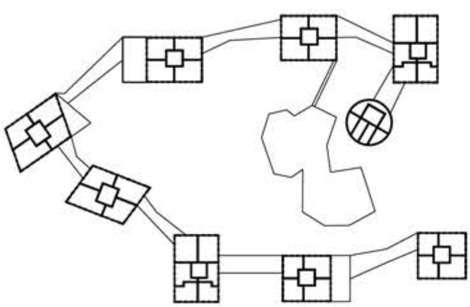
1:2000



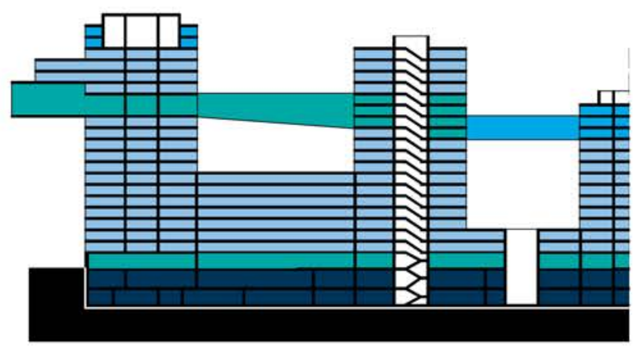
1:2000



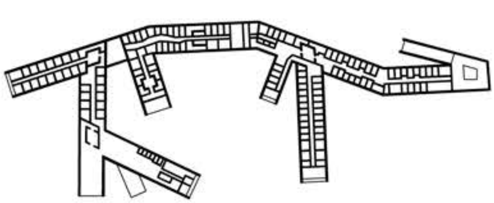
1:2000



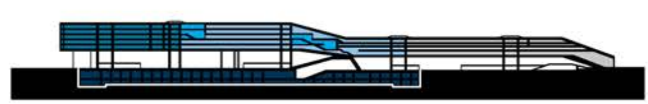
1:2000



1:2000



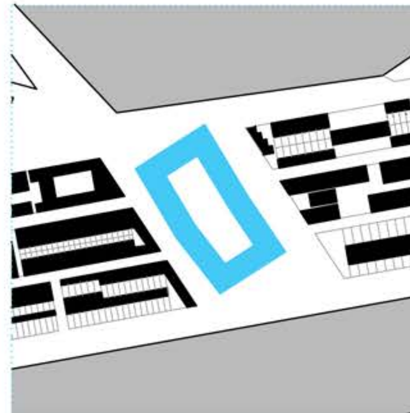
1:5000



1:5000

THE WHALE

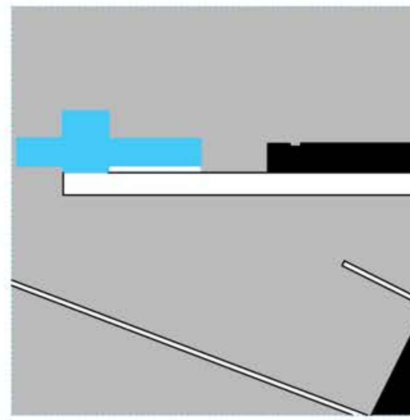
ARCHITECT: Frits van Dongen, de Architecten CIE
LOCATION: Amsterdam (NL)
DATE: 1998-2000
FUNCTIONAL PROGRAM: 150 social housing, 64 private houses, 1100 business accomodations, 179 car parking



1:5000

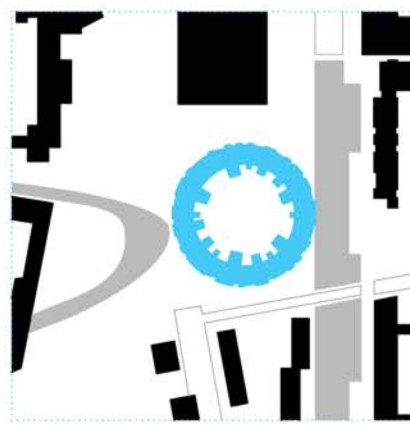
SILODAM

ARCHITECT: MVRDV
LOCATION: Amsterdam (NL)
DATE: 1998-2000
FUNCTIONAL PROGRAM: 157 dwellings, business units, restaurant



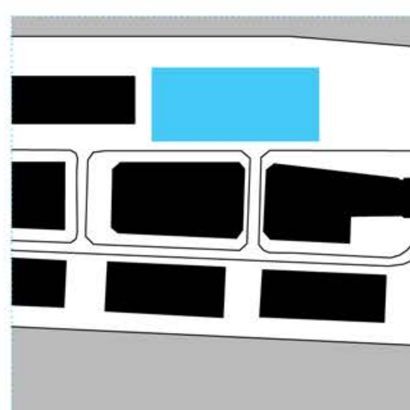
TIETGEN DORMITORY

ARCHITECT: Lundgaard & Tranberg Architects
LOCATION: Copenaghen (Denmark)
DATE: 2005
FUNCTIONAL PROGRAM: 360 students' rooms, cafe, auditorium, study and computer rooms, workshops, laundry, meeting rooms, bycicle parking

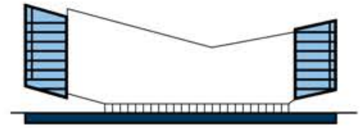


DE ROTTERDAM

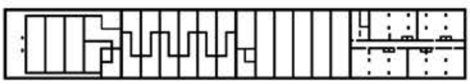
ARCHITECT: OMA Architects
LOCATION: Rotterdam (NL)
DATE: 2013
FUNCTIONAL PROGRAM: 240 dwellings, offices, shops, conference halls, restaurants, gym, car parking



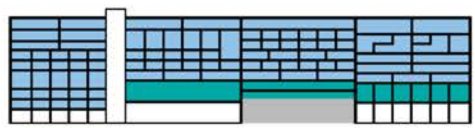
1:2000



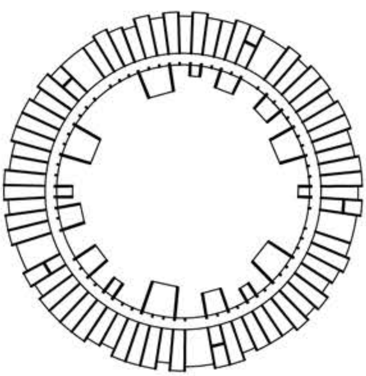
1:2000



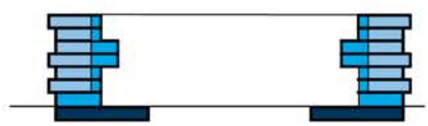
1:2000



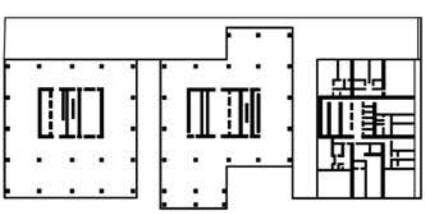
1:2000



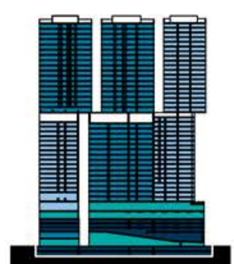
1:2000



1:2000



1:2000



1:5000

Notes - Chapter 4

(1) DREXLER H., EL KHOULI S., Holistic housing – Concepts, design strategies and Processes, Edition DETAIL, Frankfurt, 2012

(2) SCOGNAMIGLIO A., Forms of Energy #12, L' NREL Research and Support Facility in Colorado: un paradigma per la progettazione di edifici a consumo energetico quasi zero, in domus web, 2011

(3) JOHANSSON D., BAGGE H., *"Simulating energy use in multi-family dwellings with measured, non constant heat gains from household electricity"*, paper presented at the Eleventh International IBSPA Conference, Glasgow; July 27-30, 2009

(4) WEBER C., PERRELS A., *"Modelling lifestyle effects on energy demand and related emissions"*, in Energy Policy n. 28, 2000, pp. 549-566

(5) RICHARDSON I., THOMSON, M., INFIELD D., CLIFFORD C., *"Domestic electricity use: A high-resolution energy demand model"*, in Energy and Buildings n. 42, 2010, pp. 1878 - 1887

(6) According to the cited article by RICHARDSON I., THOMSON M., INFIELD D., CLIFFORD C., active occupancy is related to the presence of people who are at home and awake

(7) WIDEN J., LUNDH M., VASSILEVA I., DAHLQUIST E., ELLEGARD K., WACKELGARD E., *"Constructing load profiles for household electricity and hot water from time-use data – Modelling approach and validation"*, in Energy and Buildings n. 41, 2009, pp. 753 - 768

(8) PALUMBO M., Forms of Energy #4, "A Matter of Nature.", Domus web, 2010

(9) BARBIERI P., *"Figure ed energia"*, in CALZOLARETTI M., MANDOLESI D., Rigenerare Tor Bella Monaca, Quodlibet, Roma, 2014

(10) BJARKE INGELS, Yes is more. Un archifumetto sull'evoluzione dell'architettura, Taschen, Koln, 2011

(11) JOHANNENSON D., *"CO_2 and Cost Impact of Pre- and Post shift of Residential Electric Loads"*, master thesis at Umea Universitet (SE), 2011

(12) CIPOLLA C., *"Solutions for relational services"*, in MIETTNEN S., Service Design with Theory. Discussions on Change, Value and Methods, Rovaniemi: lapland University Press (LUP) Publishing, 2012

(13) APARECIDA VASQUES R., MITSUKO ONO M., *"Shared use – Cultural aspects and user satisfaction in doing the laundry together"*, in CESCHIN F., VEZZOLI C., ZHANG J., Sustainability in Design: now! Challenges and opportunities for Design Research, Education and Practice in the XXI Century, Proceedings of the LeNS Conference, Bangalore, India, 29th September 2010 to 1st Ocrober 2010, LeNS project funded by the Asia Link Programme, Europe Aid, European Commission

(14) CIPOLLA C., *"Relational services: service design fostering sustainability and new welfare models"*, Proceedings of the 2nd International Symposium on Sustainable Design (II ISSD), Brazil Network on Sustainable Design – RBDS, Sao Paulo, Brazil 2009

(15) DINCERI.,ZAMFIRESCU,C., Sustainable Energy Systems and Applications, Springer, London, 2011

(16) Heat capacity of an object is the ratio between the heat which is exchanged between the object and the surrounding environment and variation of temperature produced by it $C= Q/\Delta T$

(17) DINCER I., *"Thermal energy storage systems as a key technology in energy conservation"* in International Journal of Energy Research, num. 26, 2002, pp. 567-588

(18) RUBIN A., *"L' accumulo dell' energia termica: stato dell' arte e studio di sistemi e soluzioni per la media temperatura"*, Tesi di laurea, Università degli Studi di Padova, Dipartimento di Ingegneria Industriale, Corso di Laurea in Ingegneria meccanica, a.a. 2012-2013

(19) LAZZARIN R., NORO M., BUSATO F., Studio di sistemi di accumulo a cambiamento di fase nel solar cooling, Report ENEA RdS/2011/256

(20) CANTONI C., *"Il veicolo elettrico a support delle Smart grid"*, master thesis, Politecnico di Milano, Facoltà di Ingegneria dei Processi Industriali, 2012

(21) SWAN L., UGURSAL V.I., *"Modeling of end-use energy consumption in the residential sector: a review of modeling techniques"*, in Renewable and Sustainable Energy Reviews, num. 13, 2009, pp. 1819-1835

(22) SWAN L., UGURSAL V.I., Op. cit.

(23) MAILE T., FISCHER M., BAZJANAC V., *"Building Energy Performance Simulation Tools – a Life – Cycle and Interoperable Perspective"*, Standford University, Working Paper 107, 2007

(24) A dynamic simulation allows to know the instantaneous values of energy requests from the users: by a dynamic simulation, it is indeed possible to calculate energy demands and supplies of a building on time steps from minutes to years

(25) MAGELLI S., *"Towards Nearly Zero Energy Buildings (nZEBs): Metodologia di analisi e caso studio su un edificio residenziale"*, master thesis, Politecnico di Milano, Scuola di Architettura e Società, 2012

(26) MAILE T., FISCHER M., BAZJANAC V.,Op.cit.

(27) The collegial research work of several architectural departments is collected in the following book: CALZOLARETTI M., MANDOLESI D. (edited by), Rigenerare Tor Bella Monaca, Quodlibet, Roma, 2014

(28) The team of the designers was composed by the architects Casanova, Piroddi, Ianni, Bentivegna, Cascarano and the engineers Romanelli and Santolini

(29) COMUNE DI ROMA; Programma straordinario di edilizia pubblica art. 8 legge 16.02.80 – Consorzio di Tor Bella Monaca – Fascicolo 1

(30) Capo III, art. 14

(31) PENSATO D., *"Strategie passive di controllo termico degli edifici alla scala urbana ed edilizia"*, master thesis, Alma Mater Studiorum, Università di Bologna, Corso di Laurea in Ingegneria per l' Ambiente e il

Territorio, D.A.P.T. Dipartimento di Architettura e Pianificazione territoriale, 2008-2009

(**32**) Standard deviation is a measure which indicates the amount of variation or dispersion of a set of data values. If standard deviation tends to 0, it means that data points tend to be really close to the mean of the set. In the three diagrams the project situation with mixed dwellings and users has got a lower standard deviation compared to the one of the state of art: it means that use of energy during time is more widespread.

(**33**) ROSSI N., Manuale del termotecnico. Fondamenti – riscaldamento – condizionamento – refrigerazione – risorse energetiche, Hoepli, Milano, 2014

(**34**) FERNANDEZ PER A., MOZAS J., ARPA J., This is hybrid, a+t architecture publishers, Vitoria-Gasteiz, 2011

(**35**) a+t architecture publishers is an editorial company on architecture, independent from any institution or professional group. It was founded in 1992 in Vitoria-Gasteiz (Spain)

(**36**) FENTON J., Hybrid buildings, Pamphlet Architecture n. 11, New York, San Francisco, 1985, p. 33

(**37**) HOLL S., *"Prologue"*, in FERNANDEZ PER A., MOZAS J., ARPA J., This is hybrid, a+t architecture publishers, Vitoria- Gasteiz, 2011

(**38**) FENTON J., Op. Cit

(**39**) FERNANDEZ PER A., MOZAS J., ARPA J., Op. Cit.

(**40**) FENTON J., Op. Cit, p. 5
(**41**) FENTON J., Ibidem

(**42**) MITCHELL W., *"The era of the E-topia: The right reactions to* the dig*ital revolution can produce leed and green cities"*, Architectural Record, 1999, vol. 187, Issue 3

(**43**) MAZZOLENI P., Abitare nella società dell' informazione – Il progetto dei luoghi dell' abitare tra permanenze e mutazioni, Libreria Clup, Milano, 2006

(**44**) FENTON J., Op. Cit, p. 6

(**45**) FENTON J., Op Cit., p. 7

(**46**) FERNANDEZ PER A., MOZAS J., ARPA J., Op. Cit.

CHAPTER 5

FROM THE BUILDING TO THE DISTRICT: REFLECTIONS UPON URBAN MORPHOLOGY

"The necessary step following the ZEB is the zero-energy district, prelude of the zero-energy city"

(F. Butera)

5.1 The energy issue as a new key for urban regeneration

As already stated in the previous chapter, hybrid building is a multifunctional building based on the idea of self-sufficiency, so as to create a sort of City into the City. Hybrid buildings usually tend to assume a monumental character, due to the idea they should work as urban catalysts and social condensers. Concentrations of activities inside them allow to get a dense settlement, so as to save soil and reduce mobility. At the same time they have a great potential as regards a flexible management of energy flows, since their layout favors flexibility and allows a greater control on loads' usage.

On the other hand this self-sufficiency could in some cases generate a sort of closure to urban context. For this reason several contemporary architectural projects studying hybridity are nowadays starting to investigate an intermediate scale between the building scale and the urban one: design scale becomes the one of the **block** or even that one of the **district** and design of public spaces in between is an integral part of the architectural design.

Moreover the intermediate scale of the district could represent also an interesting scale for the management of energy flows in the duo architecture/energy grid. The specific scale of urban neighborhoods could indeed offer an intermediate scale in its own right which holds the potential for a better understanding of energy supply and demand structures in the energy assessment of high performance buildings and settlements (**1**). District scale appears as particularly suitable in relation to the concept of "microgrid" and, strictly related, to the one of "energy district".

An **energy district** is a territorially localized settlement using energy: it is configurable as a single controllable unit in its relation with the electric grid. Transferring the concept to the architectural discipline, the energy district is a neighborhood, mostly autonomous in energy production and usage, which interfaces with the Smart Grid **as a single identity**. The concept appears as particularly fascinating, as it establishes a **relationship between organization of the energy network and urban morphology**.

Energy demand and supply have in many cases influenced planning: the physical-spatial value of energy is indeed universally recognized. The attainment of a considerable reduction of energy consumption cannot therefore be exhausted by the only intervention at the scale of the building, but should also necessarily involve the district scale. Urban form has got direct consequences on the energy usage and energy efficiency in cities. Several researches on energy planning in the more or less recent past have been focused on relationship between the morphology of urban settlements and

sunlight availability, since the site layout is one of the most important factors affecting solar gains.
If the relation between buildings, solar exposure and shading, the role of the S/V factor and analysis on mitigation given by green areas have been deeply analyzed by theoretical and practical research since the earliest experiments of the Modern Movement, a new approach to be discussed today is the possible relationship between urban morphology and energy management. Which kind of urban settlement favors a smart management of the energy loads? **Which features a neighborhood should have to work as an energy district?**
Try to answer these questions means to think about forms of urban aggregation according to a new conceptual paradigm. Moreover this reasoning could regard either the design of new neighborhoods or the intervention on existing districts. The **issue of urban regeneration** of neighborhoods in key energy is today highly topical: most of the Italian Public Housing estate reveals indeed today social, material and energetic decay. Particularly, we refer to public housing districts which have been built between the decade before the Second World War and the 80's of the Twentieth Century. These urban neighborhoods are today immediately recognizable into contemporary urban configurations: they indeed emerge as experiments which, in different historical periods, have tried to offer new visions on the theme of inhabiting, by the investigation and experimentation on the relationship between building typology and urban morphology. Conditions of environmental and economic crisis characterizing contemporary society represent the reasons why there is today a new deep interest around these neighborhoods.
Here the following the above mentioned questions will be generally discussed: particularly some reflections will be done on the case study of Tor Bella Monaca neighborhood.

5.1.1 The Virtual Power Plant model and the idea of Virtual Building

The progressive liberalization of the electricity sector and transition towards decentralized systems based on on-site technologies require an in-depth reflection on the future urban design. New layers of complexity need a multidisciplinary approach and a conscious design of the urban scale becomes necessary for the future energy management based on the Smart Grid model.
Since Smart Grids are organized on decentralized and multiple generations, the district scale of urban design becomes crucial, indeed "at the

district scale it is easier to modulate the demand and supply profile by means of different forms of virtual or physical storage, by using technologies that scale economy makes more economically viable. The necessary step following the ZEB is the zero-energy district, prelude of the zero-energy city” (**2**).

The urban form will be necessarily and directly affected by this new model of energy management, with formal implications regarding to urban density and building typologies.

Within the discipline of energy and electric engineering an interesting concept is that one of **Virtual Power Plant** (VPP). The VPP concept consists of aggregating the capacity of many distributed energy resources (DER) in order to make them more accessible and manageable across the energy markets (**3**). By the aggregation of DERs, a single operating profile is created, to make it more accessible and manageable across the energy market . Virtual Power Plants can be defined as collective generators of renewable energy sources that can store and adjust energy output on demand and at will (**4**). They can be employed to co-generate with current grids or operate alone. The Smart Grid model needs virtual power plants´ units to locally better control generation, storage and demand of energy of the system, which otherwise would be too complex to be managed in a properly way.

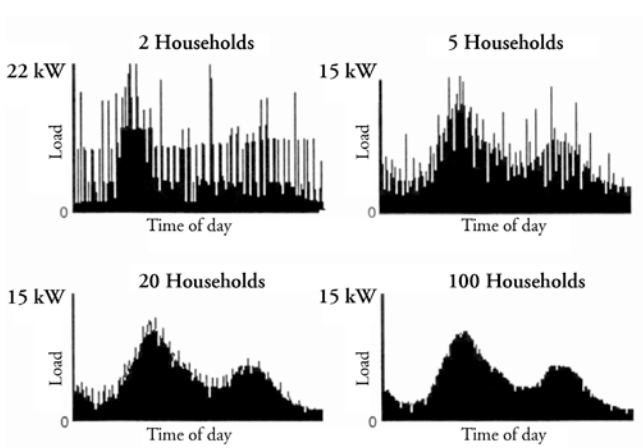
The energy district is the **paradigm to identify a new sustainable energy system** set on the concept of Virtual Power Plant: it is indeed intended as the spatial configuration of a Virtual Power Plant: **a “unit” which interfaces to the grid as a single profile**.

A further development of this concept could be then introduced, the one of “Virtual Building”: **a Virtual Building could be defined as a group of buildings (e.g. buildings of a neighborhood) which operate in their relation with the grid as a single one**. The Virtual Building concept is based on the virtual power plant model, since it is the result of aggregation of different buildings with an own energy behavior , so as to form a unit which interfaces individually to the energy grid. If we imagine the neighborhood as a Virtual Building, it is easy to consider it like a sort of huge hybrid building interfacing to the electric grid.

5.1.2 Why urban design at the neighborhood scale?

The main purpose of this section is to demonstrate that what has been analyzed at the scale of the building could work, and perhaps also with a greater level of effectiveness , even at the urban scale of the neighborhood,

considered as a Virtual Building. As mentioned, it is just at the scale of the neighborhood which in the last years, since the introduction of the concept of Smart Grid, the relationship between the energy network and buildings has been identified and defined: it appears quite clear if we consider the definition itself of "energy district". However, this relationship has been mainly been focused on systems of energy production and distribution and on the development of ICT technologies for real-time control of demand and supply. Urban morphology has almost not been involved into the reasoning, mainly focused on a purely engineering technical aspect.
We state that all the considerations we have analyzed through the case study in the previous chapter (R5 building) could then be easily transferred by **analogy** to the urban scale of the district, with **even a better chance of energy saving**.
This is because the district, compared to the building, has got:
a- **Greater possibilities regarding to design actions**: structural and dimensional limitations of the building scale are significantly reduced, so that possibilities of urban settlements increase. Generally speaking, it is indeed easier to place mixed users and different functions at a larger scale that matches that one of the district, that within a single building.
b- **Expected flattening of the load curve**: while individual uses often show very peaky patterns linked to the individual system's operation a large number of users show a smoothing of loads related to the time shifts of use patterns. Hourly load curves indeed vary depending on the scale of the assessment yet above a certain number of households the systems can be



44. Average energy load curves per number of households. We can notice that, with the increase in the number of inhabitants, the average curve tends to be more uniform expected to behave similarly without showing a strong smoothing effect by further enlargement of the system boundary (5). This concept is at the base of the statistical discipline (refer to image 44)

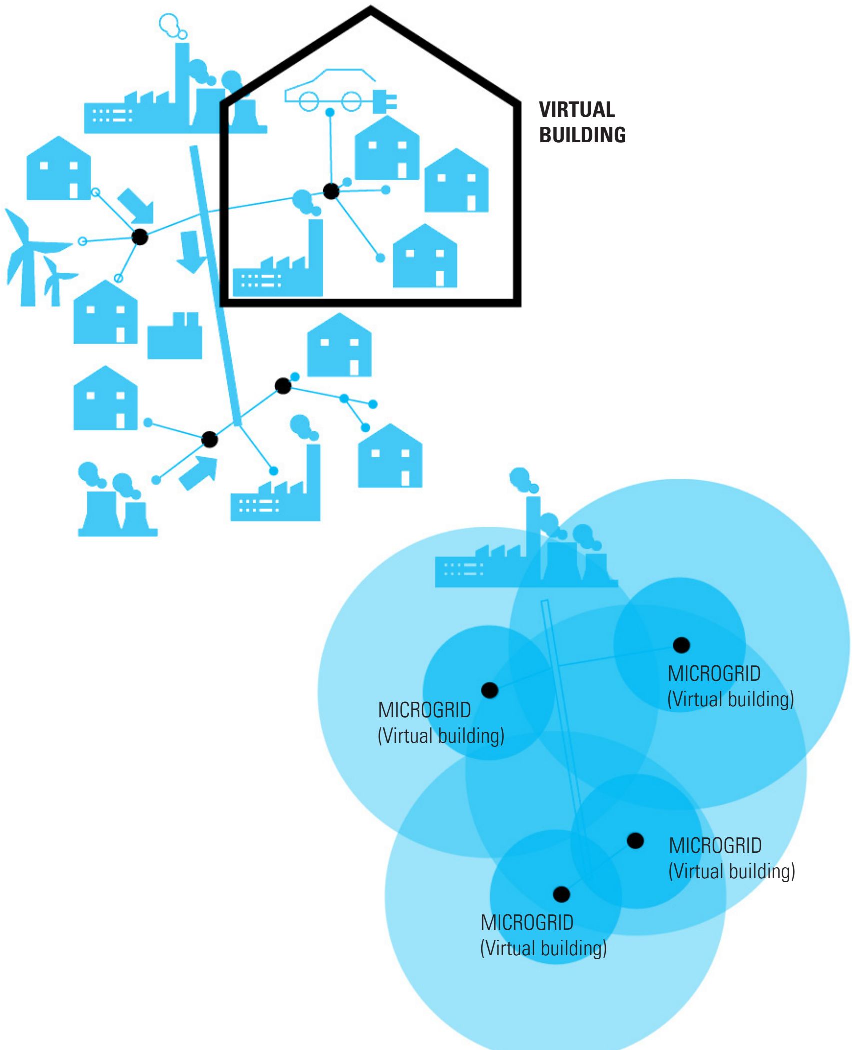
c- **Greater repeatability** within the urban fabric: it is indeed easier to replicate energetic self-sufficient districts than self-sufficient individual buildings (this is due to the typology itself of the hybrid, which cannot adapt to every kind of urban context and sometimes does not work if repeated several times into the urban pattern)

d- **Greater efficiency of plants**: up to a certain size, due to a scale factor, a unique big plant is more efficient than several smaller plants whose sum of powers is equal to the one of the big plant.

e- **Chance to consider more consistent energy loads** (refer to paragraph 4.2.2 for cogeneration at the district scale), which are more interesting for the global energy management at a regional or even national scale

5.2 Case study at the district scale: Tor Bella Monaca neighborhood

The on-going reasoning could of course be applied both at the design of new neighborhoods or to existing districts. Particularly, it is interesting a deep **reflection on existing neighborhoods**, which could quite easily function as energy districts through just simple targeted design actions. To do this, as mentioned, it would be necessary to replicate those features identified and verified through the development of the case study for the individual hybrid building. Next paragraphs are dedicated to an analysis at the district scale: once again new design operations are conducted, in order to test effects of the identified parameters (mixed users, different models of consumption, temporal flexibility, independence and self-sufficiency), but this time the study is carried on at the district scale, on Tor Bella Monaca neighborhood. This case study is just an **outline for a possible development of future research**: it is indeed a highly simplified case that could only give a general idea of the potentialities of urban scale for a development of energy management into the contemporary city. Since an accurate and precise energy simulation at the scale of the whole neighborhood is extremely complicated and involved parameters would be many and varied, here below a number of simplifications are conducted: they will be one by one explained in the following paragraphs.



45/46. The scheme shows the concept of "Virtual Building" as the aggregation of several buildings and utilities interfacing to the grid as a single profile. According to this model, Tor Bella Monaca could be considered as a Virtual Building which works as a unit in its relation with the main energy grid

5.2.1 Mixed users

An example comparison between a monofunctional layout and a one inhabited by mixed users is conducted. Analysis is led with the repetition of the same building, which is the one of the case study at Chapter 4 (R5). In order to get a precise analysis, calculation should be done analytically on every building of the neighborhood: however this type of calculation would be too difficult and not all the input data of the involved buildings are known. For this reason a simplified model is created: R5 is then repeated 6 times and a different usage profile has been assigned to every building. Usage profiles are the same used for the different dwelling typologies of Chapter 4. Here the following the simplifications applied to the realized model are listed:

- All the repeated buildings are oriented at the same way and enough far away each other to not affect their mutual solar gains
- At the time when the effects of mixed users are tested, a usage profile for each of the 6 buildings is considered: this means that different utilities are not evenly spread in the 6 buildings. Taken individually, each building appears as monofunctional, but the whole group of buildings appears as inhabited by mixed users

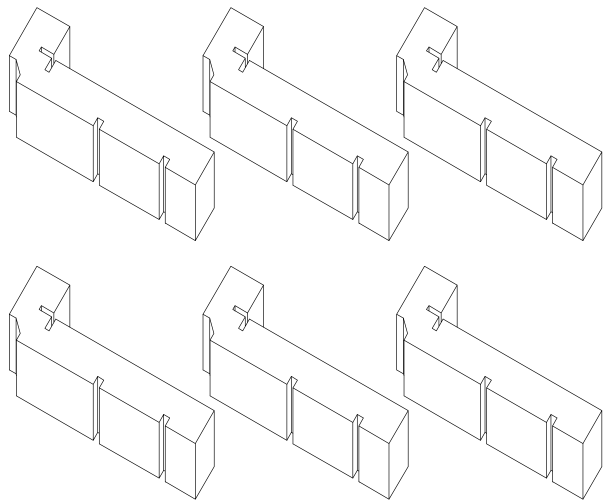
The method is the same used at the scale of the single individual building (Chapter 4): the comparison of the energy load curves through standard deviations of each one of them (Image 53).

The energy load curves of the two different configurations may be obtained from the sum of the individual load curves of each building. Once again, it is noticed that the group of buildings inhabited by different type of users has got a lower standard deviation, compared to the monofunctional layout. This means that energy usage over time is more constant during the 24 hours of a day and energy peak loads are reduced compared to the ones of monofunctional settlement.

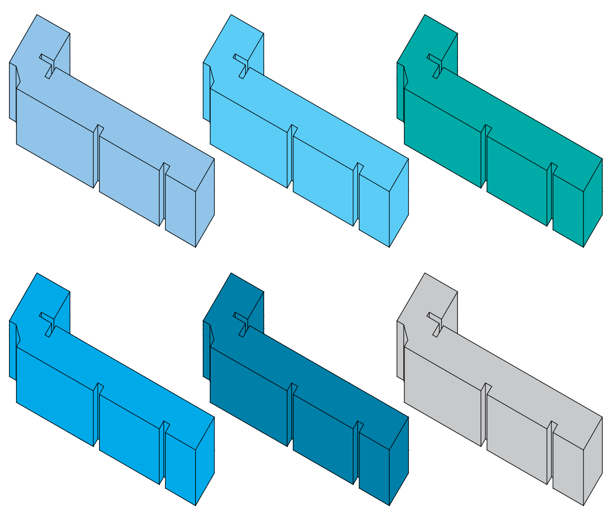
47. DRAWING 7

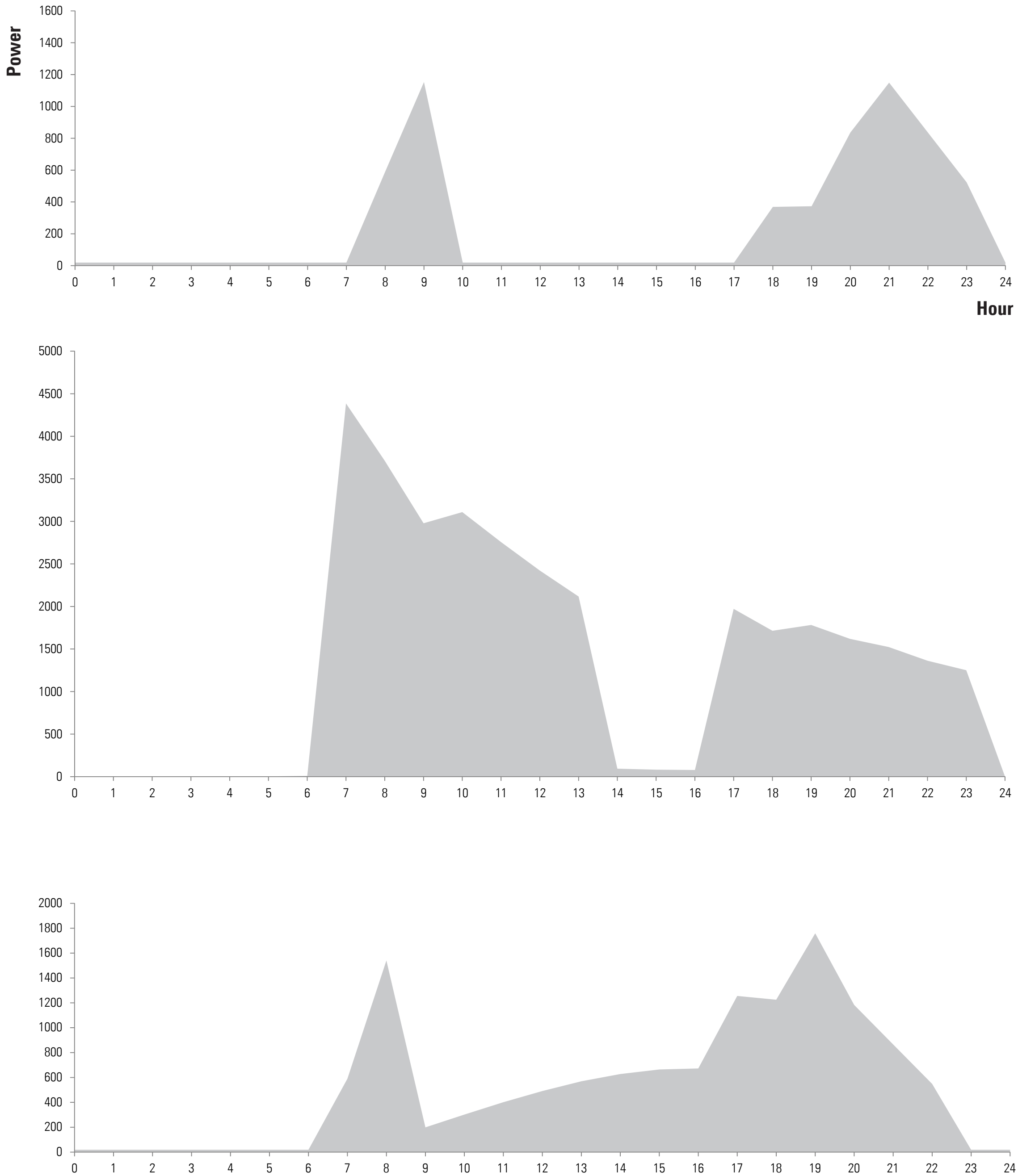
In the monofunctional layout the same building typology is repeated 6 times. The usage profile used for calculation is the one of the state of art, which has been reported 6 times. In the mixed users' settlement building typology is again the same, but we have hypothesized to insert a different dwelling typology in each of the 6 buildings which compose the district. For convenience of calculation, usage profiles are taken from the ones of the dwellings designed at the building scale. This means that each building is hypothetically occupied by the same dwelling type and, consequently, by the same type of user. However, taken as a whole, the neighborhood is inhabited by mixed users

MONOFUNCTIONAL DISTRICT



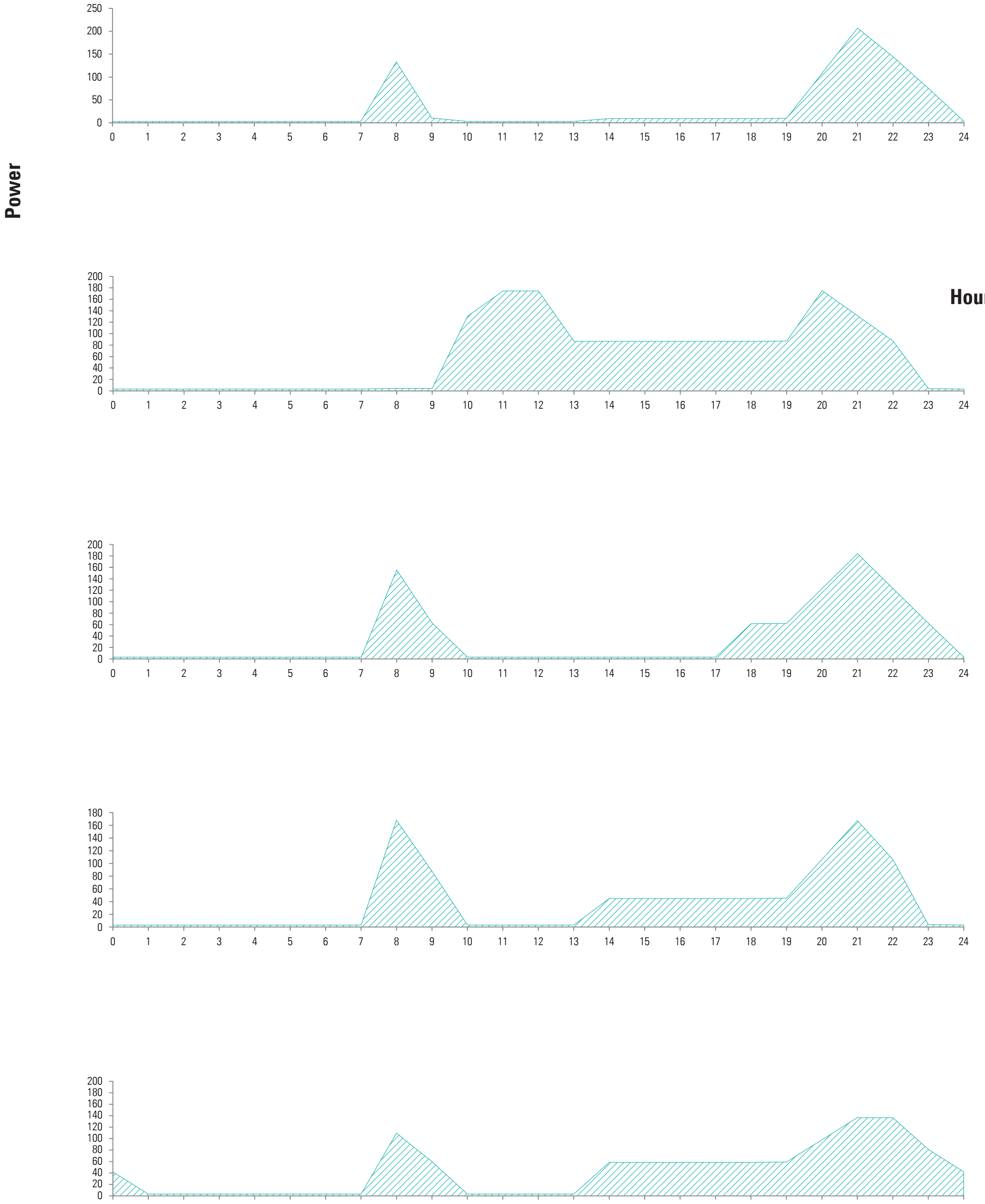
MIXED USERS' SETTLEMENT



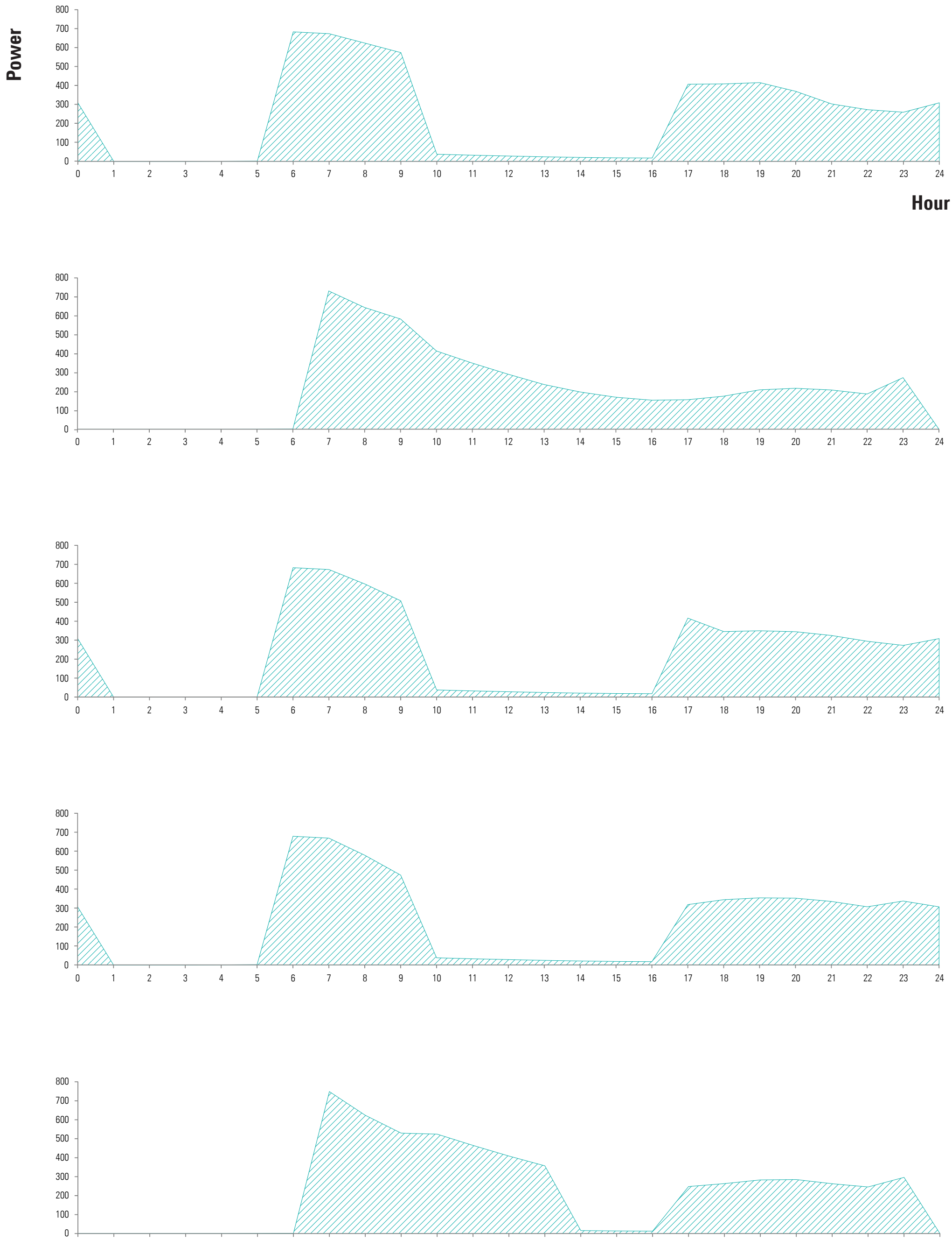


48. Used power for gas and electricity consumption in the monofunctional district composed of 6 buildings and the same type of users

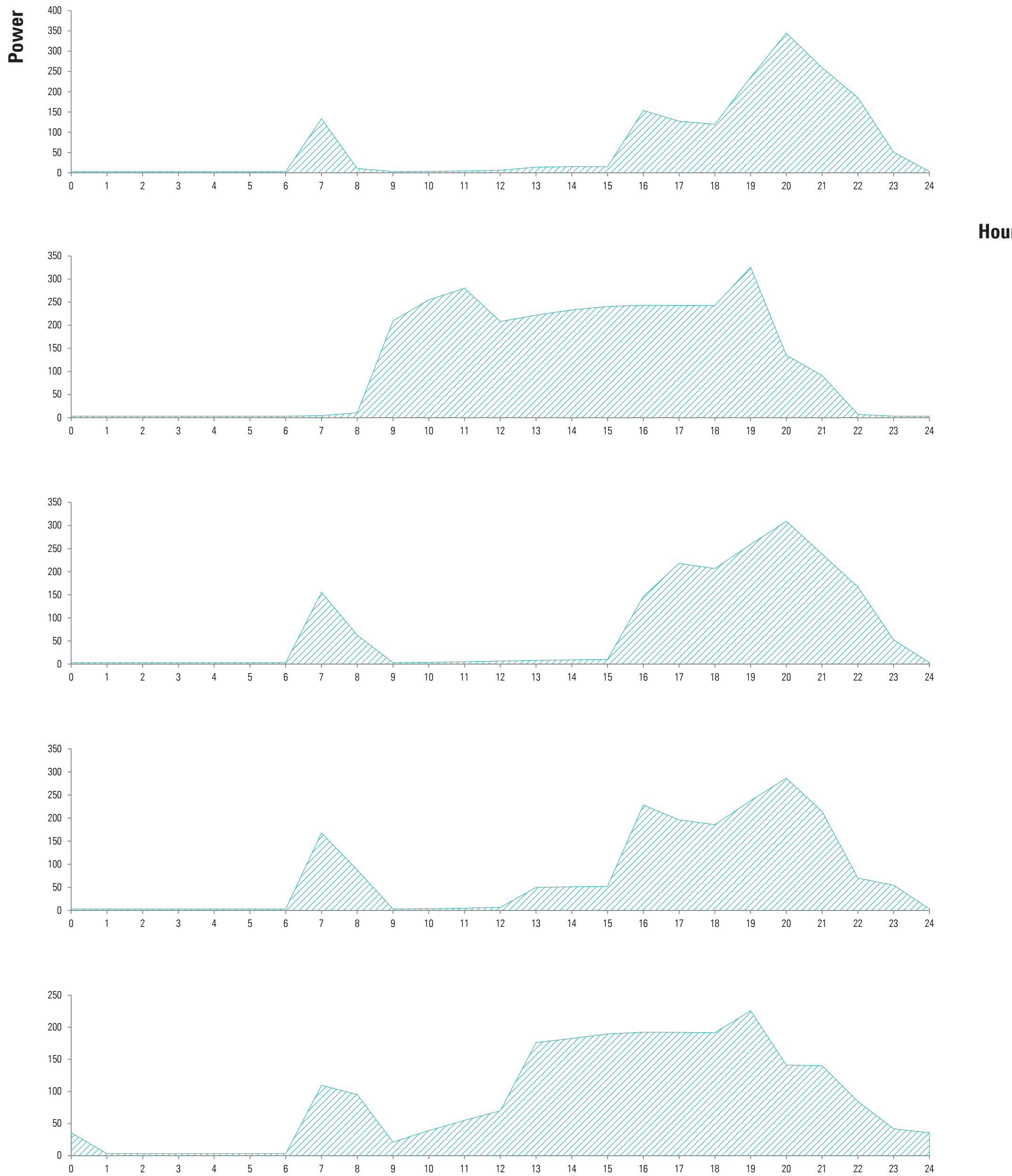
a. Electricity / 1st January
b. Gas / 1st January
c. Electricity / 15th July



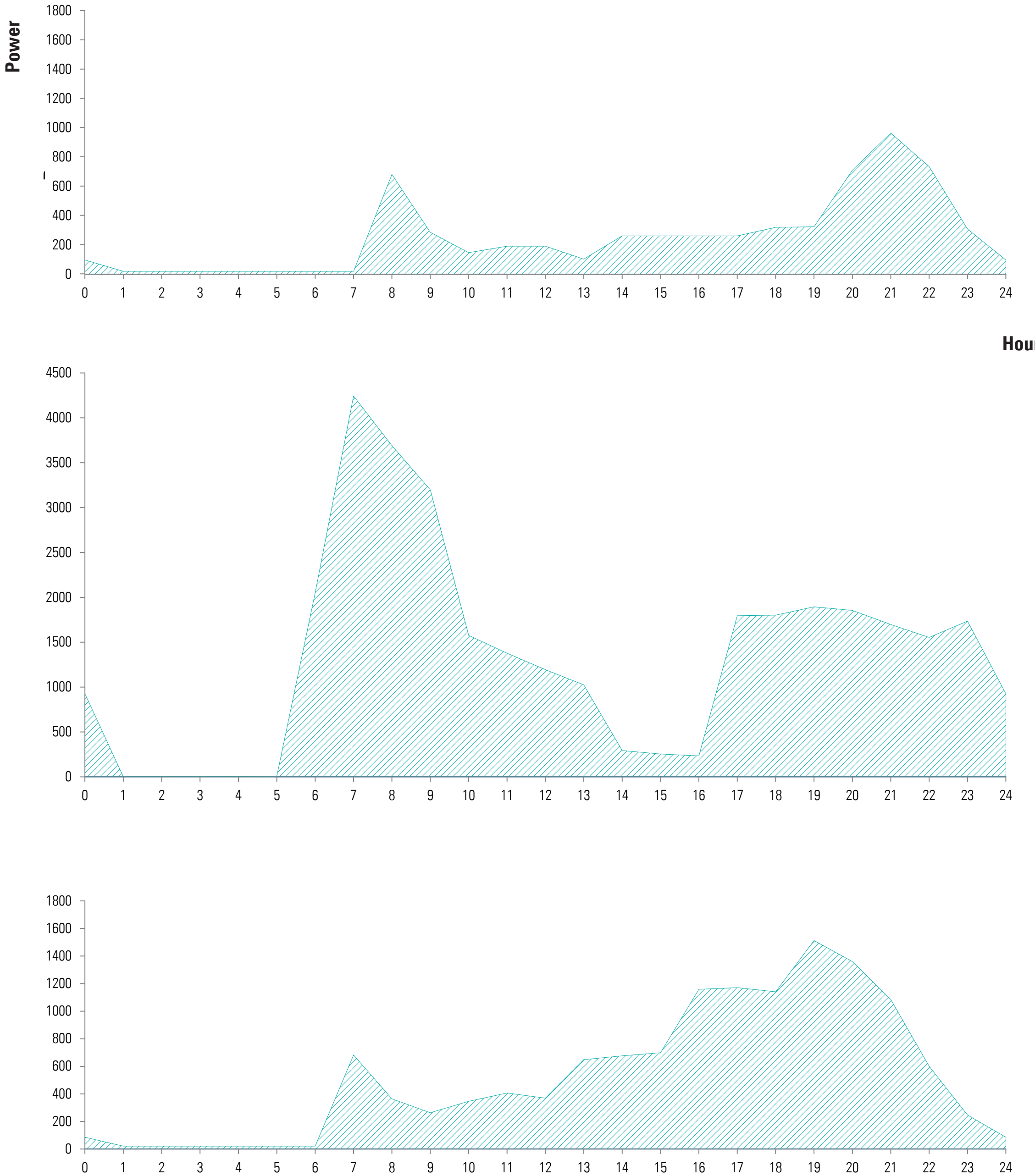
49. Energy load curves for electricity consumption of each building of the mixed users' settlement at a winter day (1st January) are here showed, to be lately summed in a general load curve.
First graph represents the building with the usage profile of *Type a* of the paragraph 4.3.3.2, the second one is the one of the building with the usage profile *b*, the third one corresponds to *Type c*, the fourth one *Type d*, while the fifth one has got the usage profile of *Type e, f* and *g*. What appears both from this graphs and from the following ones (Images 50 and 51) is that load curves have different peaks of demand: by the mixing of these buildings into the same urban neighborhood global peak loads are then intuitively reduced



50. Energy load curves for gas consumption of each building of the mixed users' settlement at a winter day (1st January) are here showed, to be lately summed in a general load curve. First graph represents the building with the usage profile of *Type a* of the paragraph 4.3.3.2, the second one is the one of the building with the usage profile *b*, the third one corresponds to *Type c*, the fourth one to *Type d*, while the fifth one has got the usage profile of *Type e, f* and *g*



51. Energy load curves for electricity consumption of each building of the mixed users' settlement at a summer day (15th July) are here showed, to be lately summed in a general load curve. First graph represents the building with the usage profile of *Type a* of the paragraph 4.3.3.2, the second one is the one of the building with the usage profile *b*, the third one corresponds to *Type c*, the fourth one to *Type d*, while the fifth one has got the usage profile of *Type e, f* and *g*



52. Used power for gas and electricity consumption in the mixed users' settlement composed of 6 buildings

a. Electricity / 1st January
b. Gas / 1st January
c. Electricity / 15th July

53. Curves of the daily consumption of gas and electricity of the two urban settlements.
Standard deviation of the two curves is compared in the 3 cases: what emerge is that standard deviation of the new design is always smaller. It means that peak loads are overall reduced

a. Electricity / 1st January
b. Gas / 1st January
c. Electricity / 15th July

5.2.2 Different models of consumption

We have seen in paragraph 4.3.3.3 that different models of consumption could favor an on-site use of energy, if technologies such as cogeneration or trigeneration are integrated to the project. In this case some considerations are conducted not on the simplified model (as in the previous paragraph), but on the whole Tor Bella Monaca district.

At the scale of the neighborhood it is obviously easier to provide for a **diversification of functions**: according to a functional analysis, Tor Bella Monaca already hosts a great extent of residences, but also sport facilities (such as playgrounds and a pool), a service center with office activities for the community and retail, primary and secondary schools. This kind of layout, if implemented in its multifunctionality and associated with a trigeneration plant and a set of storages, favors the simultaneous and *in loco* production of electricity and thermal energy in the form of heating and cooling, reducing the energy demand to the main electric grid.

At the district scale, however, this type of system, if taken alone, could not be the most efficient one: what appears from literature review is indeed the importance at the district level of a **diversification of energy sources**. We can trace several recent studies investigating the coexistence of sources so as to maximize the global energy management of the district (**6**). At the scale of the neighborhood, together with cogeneration/trigeneration, it would be instead appropriate and extremely indicated to provide for the diversification of sources of energy supply, so has to have a **better tracking of energy loads over time**. This means that, in the case of blackout or general overload of one of these systems, still there would be other forms of supply which determine the energy independence of the neighborhood. Diversification of energy supply could be realized by the **integration of renewable sources into urban design**, such as thermal solar, photovoltaic, geothermal or wind power. At the district scale would therefore be important, together with a diversification of functions, to start reasoning on the **role of renewable technologies into urban design**, on their relationship with buildings of the district and on their location inside the urban settlement. Finally, at the scale of the district, it would be good to combine together a multifunctional layout which favors a system of energy offsettings and a diversification of energy resources, which contributes to allow a certain level of independence of the neighborhood from the main electric grid. At the end of the chapter urban strategies towards the Virtual Building model have been identified and reported through plans and sections' diagrams: also, the best position to locate plants for energy production and storages (trigeneration plant+thermal storages) has been identified (refer to Drawing 9).

5.2.3 Temporal flexibility

Temporal flexibility in the use of urban areas is commonly indicated as an important factor to determine success of a urban settlement in terms of social integration and livability. Since the first critics of the Modern Movement it has been indeed indicated as an added value for development of urban settlements, since it is the means both to achieve a state of social mix and to avoid ghettoization. The "prevalent use of blocks" is an index which identifies the main functions into the urban fabric: it is extremely important to understand livability and behavior of a neighborhood. It is commonly used as a yardstick in urban policies, so much to be considered also a key indicator to determine the level of security of a district (7). This means that **functions and temporal use of spaces** are two strictly linked parameters.

From the analysis of energy behaviour at the building scale, it emerged that the availability to anticipate or post-pone some activities over time is particularly important for the global energy management of the building itself. At the neighborhood scale it is probably more complex to act on the use of spaces, by opening or closing them according to the real-time needs of the electric grid, since variables involved increase. However what becomes essential at the district level is the **coexistence of functions with different time-usage over the day**, so as to obtain an energy usage as much as possible **uniform over the 24 hours**: this means to fix the goal of mixed-use districts both regarding to new urban design and regeneration of existing urban areas. Serge Salat defines some principles for the design of new neighborhoods responding to a sustainable approach: among them we can find Principle 1 ("High density and mixed use"), in which he emphasizes the importance to create a rich network of diversified destinations. This principle is reinforced and supported by Principle 6, in which he states the necessity to provide for heterogeneous communities. Both these principles have been analyzed since they favor social mix and they reduce travel distances, but they appear also essential to guarantee a more distributed use of spaces over time (8).

Alberico B. Belgiojoso states that the time factor is absolutely crucial in architectural design, as architects do not deal with static situations corresponding to the starting time of the design action, but on the contrary each project might be analyzed in its temporal development. He then identifies

those factors in which the time variable becomes decisive: one of them is the functioning of the city itself, with its uses and activities over time (**9**). Urban land policies are nowadays increasingly focused on the time factor, for an efficient and sustainable use of spaces.
Reasoning on the role of the time dimension into urban design becomes then fundamental both for an effective design at the urban scale and also for an efficient use of energy, so as to distribute as much as possible energy loads over time. **Spatial and temporal use** of the city take therefore both the equal importance in the control of energy flows of the Virtual Building.

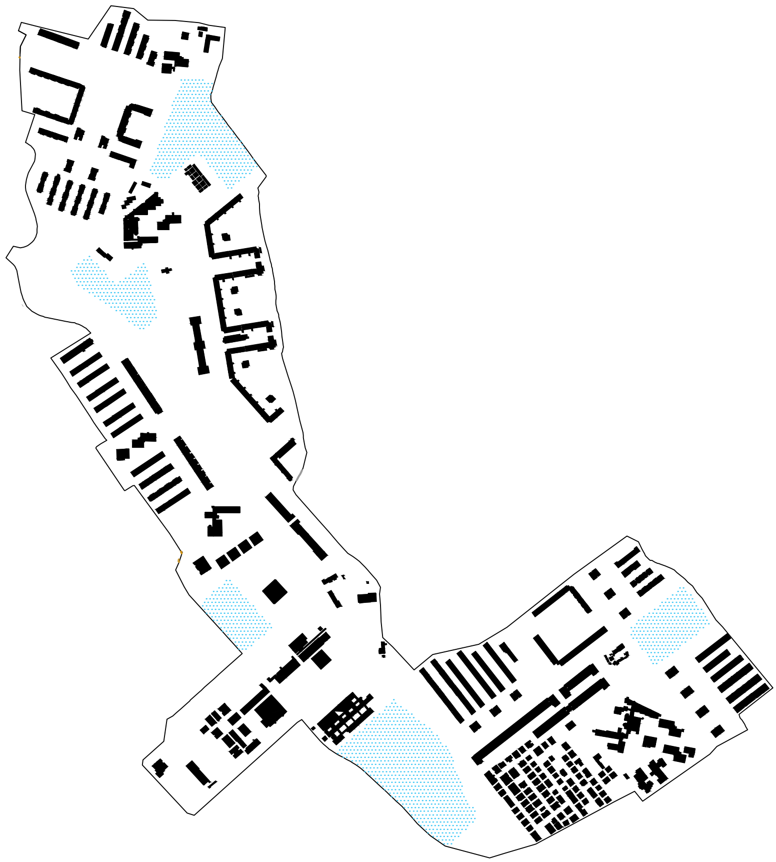
5.2.4 Independence and self-sufficiency

Storage systems are essential elements in the microgrid of the district scale. Particularly, they become fundamental if the microgrid is integrated with renewable sources at the intermediate scale of the neighborhood. As already stated, renewables are indeed characterized by a certain level of umpredictability: that is why it would be important to guarantee a minimum threshold of stored energy for the energy supply of the district.
Moreover energy production tipically takes place in certain moments of the day which usually don't fit with the time of energy demand (for example if we think about solar energy production it usually reaches the maximum level of performance during the central hours of the day, while the peak of energy demand is usually at late evening). Short term energy storages become essential to shift energy usage when it is more useful during time.
For these reasons plants for energy storage are becoming more and more essential in the Smart Grid system at the urban scale and architects should take into consideration the issue of placement of this technological equipment from the first steps of urban design.
They can both be located immediately close to the energy production (typically small storages close to every single building), or they can be bigger ones not strictly close to each user (where the user is intended here as every single building). In both cases the integration between plants and buildings or between plants and neighborhoods should be taken into account.
Sizing of storages at the district level is particularly complex since there are many involved variables: this type of work is purely related to engineering. What should be of interest to the architects is **the role that this technical apparatus will take in the urban design of the city**. These elements should

in fact not be considered only as a technical support to the built environment, but as an integral part of the urban landscape of contemporary cities. Regarding to this topic, architectural compositional research is still mainly non-existent, but this issue would probably become crucial in the close future in order to define new urban spaces which will be able to reply to the contemporary energy emergence.

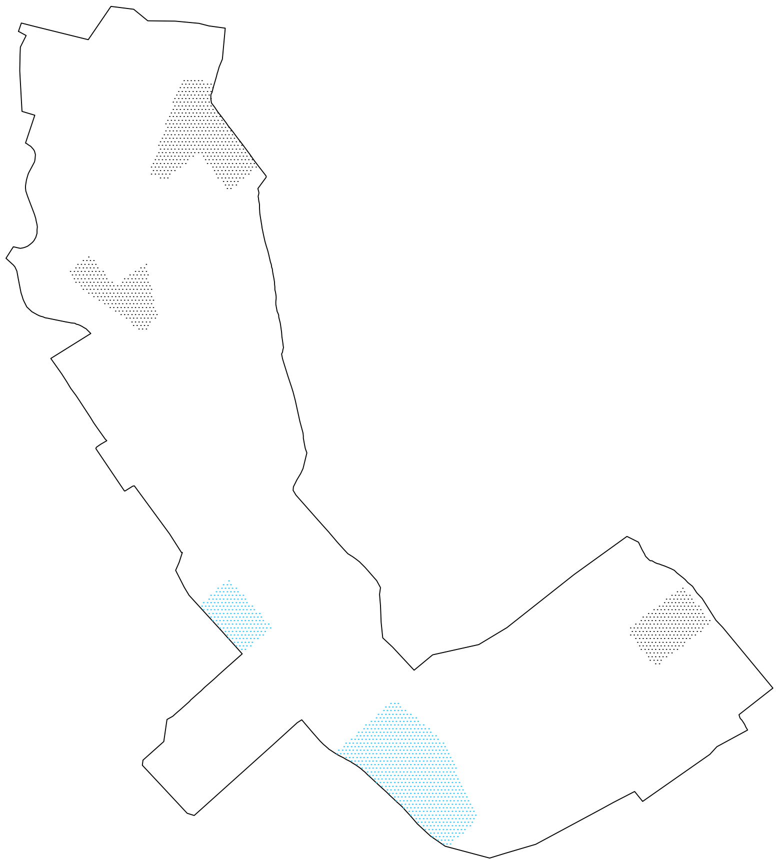
5.3 Urban strategies

What emerge from literature review and the conducted analysis is that the intermediate scale of the neighborhood would be particularly favorable for the energy management of buildings in their relation to the grid. The main idea is to consider the district as a kind of big unique system (what we have called "virtual building") facing to the grid as a unit. As we have seen at the building scale, even at the urban scale of the neighborhood, through a series of design expedients, it is possible to favor a good energy behavior for the district itself: these design operations are, again, linked to parameters we have already defined for the single building (mixed users, different models of consumption, temporal flexibility, independency and self-sufficiency) At the beginning of this chapter we have reasoned by analogy from the hybrid building, intended as an autonomous social condenser of activities, to the small neighborhood. We also found that neighborhoods are potentially even more suitable to act as "energy units" interfacing to the energy network because of several reasons, listed at paragraph 5.1.2. Once affirmed and analyzed these potentials, here below some architectural design strategies and operations of regeneration at the urban scale which could affect the energy management of the neighborhood are synthesized through the instruments of plan and section diagrams (**10**). What emerge is that some typical operations which are typical of architectural composition (design of the typology, design of the building's ground floors and coverings, densification, integration between architecture and urban infrastructure) are able to produce beneficial effects on the energy management of the neighborhood itself. Architectural and urban design should therefore take on a crucial role in the necessary process of energetic regeneration of several urban areas of our contemporary cities. Energy retrofit programs should not concern just the definition of parameters and minimum standards related to physical values of building elements and efficiency of plants. On the contrary energetic regeneration would be improved by a conscious design at the urban and building scale, with a conscious attention to the functional program of the building/district.

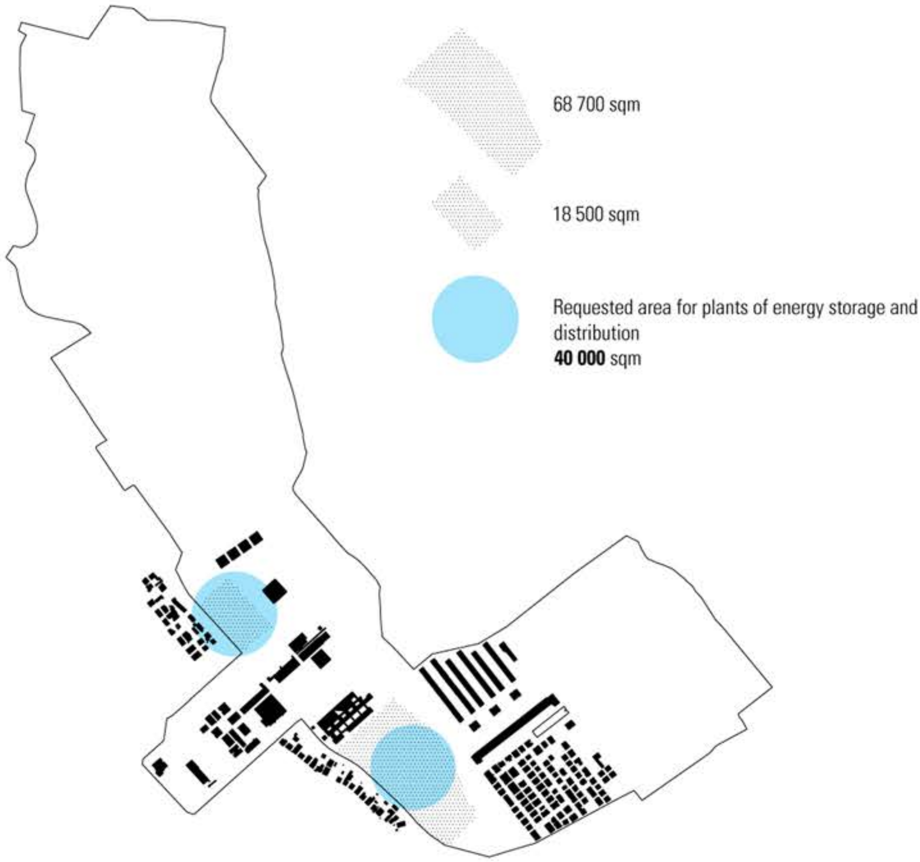


54. DRAWING 8

This series of drawing shows studies on the location of the plants for energy generation and storages in Tor Bella Monaca neighborhood. Provided indications are mainly related to the geographical location of the plants: the most important aspect is indeed their position into the neighborhood, which should be as much as possible baricentrical in order to reduce losses along the distribution line. Particularly, Drawing 8 shows urban voids of the neighborhoods, the areas for a possible location of generation plants and energy storages

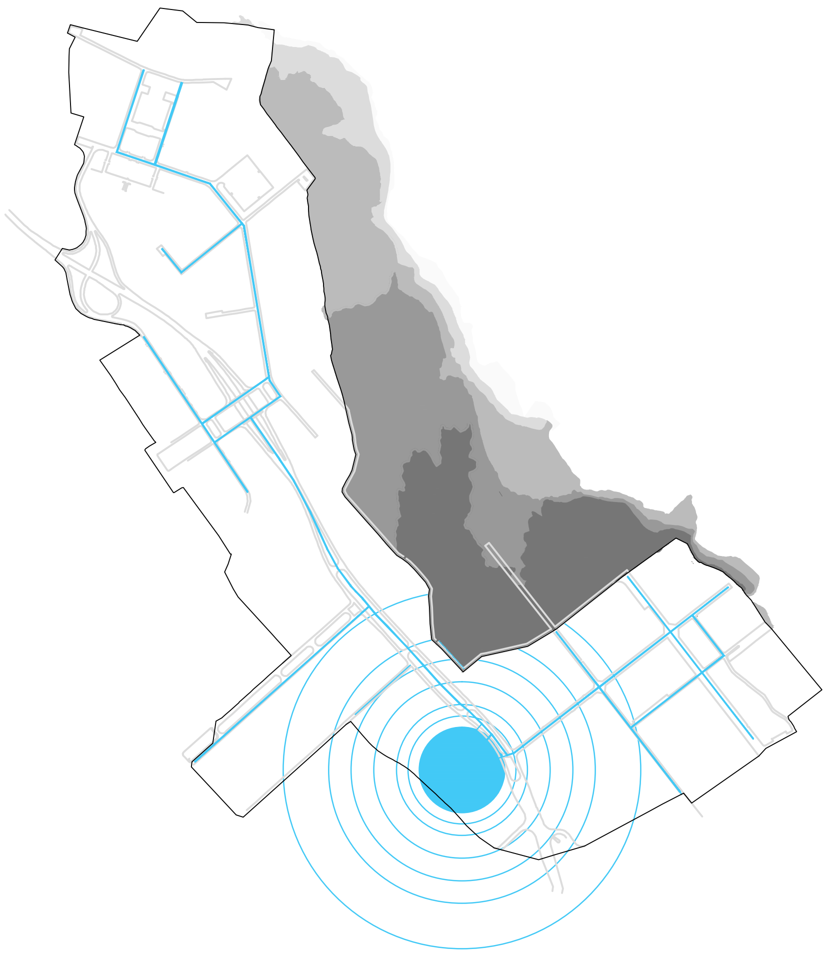


55. DRAWING 9
Plants are more efficient if located in a baricentric position. Some areas (coloured in black) are therefore not indicated to host the plants

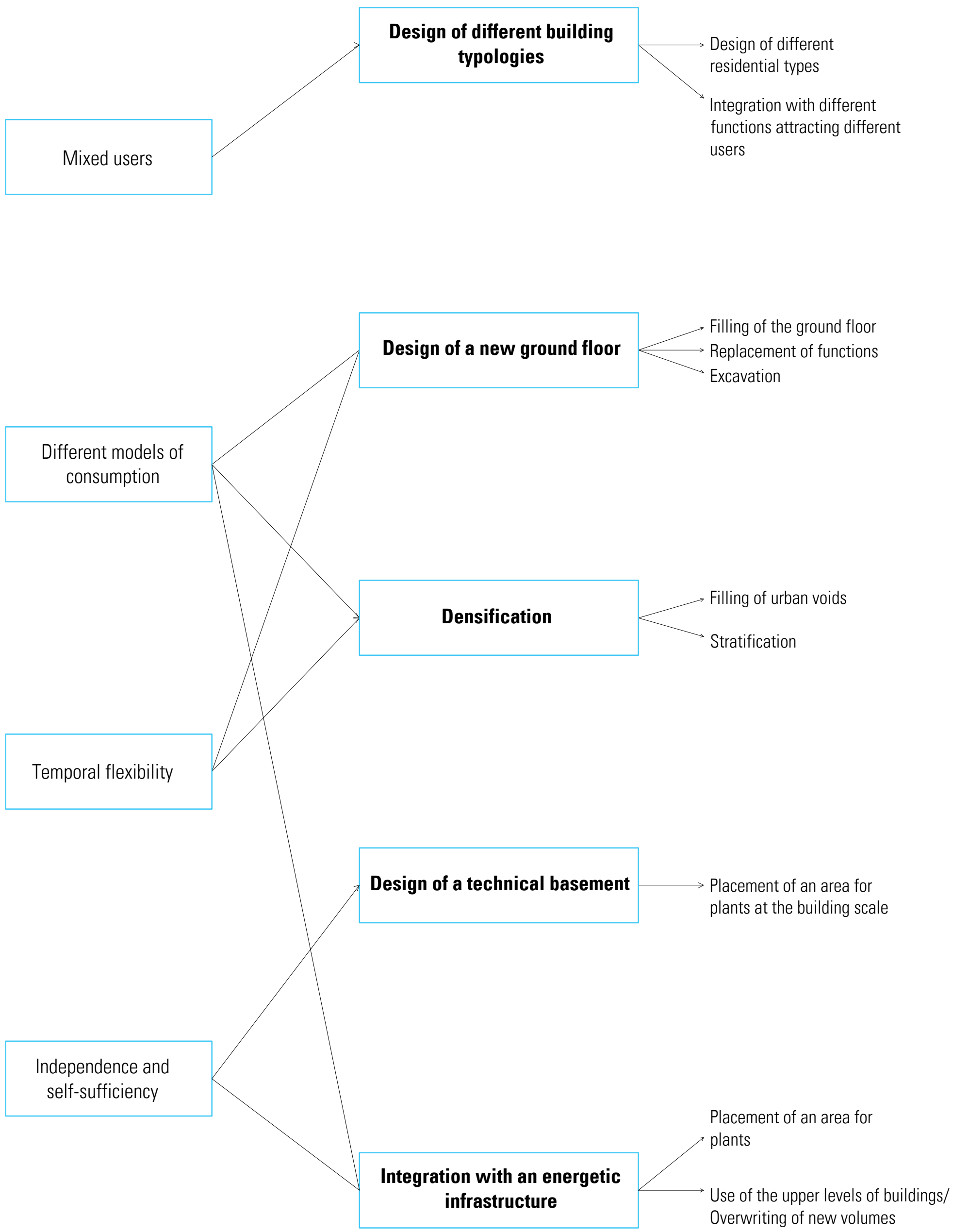


56. DRAWING 10

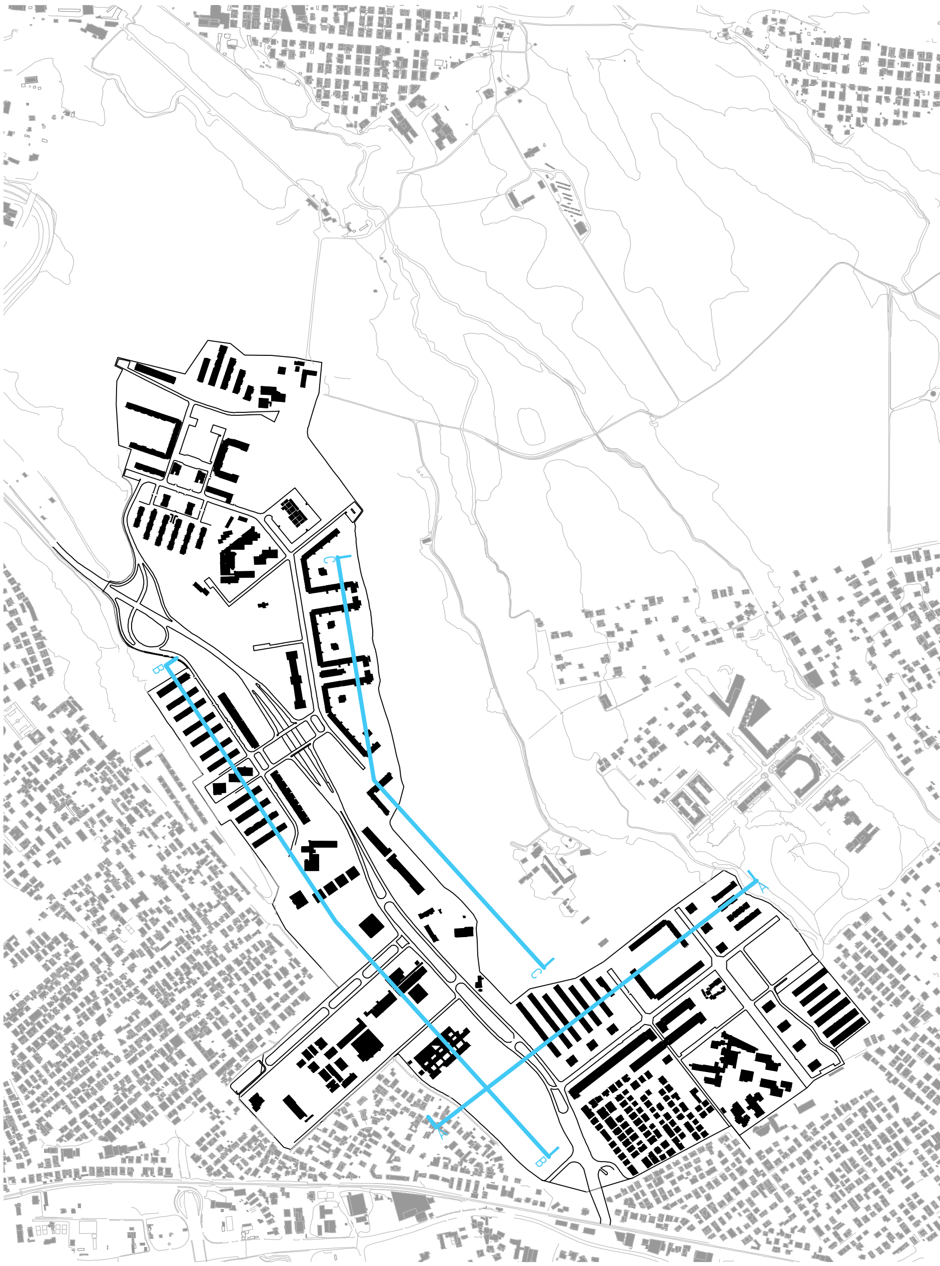
A general estimated of the necessary area for generation and storage plants has been conducted, taking into account that the whole district has got a population of 28000 inhabitants, while the studied block of R5 building hosts approximately 280 inhabitants (1/100 of the those of the district). The reasoning has therefore been conducted by making a maximum proportion to get necessary area for thermal storages and electrical and thermal generation. Moreover square meters for production by solar photovoltaic have been hypothesized (they have been exstimated 5000 sqm) and a certain amount of surface for fire estinguishing pools and security systems has been considered. In the calculation a surface 10% more has been estimated, in the event of demographic or physical expansion of the neighborhood. Obtained value is approximately an area of 40000 sqm, to be compared with the possible selected areas inside the neighborhood



57. DRAWING 11
Baricentric position of the plants allows to reduce losses along the distribution lines

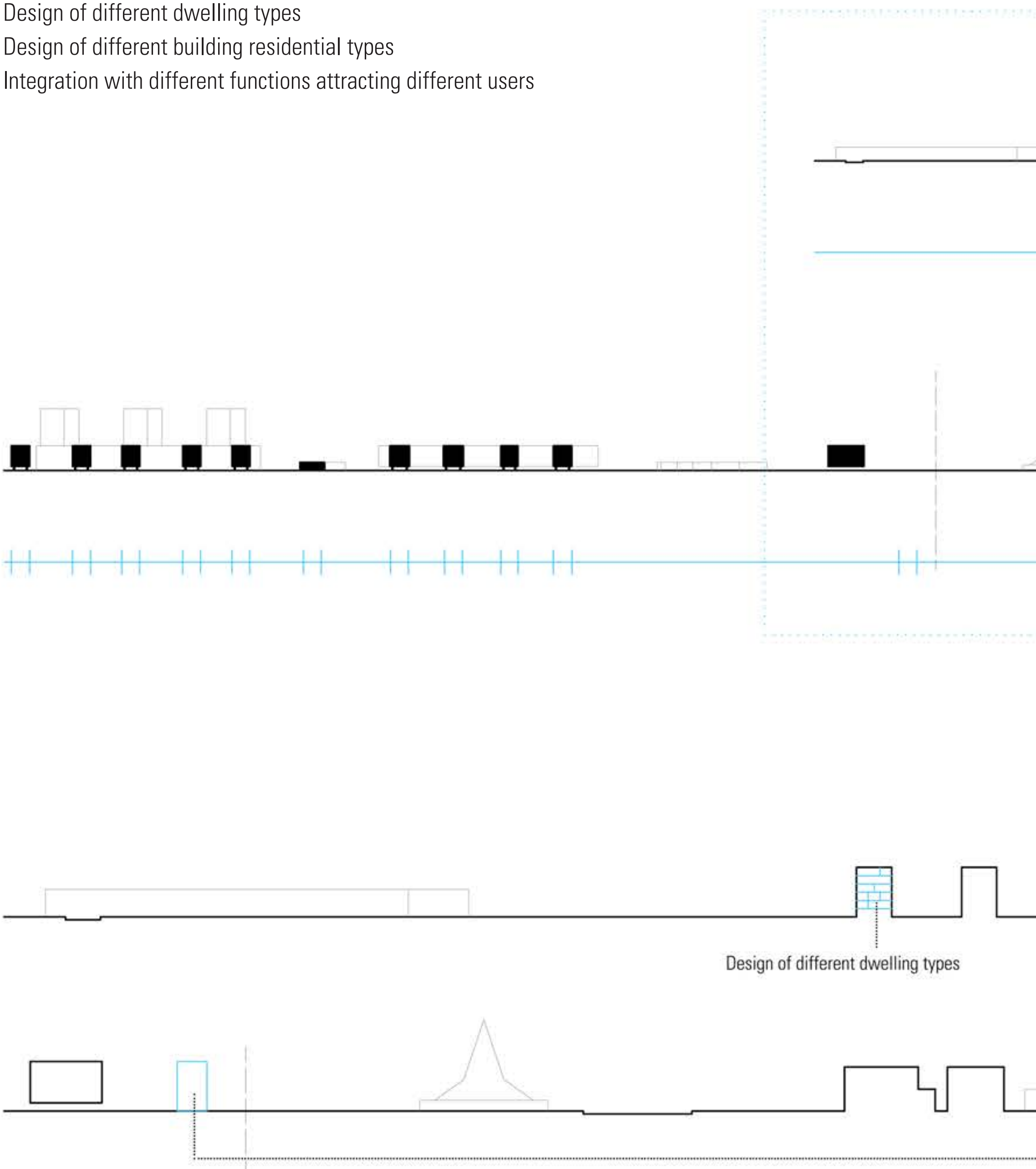


58. DRAWING 12
Map of Tor Bella Monaca: section lines are indicated

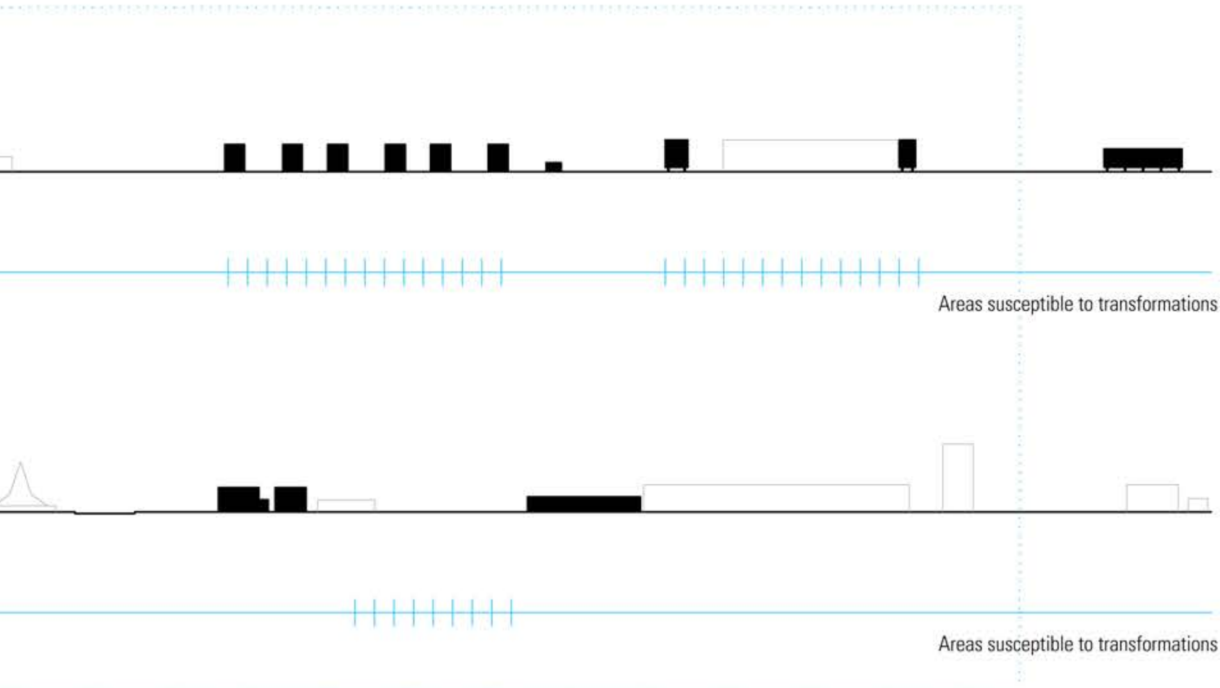

A
A
B
B
C
C

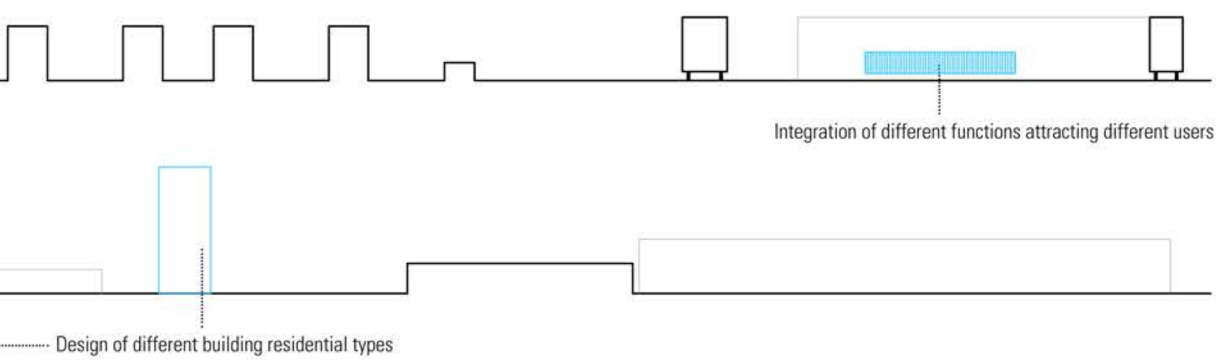
Design of different typologies

Design of different dwelling types
Design of different building residential types
Integration with different functions attracting different users



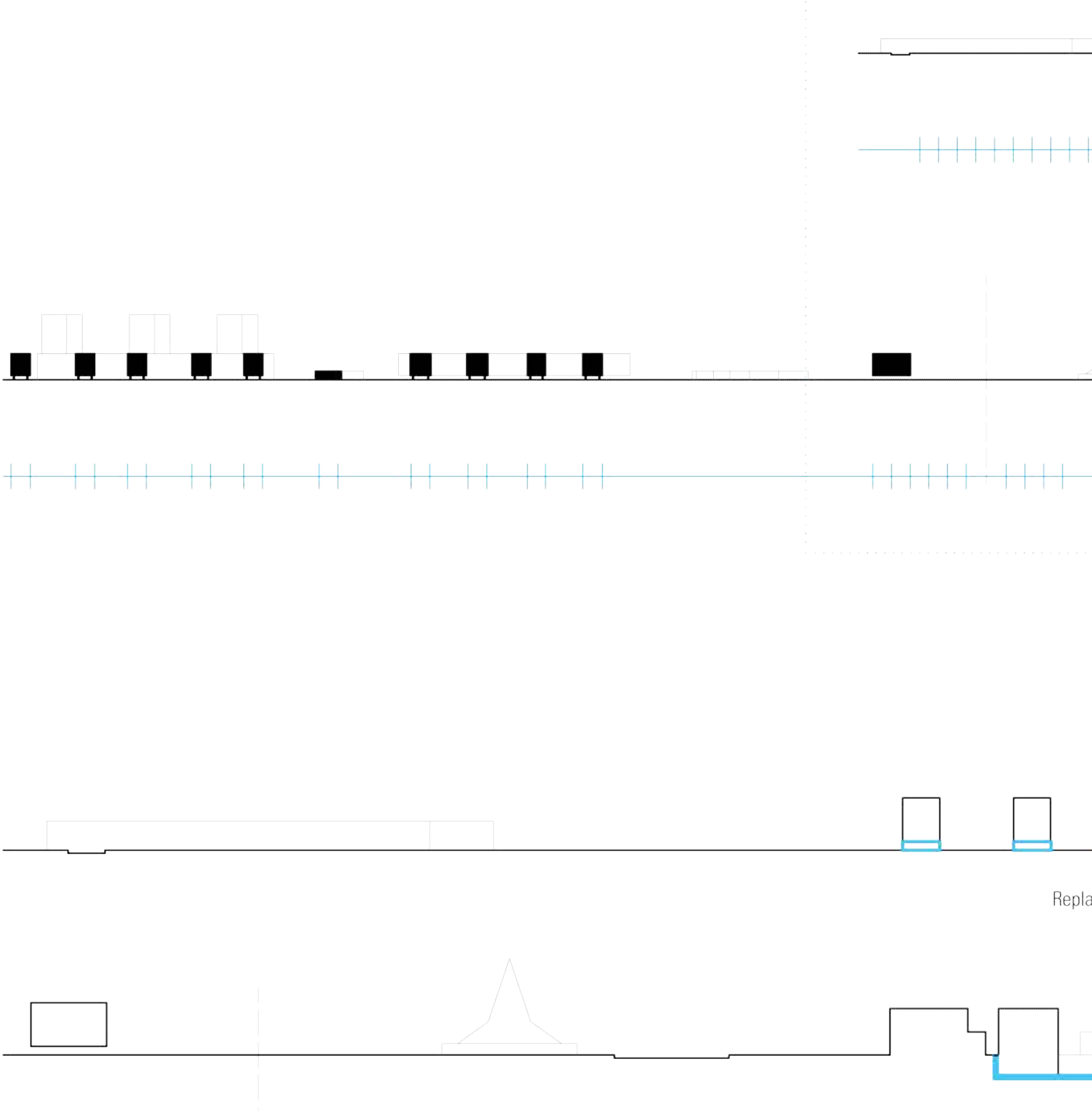
59. DRAWING 13
Sections AA and BB, scales 1:5000 and 1:2500


Areas susceptible to transformations
Areas susceptible to transformations

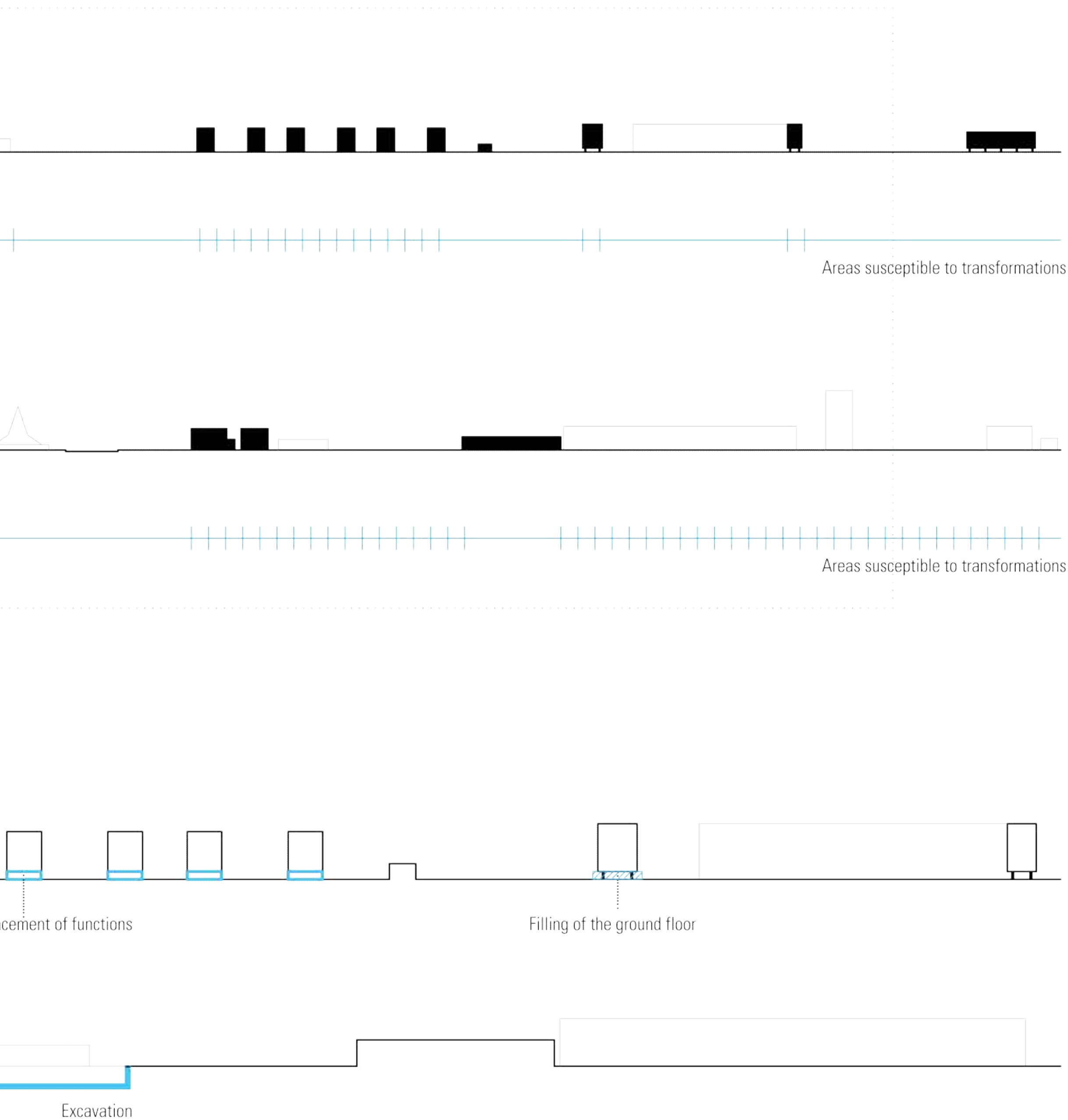

Integration of different functions attracting different users
Design of different building residential types

Design of a new ground floor

Filling of the ground floor
Replacement of functions
Excavation



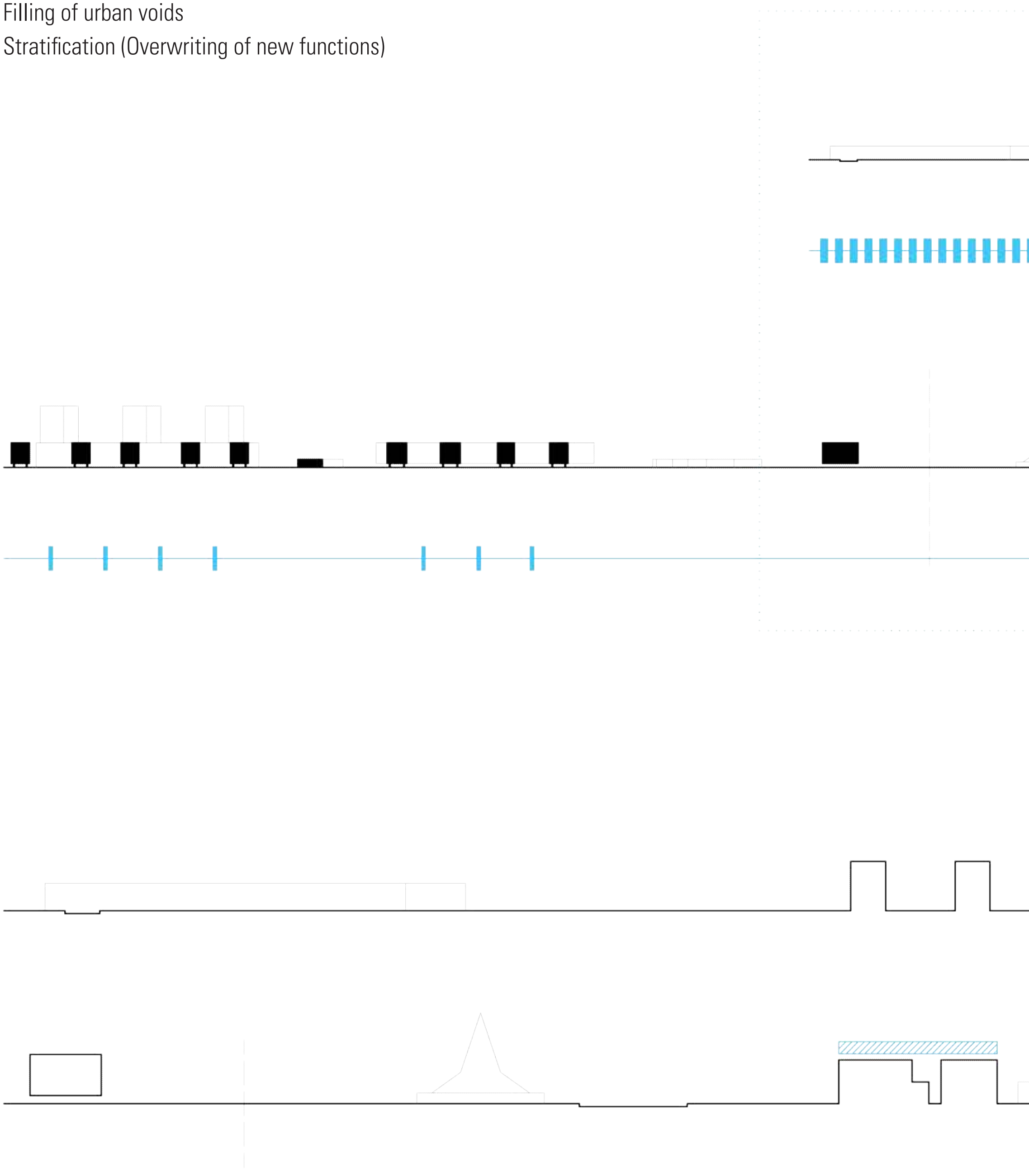
60. DRAWING 14
Sections AA and BB, scales 1:5000 and 1:2500



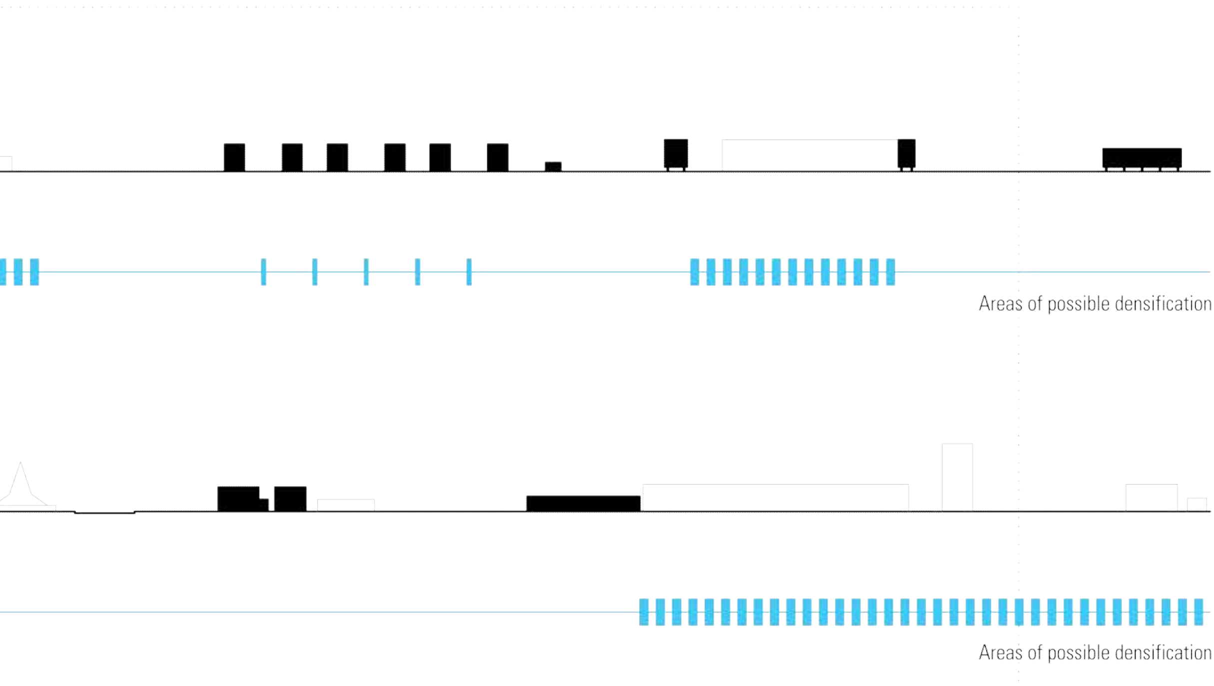
Areas susceptible to transformations
Areas susceptible to transformations
cement of functions
Filling of the ground floor
Excavation

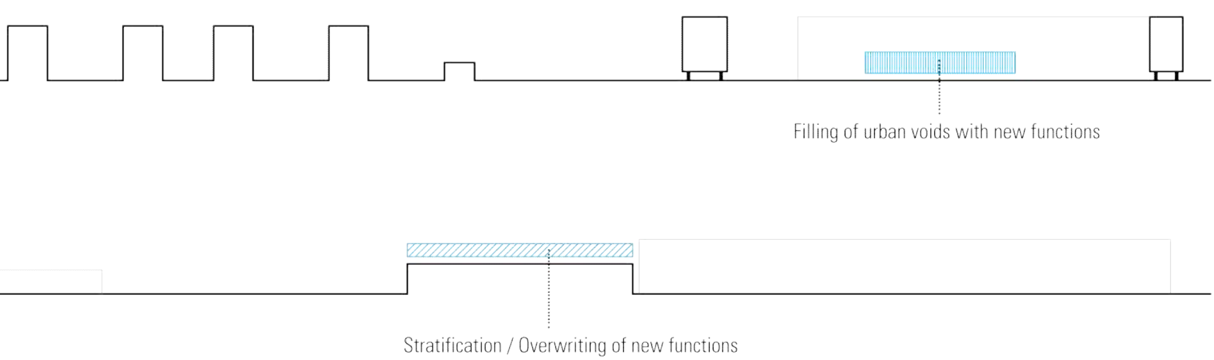
Densification

Filling of urban voids
Stratification (Overwriting of new functions)

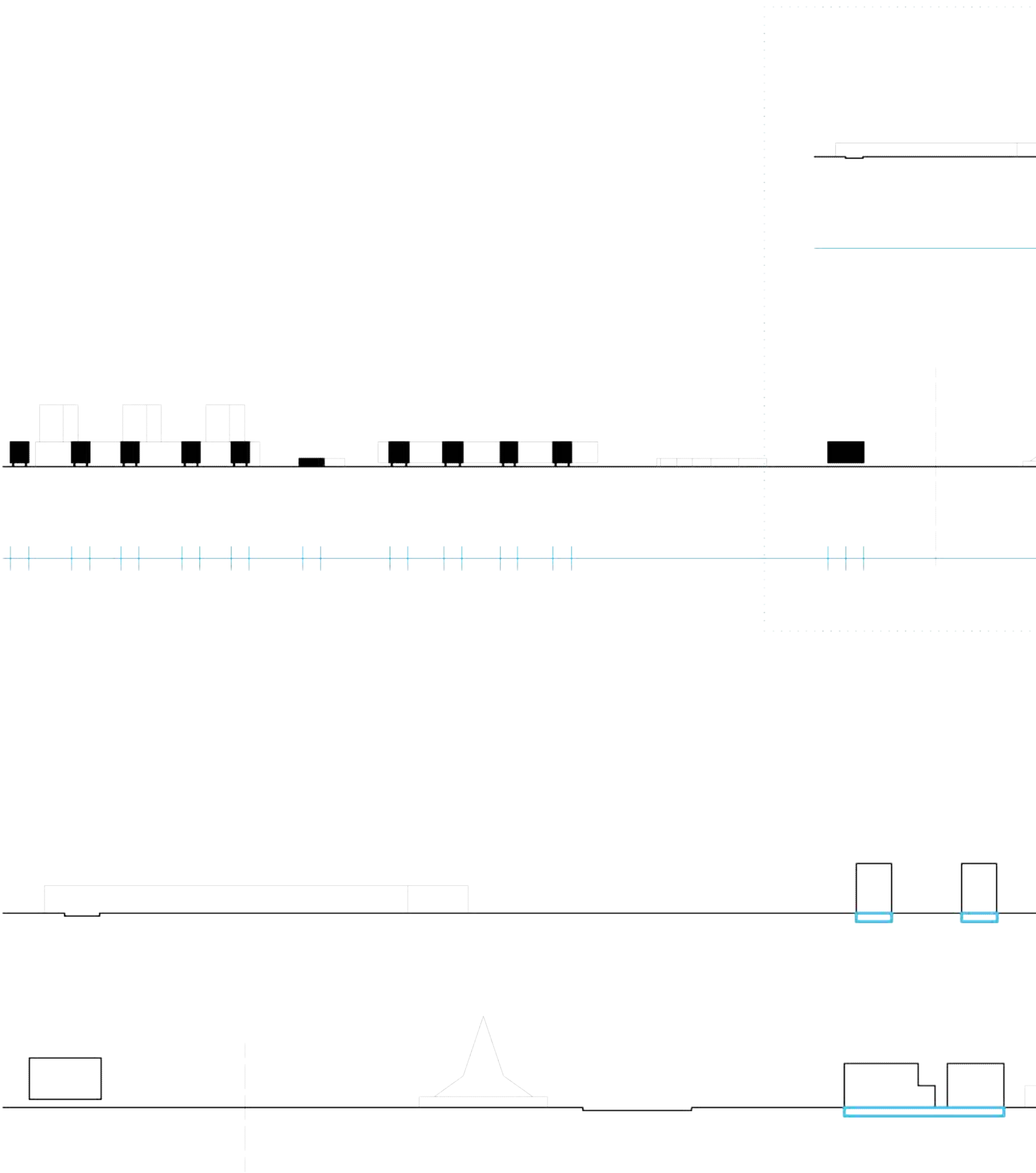


61. DRAWING 15
Sections AA and BB, scales 1:5000 and 1:2500

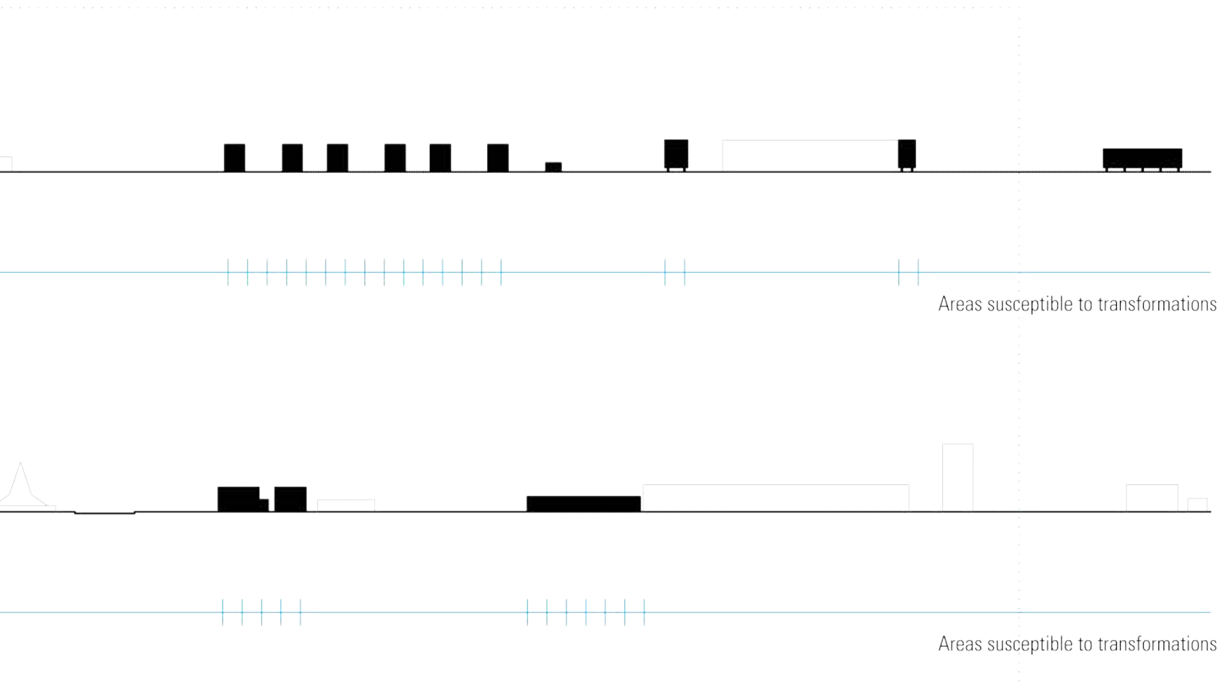

Areas of possible densification
Areas of possible densification

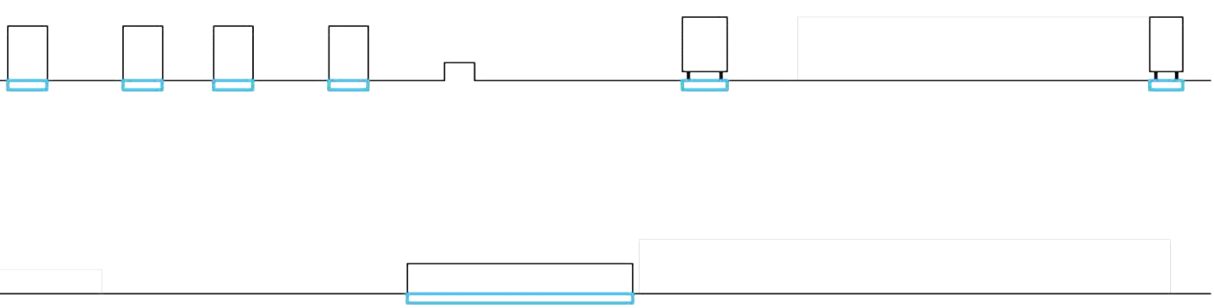

Filling of urban voids with new functions
Stratification / Overwriting of new functions

Design of a technical basement



62. DRAWING 16
Sections AA and BB, scales 1:5000 and 1:2500


Areas susceptible to transformations
Areas susceptible to transformations



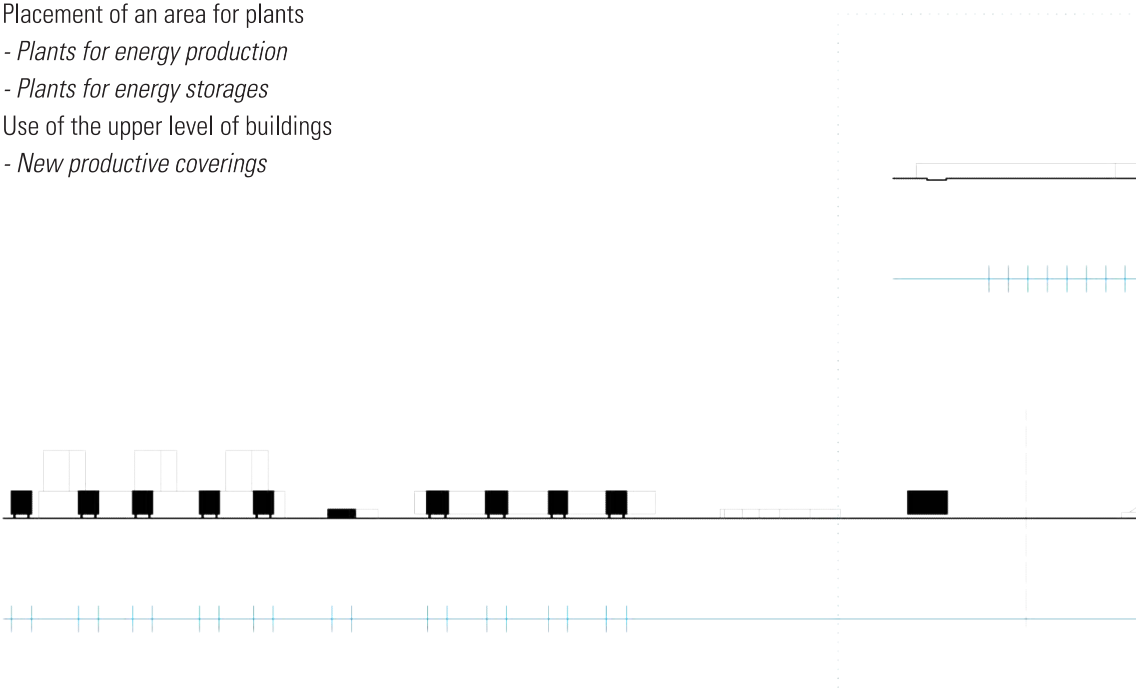
Integration with an energethic infrastructure

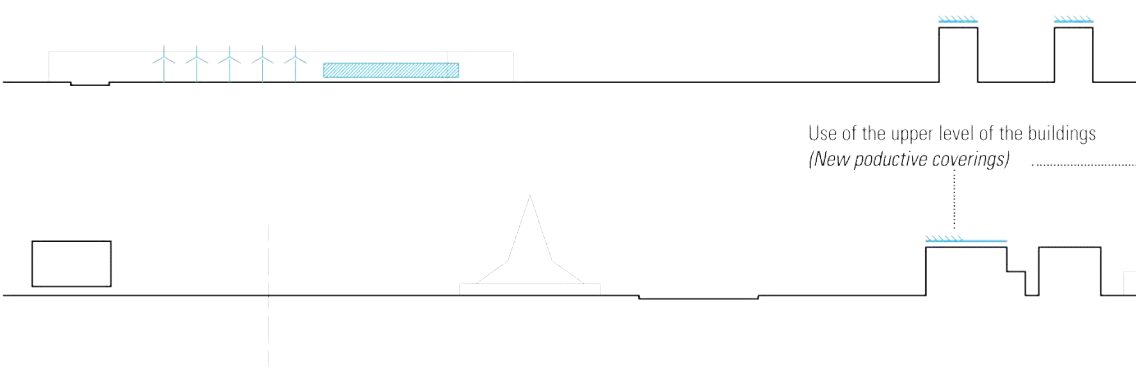
Placement of an area for plants

- *Plants for energy production*
- *Plants for energy storages*

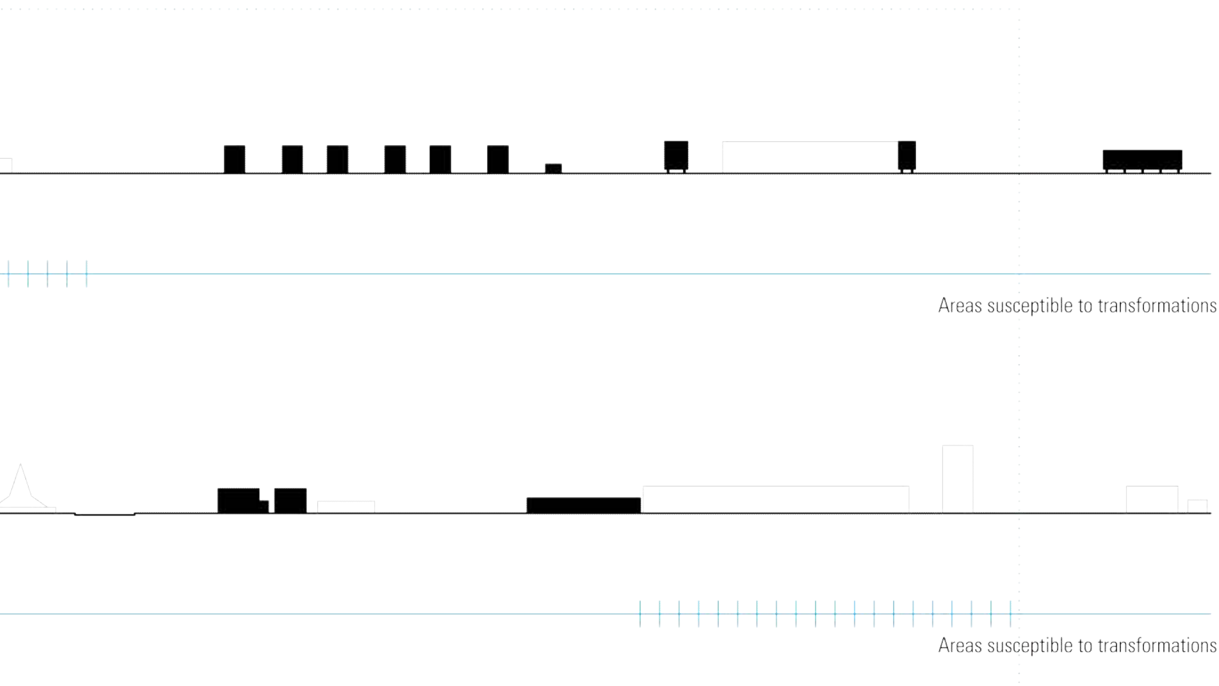
Use of the upper level of buildings

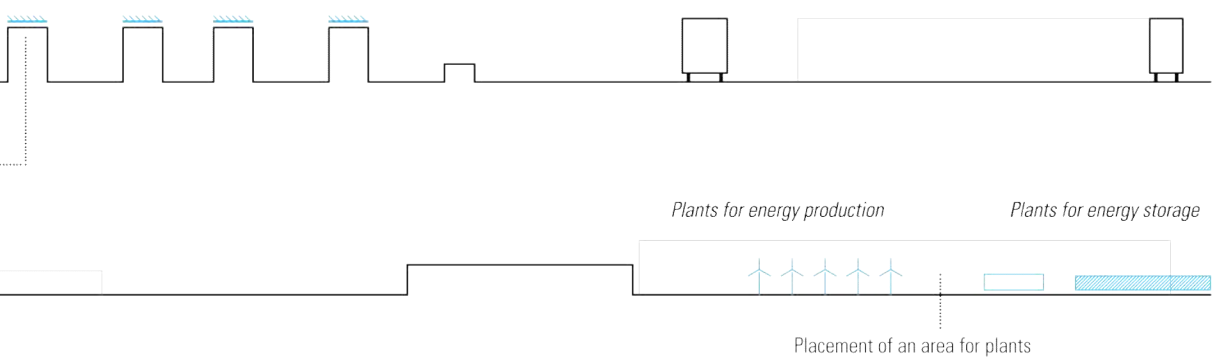
- *New productive coverings*





63. DRAWING 17
Sections AA and BB, scales 1:5000 and 1:2500


Areas susceptible to transformations
Areas susceptible to transformations


Plants for energy production
Plants for energy storage
Placement of an area for plants

Notes - Chapter 5

(1) KOTCH A., GIRARD S., *"Urban neighborhoods - an intermediate scale for the assessment of energy performance of buildings"*, ECEE (European Council for an energy efficient economy), 2011

(2) BUTERA F. M., "*Zero-energy buildings: the challenges"*, in Advances in Building Energy Research n. 7, 2013, pp. 51-65

(3) RUIZ N., COBELO I., OYARZABAL J., "*A Direct Load Control Model for Virtual Power Plant Management"* in IEEE Transactions on power systems, vol. 24, n.2, 2009

(4) CARR S., *"Virtual Power Plants"* in International Journal of Scientific & Engineering Research, Volume 2, Issue 8, Agosto 2011

(5) KOTCH A., GIRARD S., Ibid.

(6) LINDENBERGER D., BRUCKNER T., GROSCURTH H.-M., KUMMEL R., *"Optimization of solar district heating systems: seasonal storage, heat pumps and cogeneration"*, Energy 25, 2000, pp. 591-608

(7) SIMONETTI C., *"Gli aspetti temporali nella valutazione della sicurezza urbana"*, in BOSSI P., MORONI S., POLI M., La città e il tempo: interpretazione e azione, Maggioli Editore, milano, 2010

(8) SALAT S., Cities and forms on sustainable urbanism, Urban Morphology Laboratory, Hermann Editeurs des sciences et des arts, 2011

(9) BELGIOJOSO A.B., *"Una metodologia della progettazione urbana in rapporto con il tempo"*, in BOSSI P., MORONI S., POLI M., La città e il tempo: interpretazione e azione, Maggioli Editore, Milano, 2010

(10) SETTI G., *"Oltre la dismissione - Strategie di intervento architettonico per la modificazione e il consolidamento di trame, tessuti e manufatti industriali"*, PhD Thesis, Politecnico di Milano, Scuola di Architettura e Società, DASTU Dipartimento di Architettura e Studi Urbani, 2013

CHAPTER 6

CONCLUSIONS

6.1 Results and recommendations for future work

The research work has attempted to give a **new interpretation** on the subject of energy in architecture.
As stated at the beginning of this work, there are many ways to interpret the energy issue into architectural design. As we have already focused by the essay in Chapter 2, the idea of summarizing the contribution of energy issue in architecture just in a few written lines would be absolutely simplistic, since it has always been one of the key topics and main issues of architectural design itself. However, through an extreme process of simplification, we could state that at the building scale the energy issue has been during time mainly faced in connection with the performance of materials (concerning their physical parameters and their hygrothermal behavior towards outdoor climates), buildings and rooms' orientation (with consequences on the design of facades) and efficiency of plants. International, national and regional legislation of the early years of the new millennium have then defined minimum energy standards to be respected. This aspect has pushed technological research to always more performance materials and increasingly powerful systems.
At the urban scale there are also many studies on buildings' orientation and urban density in relation to solar radiance and passive systems, from the first experiences and studies of Rationalists through researches developed during the Sixties and Seventies (e.g. researches by the Cambridge Institute) to more contemporary experimentations about sustainable districts. While we can easily trace interesting applications on realized urban projects about the theme of energy in connection to urban patterns and density, the relationship between urban morphology and the energy network has instead mainly remained at utopian studies, still very interesting and significant. Many of these were developed during the Sixties and Seventies and they showed insights of technologies and urban configurations that are typical of the contemporary scene, but these formal proposals were not coupled with a technical apparatus that would allow the effective realization of them (refer to paragraph 2.3).

These last few years have seen the **beginning of a changing in the system of energy production and distribution** in comparison with the traditional one, which was widespread till the first decade of the new millennium. The main thought behind this work is that these on-going changes necessarily require a new kind of reflection on architectural design in relation to

the energy issue. The **advent of Smart Grids** and the need for a real-time regulation of energy flows are nowadays a pretext to reflect in a new way both on the relationship between the building and the grid and between the city and the grid. According to this new approach **buildings should become active actors** into the Smart Grid system: this promises to become a further step by the conceptual model of passive house to the one of active house.
This approach involves a new way of conceiving design in key energy: **we argue**, and the thesis work has been developed in order to demonstrate, **that organization of a building (and of a neighborhood) could have effects on the global management and optimization of energy flows**. The so called "organization" reflects, specifically, in the internal layout of a building (or a district) and subsequently on the **functional program**, which has got obvious influences both on building typology and urban morphology. This is an extremely powerful concept, since **it means that building typology and urban morphology are able to affect the management of energy flows**.
Right to investigate the relationship between functional program and energy management, the theme of "building envelope" at the architectural scale has been deliberately neglected, considering into the reasoning just aspects related to the functional program and architectural layout.
Chapter 4 is related to an analysis at the building scale. At the beginning of the chapter some parameters which could favor a successful relationship between buildings and the Smart Grid in the key of the energy management are hypothesized. What emerge is that these parameters are all related to a hybrid configuration. Through development of a case study they are one by one tested and proved by an architectural re-design and results are verified by the use of a software for energy simulation of the state of art and design.
Hybrid buildings are widely being researched and experimented within the contemporary architectural scene for several reasons. They indeed are dense buildings where activities are concentrated with a consequent saving of soil, they favor the coexistence of live and work with a consequent reduction of car usage and they tend to attract different types of users, since the offering of services is varied and responds to different needs. Understanding their potential from the energy point of view is then extremely interesting for the research on the architectural typology. It means indeed that their potentialities could also be used to improve the energy management of the building facing to the grid.

Research work has established a close relationship between type and energy, but certainly the study on the type in key energy which has been developed through this work is just at the beginning: it represents a breeding ground for future experimentation and it could involve in the future even other building typologies besides the residential one. Particularly, it would be extremely interesting to extend the reasoning started on residential buildings also to other building types.

While at the architectural scale the energy impact of the hybrid building type has been analyzed and tested through design and the use of a tool for quantitative verification (EnergyPlus through the graphical interface of Design Builder software), the analysis at the urban scale remained at a more general level. Firstly, the possibility of reasoning by analogy between the hybrid building model and a mixed neighborhood has been observed. At the urban scale a model of mixed use and multifunctionality could indeed generate the same benefits that the ones at the building scale and even more, since involved energy loads are more considerable and the multifunctional model at a larger scale is easier to be replicated several times into the urban pattern. The work has been limited to a general consideration of those parameters analyzed at the scale of the building in relation to the whole Tor Bella Monaca neighborhood: they have been discussed in order to give a general idea of possible reflections of the Smart Grid at the district level.

Reasoning at the scale of the neighborhood, however, introduces the development of new interesting scenarios of future research. **Necessity to integrate urban forms with urban flows** appears as evident, so as **to create a coordinated spatial structure** which is able to maximize potentialities of the grid. As already stated, there are several factors that contribute to define urban morphology which have been already studied in relation to the energy issue, such as land use, density, connectivity, proximity, green infrastructure.

However the relationship between urban form and energy grid to reach as much as possible flexibility in the management of energy flows is surely a field of investigation for the close future. A new and innovative design approach has therefore to be developed to reply to the on-going deep change into the energy chain. The thesis work has introduced the issue of the new electric grid and energy management in relation to architectural design and first possible responses to it. However the study represents a first step of investigation and the relationship between the architectural form and management of energy flows surely deserves the attention of future research. Particularly, as stated, it would be interesting to extend the reasoning both to other building typologies and, at a deeper level, at the scale of the neighborhoods through energy simulations and design applications on pilot case studies.

6.2 Glossary

Balancing Controlling electricity production so that it fully matches electricity demand (*KLIMSTRA, 2011*)

Cogeneration Method based on simultaneous production of different forms of secondary energy (electricity and heat) from a single source (either fossil or renewable) and implemented in a single, integrated system

Demand shifting and peak reduction Energy demand can be shifted in order to match it with supply and to assist in the integration of variable supply resources. These shifts are facilitated by changing the time at which certain activities take place and can be directly used to actively facilitate a reduction in the maximum (peak) energy demand level (*AA.VV, Technology Roadmap, Energy storage, International Energy Agency, 2014*)

Distributed Generation (DG) Set of small to medium generation plants distributed in a certain territory, designed to respond to the needs of local users, physically located close to the plant themselves. Distributed generation has started to be developed because of the liberalization of the energy market and spread of renewable sources.

Distribution Grid System that distributes electricity or gas to households, commercial users, and small industries (*KLIMSTRA, 2011*)

Energy Amount of physical work stored or delivered to a process. In the international system energy is measured in joule. European and national regulations also suggest the use of kWh.
Energy can be directly associated to an in-place process producing work or it can be potential energy. Energy is known in a variety of forms: the six main forms of energy are: chemical, electrical, radiant, mechanical, nuclear and thermal energy.

Energy district Territorially localized settlement using energy which is configured as a single controllable unit in it relation with the electric grid. An energy district is a urban settlement which is capable of operating in parallel to the main energy network. Its notion is partly overlapped to the one of micro grid.

Energy efficiency Using less energy for the same work (*MOE, 2013*)

Energy management Planning and operation of energy in order to achieve resource conservation and sustainable development and maximize cost savings

Energy simulation Procedure performed by the use of a software through which it is possible to define energy requirement of a building as a function of input parameters (*SWAN L., UGURSAL V.I.*, 2009)

Energy storage Storing energy for later use (*KLIMSTRA, 2011*)

Final energy use Energy used by end consumers, such as industries, commercial users and households. Final use does not include the energy consumption needed for processing fuels or power plant losses (*KLIMSTRA, 2011*)

Hybrid building Building typology based on the coexistence, in the same structure, of different functions and programs interacting each other. The peculiar feature of the hybrid building is multifunctionality, so that it tends to appear as a self-sufficient building, a sort of City within the City (*FENTON, 1985*)

Latent heat Quantity of heat absorbed or released by a substance undergoing a change of state (e.g. ice changing to water) (*AMERICAN HERITAGE DICTIONARY OF THE ENGLISH LANGUAGE, 2011*)

Micro grid Portion of the distribution system which includes units for distributed generation, energy storage systems and loads. From the main electricity grid, the micro grid is seen as an independent controlled entity.

Peak load Maximum load that occurs during a certain time span

Power The capacity to perform work within a certain time span (joule/second=watt)

Reliability The probability, often expressed in percentage of time, that a machine can statistically perform its duty (*KLIMSTRA, 2011*)

Renewable energy Energy not resulting from fossil fuels or nuclear fuel (*KLIMSTRA, 2011*)

Renewable sources Energy sources that, unlike fossils or nuclear, may be considered inexhaustible. Renewable sources include biomass, hydro, geothermal, solar, wind, ocean thermal, wave action and tidal action (*EPBD DIRECTIVE 31/10/EU*)

Sensible heat Thermal energy which is able to produce a temperature change in a certain substance (it is defined "sensible" because it produces an appreciable effect: the temperature variation). The formula of the sensible heat is $Q_s=mc\Delta T$, where
m is the mass of the substance exchanging heat
c is the specific heat of the substance
ΔT is the variation of temperature produced by the heat exchange

Smart Grid a Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies (*EUROPEAN SMART GRIDS TECHNOLOGY PLATFORM, 2012*)

Trigeneration Simultaneous production of electricity/mechanical energy and thermal energy (both heating and cooling) by using the same energy source

Variable renewables Technologies such as wind, solar, run of river hydro and tidal where production of electricity is based on climatic conditions and therefore cannot be dispatched based on a need for additional power alone (*INTERNATIONAL ENERGY AGENCY, TECHNOLOGY ROAD MAP*)

Virtual building Group of buildings (e.g. buildings of a district) which operate in their relation with the grid as a single one. The virtual building concept is based on the virtual power plant model since it is the result of aggregation of different buildings with an own energy behavior to form a unit which interfaces to the energy grid.

Virtual Power Plant (VPP) Cluster of distributed generation installations. The VPP is an aggregation of distributed energy resources (DER) so as to make them more accessible and manageable across energy markets

ENDNOTES

a. List of figures

(graphical interface of EnergyPlus)

32. Graphics edited by the author with the use of the software Design Builder (graphical interface of EnergyPlus)

33. DRAWING 2, edited by the author

34. Graphics edited by the author with the use of the software Design Builder (graphical interface of EnergyPlus)

35. DRAWING 3, edited by the author

36. DRAWING 4, edited by the author

37. Image from: ROSSI, N., Manuale del termotecnico. Fondamenti – riscaldamento – condizionamento – refrigerazione – risorse energetiche, Hoepli, Milano, 2014

38. Graphics edited by the author with the use of the software Design Builder (graphical interface of EnergyPlus)

39. DRAWING 5, edited by the author

40. Table edited by the author

41. DRAWING 6, edited by the author

42. Image from: FENTON, J., Hybrid buildings, Pamphlet Architecture n. 11, New York, San Francisco, 1985, p. 33

43. TABLE: Hybrid building references

Unitè d'habitation: www.wikipedia.org

Corviale: www.biourbanism.org

Linked Hybrid: www.stevenholl.com

Vanke Center: www.stevenholl.com

Silodam: www.arcspace.com

The Whale: architizer.com

Tietgen Dormitory: www.archdaily.com

De Rotterdam: oma.eu

44. Image from: PAATERO J., *"Computational studies on distributed energy systems"*, Phd thesis, Faculty of Information and Natural Sciences Department of Applied Physics, Espoo, Helsinki University of Technology, 2009

45/46. Diagrams edited by the author

47. DRAWING 7, edited by the author

48/49/50/51/52/53. Graphics edited by the author with the use of the software Design Builder (graphical interface of EnergyPlus)

54. DRAWING 8, edited by the author

55. DRAWING 9, edited by the author

56. DRAWING 10, edited by the author

57. DRAWING 11, edited by the author

58. DRAWING 12, edited by the author

59. DRAWING 13, edited by the author

60. DRAWING 14, edited by the author
61. DRAWING 15, edited by the author
62. DRAWING 16, edited by the author
63. DRAWING 17, edited by the author

b. List of abbreviations

AEEG Autorità per l' Energia Elettrica e il Gas
DER Distributed energy resources
DG Distributed Generation
EPBD Energy Performance of Buildings Directive
EU European Union
EV Electric vehicles
GHG Greenhouse Gas Emissions
HVAC Heating, Ventilation and Air Conditioning
ICT Information and Communication Technologies
IEA International Energy Agency
MS Member States
nZEB Nearly Zero Energy Building
Net ZEB Nearly Zero Energy Building integrated to the energy net
PCM Phase Change Materials
RES Renewable Energy Sources
RESS Residential Energy Storage Systems
VPP Virtual Power Plant

BIBLIOGRAPHY

Bibliography Chapter 1

AA.VV., 25 Energy efficiency Policy Recommendations 2011 Update, IEA International Energy Agency, Paris, 2011

AA.VV., Carta di Aalborg, Aalborg, 1994

AA.VV, European, Commission, "Energy roadmap 2050", 2011

AA.VV, European Commission, "The European Strategic Energy Technology Plan. Towards a low-carbon future", 2010

AA.VV., "Dichiarazione delle Nazioni Unite sull´ambiente umano", Stoccolma, 1972

AA.VV., Recast EPBD Directive 2010/31/EU, 19th May 2010

AA.VV. "Sviluppo sostenibile in Europa per un mondo migliore: strategia dell'Unione europea per lo sviluppo sostenibile", Goteborg, 2006

ATANASIU B., *"Is cost optimality driving buildings towards nearly zero-energy buildings?"*, , paper presented at the WSED World Sustainable Energy Days 2014, Wels, Austria, 25-28 February 2014

BERRINI M., COLONNETTI A. (a cura di), GREEN LIFE – Costruire città sostenibili, Editrice Compositori, Milano, 2010

BUTERA F. M., *"Il Progetto sostenibile"* in Dell´architettura di vetro e del Mediterraneo, 2010, pp. 58 – 65

HART C., Doing a Literature Review – Releasing the Social Science Research Imagination, SAGE Publications, London, Thousand Oaks, New Delhi, 1998

HOWELL K., An introduction to the philosophy of methodology, SAGE, New Delhi, 2013

KRANZL L., ATANASIU B., BONETA M., BURGER V., KENKMANN T., MULLER A., TOLEIKYTE A., PAGLIANO L., PIETROBON M., ARMANI R., *"nZEB Renovation in the building stock: policies, impact and economics*", paper presented at the WSED World Sustainable Energy Days 2014, Wels, Austria, 25-28 February 2014

MAGELLI S., *"Towards nearly Zero Energy Buildings (nZEBs): Metodologia di analisi e caso studio su un edificio residenziale"*, master thesis, Politecnico di Milano, Scuola di Architettura e Società, 2012

SCATTOLINI E., *"Buildings and smart grids: the architectural design of energy flexible residential buildings"*, PLEA 2015 - 31st International PLEA Conference - Ass. Building Green Features, Bologna, 2015

Bibliography Chapter 2

AA.VV., *"Our Common Future – Report of the World Commission on Environment and Development"*, United Nations, 1987

BANHAM R., *"A clip-on architecture"* in Design Quarterly 63, Walker Art Center, Minneapolis, 1965

BANHAM R., *"A home is not a house"*, in Art in America n. 2, 1965

BANHAM R. , The Architecture of the Well-Tempered Environment, The Architectural Press, London, 1984

BANHAM R., Architettura della seconda età della macchina, Electa, Milano, 2004

BARBER A., *"Hubbert's Peak, Eneropa, and the Visualization of Renewable Energy"*, in Places Journal, MIT, 2013

BOVATI M., L´ambiente dell´architettura. Alterità progettuale del paradigma ecologico, Maggioli Editore, Collana Politecnica, Milano, 2010

BOVATI M., *"Sustainable Strategies (for Cities in Transformation)"*, in BOVATI,M., CAJA M., FLORIDI G., LANDSBERGER M., Cities in Transformation Research &Design, EAAE/ARCC Milano, International Conference on Architectural Research, IlPoligrafo, Milano, 2014

BRAHAM W., HALE J. (edited by), Rethinking Technology – A Reader in Architectural Theory, Routledge, London and New York, 2007

BRAHAM W., WILLIS D., Architecture and Energy: performance and style, Routledge, Oxon, 2013

CALVO M.W., Archigram/Metabolism – Utopie negli anni Sessanta, Clean Edizioni, Napoli, 2007

CARDINALE N., ROSPI G., STEFANIZZI P., *"Energy and microclimatic performance of Mediterrenean vernacular buildings. The Sassi district of Matera and the Trulli district of Alberobello"*, in Building and Environment n. 59, 2013, pp. 590-598

CIORRA P.(edited by), Energy: Architettura e reti del petrolio e del post-petrolio, Roma, MAXXI, 2013

COMMISSIONE EUROPEA, "Smart Cities and Communities – European Innovation Partnership", 2012
COOK P. (edited by), Archigram, Studio Vista London, 1972

D' ARCY THOMPSON, On Growth and Form, Dover Publications, New York, 1992

DAL CO F., TAFURI M., Architettura contemporanea, Electa, Milano, 1976

EMILI A. R., Richard Buckminster Fuller e le neoavanguardie, Edizioni Kappa, Roma, 2003

FATHY H., Natural energy and vernacular architecture : principles and examples with reference to hot arid climates, Ed. Walter Shearer, 1986

FERNANDEZ-GALIANO L., Fire and Memory: On Architecture and Energy, MIT Press, Cambridge MA, 2000

FRAMPTON K., Storia dell'architettura moderna, Zanichelli Editore, Bologna, 1986

GALLO C., SALA M., SAYIGH A M.M., Architecture - comfort and energy, Pergamon, 1988

GREGOTTI V., Architettura, tecnica, finalità, Laterza, Roma-Bari, 2012

KNOWLES R., LANGEVIN J., *"Reyner Banham"*, Architectural Theory Review, 16: 1, 2 — 21, Routledge, 2011

LOS S., Geografia dell' architettura – Progettazione bioclimatica e disegno architettonico, Il poligrafo, Padova, 2013

MANTZIARAS P., *"Contemplating the network"*, Forum International; Quaderns 214, 1997

MAY J., Buildings without architects : a global guide to everyday architecture, Anthony Reid consultant editor. - New York : Rizzoli International, 2010

MOE K., Convergence. An architectural agenda for energy, Routledge, Abingdon Oxon, 2013

PARIS S., *"Sostenibilità, tecnologia e qualità dell' architettura. Il mediterraneo"* in BAGNATO V., PARIS S., "Architettura e tecnologia. Lectures", DesignPress, Roma, 2010

PENSATO D., *"Strategie passive di controllo termico degli edifici alla scala urbana ed edilizia"*, master thesis, Alma Mater Studiorum, Università di Bologna, Corso di Laurea in Ingegneria per l' Ambiente e il Territorio, D.A.P.T. Dipartimento di Architettura e Pianificazione territoriale, 2008-2009

PERINI K., PORCILE G., Architettura & Energia – ICAR 65 Percorsi multidisciplinari di ricerca, vol.I, Genova University Press, Genova, 2014

REALE L., Densità città residenza: tecniche di densificazione e strategie antisprawl, Gangemi Editore, Roma, 2008

ROGORA A., Progettazione bioclimatica per l' architettura mediterranea, Wolters Kluwer, 2012

SEVERINO E., Tecnica e Architettura, Raffaello Cortina Editore, Milano, 2003

VIDLER A., *"Toward a theory of the Architectural Program"*, october, 106 (autumn 2003), pp.59-74

VITRUVIO, De architectura

Bibliography Chapter 3

AA.VV., Comuni Rinnovabili 2013, Rapporto di Legambiente

AA.VV., Smart Grid Legislative and Regulatory Policies and Case studies, EIA U.S. Energy Information Administration, 2011

AA.VV., Smart Grid SRA 2035, Strategic Research Agenda, Update of the Smart Grids SRA 2007 for the needs by the year 2035, European Technology Platform Smart Grids, 2012

AA. VV., Vademecum della Borsa Elettrica, Roma, GME, 2009

ACKERMANN T., ANDERSSON G., SODER L., *"Distributed generation: a definition"*, in Electric Power systems research, n. 57, 2001, pp. 195 – 204

BERTINI I., DI PIETRA B., GRADITI G., Quaderno - L' efficienza nel settore delle reti energetiche, ENEA Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile, Roma 2011

BROWN R., *"Impact of smart grid on distribution system design"* published in Power General meeting – Conversion and Delivery of Electrical Energy in the 21st century, 2008 IEEE

BUTERA F M.., *"Zero-energy buildings: the challenges"*, in Advances in Building Energy Research n. 7, 2013, pp. 51-65

CHEN H., CHOU P., SASTRY D., HUI L., REASON J., *"The Design and Implementation of a Smart Building Control System"*, in IEEE International Conference on e-Business Engineering, 2009

CHOI Y., HEUI CHO S., TAI KIM J., *"Energy consumption characteristics of high rise apartment buildings according to building shape and mixed-use development"*, in Energy and Buildings, n. 46, 2012, pp. 123-131

COLAK I., KABALCI E., FULLI G., LAZAROU S., *"A survey on the contributions of power electronics to Smart Grid systems"*, in Renewable and Sustainable energy Reviews, vol. 47, july 2015, pp. 562-579

DELFANTI M., OLIVIERI V., *"Sviluppo delle Smart Grid: opportunità per le aziende italiane del settore"*, Politecnico di Milano, conference, 2013

DIRECTIVE 2009/72/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 13 July 2009concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC

HAFNER K., LYON M., Where Wizards Stay Up Late – The Origins of the Internet, Simon & Shuster, 1996

HEGGER M., FUCHS M., STARK T., ZEUMER M., Energy Manual – Sustainable Architecture, Birkhauser, Edition Detail, Munich, 2008

KLIMSTRA J., HOTAKAINEN M., Smart Power Generation, Avain Publishers, Helsinki, 2011

MANFREN M., *"Sistemi ad alta efficienza per la generazione distribuita a scala urbana"*, PhD thesis, Politecnico di Milano, Dipartimento BEST Scienza e Tecnologie dell' Ambiente Costruito, 2009

MANFREN M., CAPUTO P.,COSTA G., *"Paradigm shift in urban energy systems through distributed generation: methods and models"*, in Applied Energy n. 88, 2001, pp. 1032- 1048

MARSDEN J. *"Distributed Generation Systems: A New Paradigm for Sustainable Energy"*, paper presented at the 2011 IEEE Green Technologies conference, April 14-15, 2011, Baton Rouge LA

MAZZARI L., Design per l' energia – strumenti e linguaggi per una produzione diffusa, Alinea Editrice, Firenze, 2011

MITCHELL W., E- topia: urban life, Jim-but not as we know it, Cambridge (Mass.), London, The MIT Press, 1999

NEWTON P. W., TUCKER S.N., Hybrid buildings: pathways for greenhouse gas mitigation in the housing sector, SWINBURNE Institute for Social Research, Swisburne University of Technology Melbourne, 2009

PERNECHELE M., TANSINI A., TARDIVO A., *"Il nuovo paradigma della generazione distribuita di energia: opportunità e limiti allo sviluppo delle smart grid"*, master degree thesis, Politecnico di Milano, Facoltà di Ingegneria dei Sistemi, Corso di Laurea Specialistica in Ingegneria Gestionale, Milano, a.a. 2009/2010

POWELLS G., BULKELEY H., BELL S., JUDSON E., *"Peak electricity demand and the flexibility of everyday life"*, in GEOFORUM, Volume 55, August 2014, pp. 43 - 52

SARTORI I., NAPOLITANO A., VOSS K., *"Net zero energy buildings: a consistent definition framework"*, in Energy and Buildings n. 48, 2012, pp.220 – 232

SECHILARIU M., WANG B., LOCMENT F., *"Building- integrated microgrid: Advanced local energy management for forthcoming smart power grid communication"*, in Energy and Buildings, n. 59, 2013, pp. 236 - 243

SIANO P., *"Demand response and smart grids – A survey"*, in Renewable and Sustainable Energy Reviews, n. 30, 2014, pp. 461-478

Bibliography Chapter 4

AA.VV., "Concept: High-density housing", in DETAIL n.3, 2014

AA.VV., New forms of collective housing in Europe, Birkhauser Architecture (arc revecentre d' architecture), 2009

AA.VV., "Social housing", TECHNE n.4, Firenze, 2012

AHRENTZEN S., Hybrid Housing: a contemporary building type for multiple residential and business use, Centre for Architectural and Urban Planning Research monographs, Book 40, 1991

ANNUNZIATO M. (edited by), *"Dall' eco-building al distretto energetico: ricerca e governance verso nuovi modelli di sviluppo"*, ENEA, Roma, 2007

APARECIDA VASQUES R., MITSUKO ONO M., *"Shared use – Cultural aspects and user satisfaction in doing the laundry together"*, in CESCHIN F., VEZZOLI

C., ZHANG J., Sustainability in Design: now! Challenges and opportunities for Design Research, Education and Practice in the XXI Century, Proceedings of the LeNS Conference, Bangalore, India, 29th September 2010 to 1st Ocrober 2010, LeNS project funded by the Asia Link Programme, Europe Aid, European Commission

APPIANI A., *"Edifici a energia zero in Europa: casi di studio e prospettive future"*, master thesis at Politecnico di Milano, Facoltà di Architettura e Società, a.a. 2010-2011

ATAEN E., *"Storage of thermal energy"*, in Energy Storage systems, vol. 1, EOLSS

AVITABILE, F., *"Prospettive ibride negli spazi urbani contemporanei"*, PhD thesis, Progettazione Urbana e Urbanistica, Università degli Studi di Napoli Federico II, Faculty of Architecture

BERTINI I., DI SILVESTRE M. L., GRADITI G., IPPOLITO M.G., RIVA SANSEVERINO E., ZIZZO G., "Architetture e logiche di controllo ottimale di microreti per la razionalizzazione energetica – report 1 – Identificazione ed analisi di architetture e logiche di controllo ottimale di microreti per la razionalizzazione energetica", ENEA, 2011

BJARKE INGELS, Yes is more. Un archifumetto sull'evoluzione dell'architettura, Taschen, Koln, 2011

BUCCI S., *"John Belushi ci insegna a (con)vivere – Il co-housing secondo Cino Zucchi: Animal House fu l'inizio"* in LA LETTURA, Corriere della Sera, Milano, 2 Febbraio 2014, pp. 16-17

BURTON E., JENKS M., WILLIAMS K., Achieving Sustainable Urban Form, E&FN SPON, Taylor & Francis Group, London, 2000

BUTERA F. M., *"Zero-energy buildings: the challenges"*, in Advances in Building Energy Research n. 7, 2013, pp. 51-65

CALZOLARETTI M., MANDOLESI D. (edited by), Rigenerare Tor Bella Monaca, Quodlibet, Roma, 2014

CANTONI C., *"Il veicolo elettrico a support delle Smart grid"*, master thesis, Politecnico di Milano, Facoltà di Ingegneria dei Processi Industriali, 2012

CARR S., *"Virtual Power Plants"* in International Journal of Scientific & Engineering Research, Volume 2, Issue 8, Agosto 2011

CESCHIN F., VEZZOLI C., ZHANG J., Sustainability in Design: now! Challenges and opportunities for Design Research, Education and Practice in the XXI

Century, Proceedings of the LeNS Conference, Bangalore, India, 29th September 2010 to 1st Ocrober 2010, LeNS project funded by the Asia Link Programme, Europe Aid, European Commission
CIPOLLA C., *"Relational services: service design fostering sustainability and new welfare models"*, Proceedings of the 2nd International Symposium on Sustainable Design (II ISSD), Brazil Network on Sustainable Design – RBDS, Sao Paulo, Brazil 2009

CIPOLLA C., *"Solutions for relational services"*, in MIETTNEN S., Service Design with Theory. Discussions on Change, Value and Methods, Rovaniemi: lapland University Press (LUP) Publishing, 2012

CONTRINO R., "*Le forme della densità: nuovi scenari per il territorio contemporaneo"*, phd thesis in Urban and Architectural Design, Politecnico di Milano, 2004

DELERA A., *"Housing sociale per una nuova morfologia della città"* in "Social housing", TECHNE n.4, Firenze, 2012

DE PASCALI P., Città ed energia: la valenza energetica dell´organizzazione insediativa, Franco Angeli Editore, Milano, 2008

DI GIORGIO A., LIBERATI F., CANALE S., *"Electric vehicle charging control in Smart Grid: a model predictive control approach"*, in Control Engineering Practice, n. 22, 2014, pp. 147-162

DINCER I., DOST S., LI X., *"Performance analyses of sensible heat storage systems for thermal applications"*, in International Journal of energy research, vol. 21, 1997, pp. 1157- 1171

DINCER I., ZAMFIRESCU C., Sustainable Energy Systrems and Applications, Springer, London, 2011

DINCER I., *"Thermal energy storage systems as a key technology in energy conservation"* in International Journal of Energy Research, num. 26, 2002, pp. 567-588

DREXLER H., EL KHOULI S., Holistic housing – Concepts, design strategies and Processes, Edition DETAIL, Frankfurt, 2012

DUANY A., PLATER-ZYBERK E., SPECK J., Suburban Nation: The rise of Sprawl and the Decline of the American dream, North Point Press, New York, 2000

EWING R., RONG F., *"The impact of urban form on U.S. Residential energy Use"* in Housing Policy Debate n. 19.1,Taylor & Francis, 2010, pp. 1-30D

FENTON, J., Pamphlet Architecture n. 11 – Hybrid Buildings, Princeton Architectural Press, New York, 1985

FERNANDEZ PER A., MOZAS J., ARPA J., This is hybrid, a+t architecture publishers, Vitoria- Gasteiz, 2011

GELSOMINO L.,MARINONI O. (edited by), Territori europei dell' abitare 1990-2010, Editrice Compositori, 2009

GHOLAMI M., *"Equilibrium model for electicity market"*, PhD thesis, Politecnico di Milano, Dipartimento di Energia, 2013

HOLL, S., *"Hybrid creatures"*, interview in Icon Eye, Icon Magazine on line, Icon 097, July 2011

JENKS M., BURTON E., WILLIAMS K., The Compact City – A sustainable urban form?, E & FN SPON, Oxford, 1996

JOHANNENSON D., *"CO2 and Cost Impact of Pre- andPost shift of Residential Electric Loads"*, master thesis at Umea Universitet (SE), 2011, in collaboration with ABB, 2011

LAZZARIN R., NORO M., BUSATO F., *"Studio di sistemi di accumulo a cambiamento di fase nel solar cooling"*, Report ENEA RdS/2011/256

LI C., WANG R.Z., *"Building integrated energy storage opportunities in China"*, in Renewable and Sustainable Energy Reviews, n.16, 2012, pp. 6191-6211

MAZZOLENI P. (a cura di), AAA Architetti Cercasi 2008 – Nuove forme progettuali per la residenza cooperativa, Allemandi, Torino 2009

MAZZOLENI P., Abitare nella società dell' informazione – Il progetto dei luoghi dell' abitare tra permanenze e mutazioni, Libreria Clup, Milano, 2006

MELOTTO B., PIERINI O. S., Housing Primer – Le forme della residenza nella città contemporanea, Maggioli Editore, Politecnica, Milano, 2012

MORELLO E., *"Progettazione ambientale della forma urbana"* in Bertoldini, M., Campioli, A. (editors), Cultura tecnologica e ambiente, UTET Città Studi Edizioni, Torino, 2009

NG E., Designing high densitiy cities/ For social & environmental sustainability, Routledge, 2009

OWEN D., Green metropolis – La città è più ecologica della campagna?, Milano, Egea, 2011

PEDERSEN P.B., Sustainable Compact City - Centre for strategic urban research, Denmark, 2009

REALE L., Densità città residenza: tecniche di densificazione e strategie antisprawl, Gangemi Editore, 2011

RICHARDSON I., THOMSON M., INFIELD D., CLIFFORD C., *"Domestic electricity use: A high-resolution energy demand model"*, in Energy and Buildings n. 42, 2010, pp. 1878 - 1887

ROSSI N., Manuale del termotecnico. Fondamenti – riscaldamento – condizionamento – refrigerazione – risorse energetiche, Hoepli, Milano, 2014

RUBIN A., *"L' accumulo dell' energia termica: stato dell' arte e studio di sistemi e soluzioni per la media temperatura"*, Tesi di laurea, Università degli Studi di Padova, Dipartimento di Ingegneria Industriale, Corso di Laurea in Ingegneria meccanica, a.a. 2012-2013

RUIZ N., COBELO I., OYARZABAL J., *"A Direct Load Control Model for Virtual Power Plant Management"* in IEEE Transactions on power systems, vol. 24, n.2, 2009

SALVADOR M., GRIEU S., *"Methodology for the design of energy production and storage systems in buildings: Minimization of the energy impact on the electricity grid"*, in Energy and Buildings n.47, 2012, pp. 659-673

SANTIAGO I., LOPEZ-RODRIGUEZ M.A., TRILLO-MONTERO D., TORRITI J., MORENO-MUNOZ A., *"Activities related with electricity consumption in the Spanish residential sector: Variations between days of the week, Autonomous Communities and size of towns"*, in Energy and Buildings n. 79, 2014, pp. 84-97

SANTOS J., S. MOURA P., T. DE ALMEIDA A., *"Technical and economic impact of residential electricity storage at local and grid level in Portugal"*, in Applied Energy n. 128, 2014, pp. 254- 264

SPOSITO C., *"Identita´, Flessibilita´e Sostenibilita´per un nuovo Social Housing"* in TECHNE n. 4, Firenze, 2012

SUN Y., WANG S., XIAO F., GAO D., *"Peak load shifting control using different cold thermal energy storage facilities in commercial buildings: A review"*, in Energy Conversion and Management, n. 71, 2013, pp. 101-114

WEBER C., PERRELS A., *"Modelling lifestyle effects on energy demand and related emissions"*, in Energy Policy n. 28, 2000, pp. 549-566

WIDEN J., LUNDH M., VASSILEVA I., DAHLQUIST E., ELLEGARD K., WACKELGARD E., *"Constructing load profiles for household electricity and hot water from time-use data – Modelling approach and validation"*, in Energy and Buildings n. 41, 2009, pp. 753 - 768

ZANON B., VERONES S., *"Climate change, urban energy and planning practices: Italian experiences of innovation in land management tools"*, in Land Use Policy, n. 32, 2013, pp. 343-355

Bibliography Chapter 5

AA.VV. Interventi I.SV. E.UR nell' Ambito della Concessione al Consorzio Tor Bella Monaca per la realizzazione del Programma Straordinario di Edilizia Residenziale Pubblica, Scuole e Realizzazioni, mediante finanziamenti ex articoli 7 ed 8 Legge 16/2/1980 n. 25 e Fondi Comunali (presentazione a cura di Elio Piroddi)

BOSSI P., MORONI S., POLI M., La città e il tempo: interpretazione e azione, Maggioli Editore, milano, 2010

KOTCH A., *"Energy balance of Urban Quarters for the development of energy efficiency and management strategies"*, in 5th Urban Research Symposium - Cities and climate change responding to an urgent agenda, Marseille, France

KOTCH A., GIRARD S., *"Urban neighborhoods - an intermediate scale for the assessment of energy performance of buildings"*, in ECEE (European Council for an energy efficient economy), 2011

LINDENBERGER D., BRUCKNER T., GROSCURTH H.-M., KUMMEL R., *"Optimization of solar district heating systems: seasonal storage, heat pumps and cogeneration"*, Energy 25, 2000, pp. 591-608

MAGELLI S., *"Towards Nearly Zero Energy Buildings (nZEBs): Metodologia di analisi e caso studio su un edificio residenziale"*, master thesis, Politecnico di Milano, Scuola di Architettura e Società, 2012

MAGLIULO N.L., *"La grande dimensione nell' edilizia residenziale pubblica dal 1956 al 1962-riqualificare o demolire?"*, PhD thesis, Università degli Studi di Napoli Federico II, Facoltà di Architettura - Scuola di dottorato in progettazione architettonica e ambientale – sezione di composizione architettonica, XXV Ciclo

MAILE T., FISCHER M., BAZJANAC V., *"Building Energy Performance Simulation Tools – a Life – Cycle and Interoperable Perspective"*, Standford University, Working Paper 107, 2007

MARTIN L., MARCH L., Urban space and Structures, Cambridge University Press, Cambridge, 1975

MAZZARELLA L., PASINI M., *"Building energy simulation and object oriented* *modeling: review and reflections upon achieved results and further developments"*, paper presented at the Eleventh International IBPSA Conference, Glasgow, July 27- 30, 2009

PAATERO J., *"Computational studies on distributed energy systems"*, Phd thesis, Faculty of Information and Natural Sciences Department of Applied Physics, Espoo, Helsinki University of Technology, 2009

SALAT S., Cities and forms on sustainable urbanism, Urban Morphology Laboratory, Hermann Editeurs des sciences et des arts, 2011

SARZI SARTORI, G., *"Analisi Dinamica del comportamento energetico di edifici esistenti"*, master thesis, Università degli Studi di Brescia, Facoltà di Ingegneria, Corso di Laurea Spacialistica in Ingegneria Edile Architettura, 2011
http://luce-gas.it/informazioni-pratiche/consum

(**10**) SETTI G., *"Oltre la dismissione - Strategie di intervento architettonico per la modificazione e il consolidamento di trame, tessuti e manufatti industriali"*, PhD Thesis, Politecnico di Milano, Scuola di Architettura e Società, DASTU Dipartimento di Architettura e Studi Urbani, 2013

Websites

architizer.com
dati.istat.it
Ec.europa.eu
ecdm.eu
elab.epfl.ch
http://eur-lex.europa.eu
http://coolclimate.berkeley.edu/maps
http://ec.europa.eu/
http://opencities.net/
http://www.enerdata.net/
http://www.smart-cities.e
oma.eu
www.archdaily.com
www.arcspace.com
www.autorita.energia.it
www.biourbanism.org
www.citylifemagazine.net
www.confindustria.it
www.domusweb.it
www.efficienzaenergetica.enea.it
www.eia.gov
www.elettrotecnologie.enea.it
www.enea.it
www.enel.com
www.energystrategy.it
www.entranze.eu
www.epic-cities.eu/
www.fraunhofer.de
www.housingprototypes.org
www.iea.org
www.mercatoelettrico.org
www.messib.eu
www.mvrdv.nl
www.people-project.eu/portal/
www.remourban.eu/
www.rinnovabili.it
www.smartbuildinginstitute.org
www.smartgrids.eu
www.smartsteep.eu/
www.stevenholl.com
http://es.cityfied.eu/
https://placesjournal.org
http://www.oma.eu/oma
http://passiv.de/en/

ENEA

Promotion and Communication Service

www.enea.it

July 2016