ROMA TRE UNIVERSITÀ DEGLI STUDI

**DOCTORAL THESIS**

# Towards Smart Cities : methods and real life applications

*Author*:

Stefano PIZZUTI

*Supervisor*:

Ing. Mauro ANNUNZIATO

E.N.E.A.

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*at the*

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Section of Computer Science and Automation
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# Chapter 1. The Smart Cities Context

## *1.1 Background*

The world's urban population is expected to double by 2050[1]. By 2030, six out of every ten people will live in a city and by 2050 this figure will run to seven out of ten[2]. In real terms, the number of urban residents is growing by nearly 60 million people every year. As the planet becomes more urban, cities need to become smarter.

Major urbanisation requires new and innovative ways to manage the complexity of urban living; it demands new ways to target problems of overcrowding, energy consumption, resource management and environmental protection.

It is in this context that Smart Cities emerge not just as an innovative modus operandi for future urban living but as a key strategy to tackle poverty and inequality, unemployment and energy management.

Despite the current wave of discussion and debate on the value, function and future of Smart Cities[3], as a concept it resists easy definition. At its core, the idea of Smart Cities is rooted in the creation and connection of human capital, social capital and information and Communication technology (ICT) infrastructure in order to generate greater and more sustainable economic development and a better quality of life. Smart Cities have been further defined along six axes or dimensions[4]:

- Smart Economy
- Smart Mobility
- Smart Environment
- Smart People
- Smart Living
- Smart Governance

The coordination of policies along these dimensions reflects the positive feedback between city development and urbanisation; cities attract people while the availability of populations and infrastructure facilitates economic and societal development. But this feedback alone and the growth to which it gives rise are not sufficient to produce the hoped for benefits, as the problems associated with the uncontrolled growth of the mega-cities amply demonstrate[5].

The linkages between economic, societal and environmental development are not scalable as cities expand and are difficult to predict precisely, let alone control. Their beneficial evolution must therefore be facilitated by a combination of framework conditions and information and communications infrastructures. In this way a platform is provided on which governments, businesses and citizens can communicate and work together, and track the evolution of the city.

In the global profile of urban development, the Smart City is emerging as an important basis for future city expansion. Europe's global competitors among the emerging economies are pursuing large Smart City programmes. India is planning to spend EUR 66 billion developing seven Smart Cities along the Delhi–Mumbai Industrial Corridor[6] using a mixture of public–private partnerships (80%) and publicly funded trunk infrastructure investment(20%). China too is pursuing a Smart Cities strategy as part of its efforts to stimulate economic development and eradicate poverty. As poverty in China is largely a rural phenomenon, the programme seeks to attract rural workers to Smart Cities, which can then serve as giant urban employment hubs[7].

As of March 2012, this strategy, based in transforming existing cities, involved at least 54 Smart City projects totalling EUR 113 billion.

The government in South Korea set up a Smart Korea IT Plan in 2010 which aimed to interconnect and enhance the ubiquitous infrastructure which has been developed through the u-strategy. The aim is connect physical infrastructure, including broadband internet and RFID technology with a range of devices, software, platforms and network technologies.

Examples of implementation include customised service portals for citizens and businesses.

Japan are using ICT to address a range of issues including the impact of a rapidly aging society on health care, energy shortages and environmental challenges, and public safety[8].

Other emerging countries are developing Smart Cities from the ground up[9]; some countries, such as Armenia, are now branding their whole country as a 'Smart Country'[10].

Europe does not face the problems of rural poverty or runaway mega-city development on the same scale as China or India, but the Smart City idea is nonetheless highly relevant. It will be necessary to harness the power of Smart Cities in order to compete effectively with rival global economies. Moreover, experience with Smart City development can help Europe to assist developing countries in managing mega-city development in ways that improve their welfare, reduce the risk of exported problems and help them to become better trading partners for Europe. Most importantly, Europe has its own particular need for Smart City thinking. The openness and connectivity of the European Single Market have allowed its cities to become hubs for the creative economy, technological and societal innovation, welfare enhancement and sustainable development.

They do this by drawing on resources (human or otherwise) throughout Europe and the globe and returning ideas, income and other benefits. This complex ecosystem is robust and resilient, but it faces serious challenges, including economic and societal inequality, environmental change and profound demographic transition. Other changes, including increased mobility and greater access to information, may both help and hinder this development. These developments directly affect[11] the sustainability[12] and the pan-European contributions of urban environments; they may be turned to advantage by Smart City initiatives.

In view of the challenges associated with growing European urbanisation, as well as the wider agenda to tackle economic recovery poverty, unemployment and environmental damage, the Europe 2020 strategy[13] incorporates a commitment[14] to promote the development of Smart Cities throughout Europe and to invest in the necessary ICT infrastructure and human and social capital development. Smart Cities may play a part in helping to meet the targets set out in Europe 2020 by adopting scalable solutions that take advantage of ICT technology to increase effectiveness, reduce costs and improve quality of life.

The current debate over the definition of Smart City 'success' required careful analysis. As most current discussion of Smart Cities is framed in terms of the six axes mentioned above, the simplest approach would be to equate success with demonstrated activity across the full range of these dimensions.

However, this approach ignores the differing nature and severity of the problems cities face, the presence or absence of existing initiatives and infrastructures, and the critical need effectively to engage and involve a suitable range of stakeholders.

The focus and balance of the Smart City ought, in principle, to reflect the specific challenges faced by the city and the priorities and capabilities of those involved. Moreover, the success of a Smart City depends on the depth and effectiveness of targeted improvement within each area or initiative and on the coherence or balance of the portfolio of initiatives across the city. From this perspective, we chose to talk about an 'ideal' Smart City, which allows us to distinguish the Smart City as an ideal model from the current state of the city and the initiatives through which it intends to become 'Smart'.

This approach also facilitates mapping Smart Cities in the EU in a way that provides a more textured profile of the individual cities and the scope of activity across the region.

Furthermore, our approach allows us to capture the particular strengths and weaknesses of a given city in a more illuminating way, by incorporating the individual profile, background, national agenda and underpinning strategies of each Smart City into the assessment of its overall achievement.

Definitions of successful initiatives and successful cities

- Successful initiatives: observable indicators through the life cycle of the initiative: attracting wide support, having clear objectives aligned to policy goals and current problems, producing concrete outcomes and impacts, being imitated or scaled.
- Successful cities: having meaningful objectives (aligned with Europe 2020 and actual outcomes) covering a mix of policy targets and characteristics; having a balanced portfolio of initiatives; attaining maturity (on our scale); actively joining in Smart City networks.

Smart City projects, therefore, are a sub-category of Smart City Initiatives which in turn are a sub-category of Smart Cities (as outlined in Figure 1.1 below).

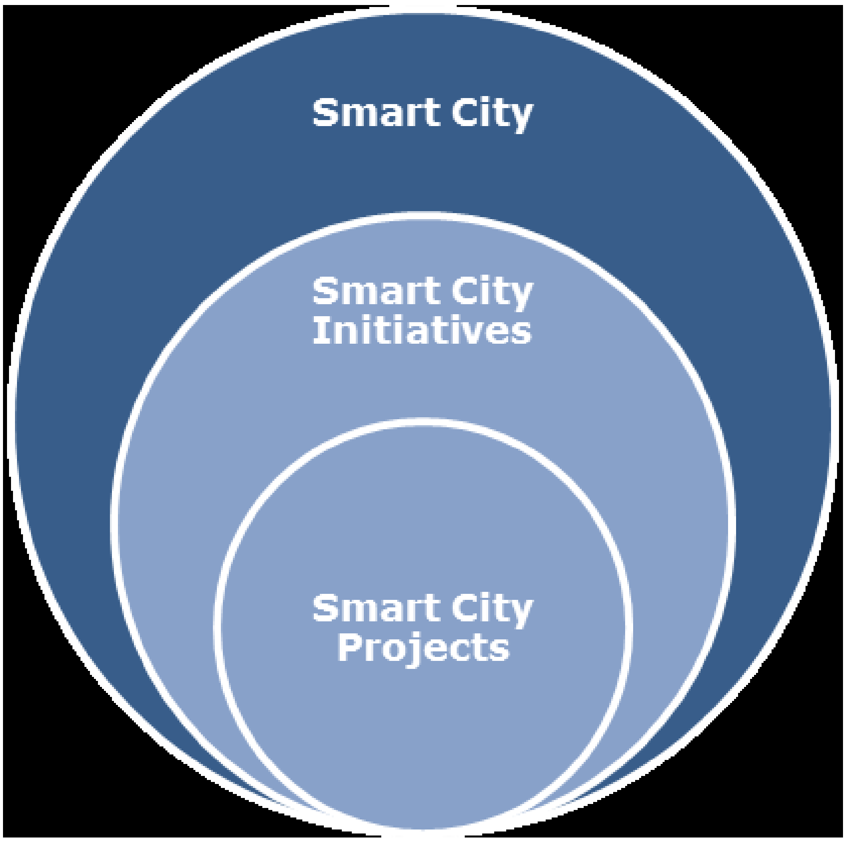



figure 1.1 : smart cities features relation

Smart Cities comprise a portfolio of initiatives, with different (though often overlapping) focal areas, modalities, participants and constituencies. As distinct from ideal Smart Cities, actual Smart Cities are more process than outcome.

Many initiatives are still in the design or early implementation phase, and their ultimate outcomes and impacts cannot be accurately or definitively assessed.

The approach taken here goes from the individual initiatives to the city level. We borrow from impact assessment practice[15] in following the development path or intervention logic of the Smart City trajectory. When considering the design and implementation of individual initiatives we consider a range of questions: Are the objectives relevant, appropriate and aligned with broader city development objectives? Does the initiative address problems of importance to the city in question? Is the mix of funding, participation, components and characteristics likely to produce the hoped for outcomes? Where possible, we consider the expected impacts as well. We seek to ascertain whether they have attained (or are they on the way to advancing) the goals of the initiative, the city and Europe as a whole.

## *1.2 Smart City definitions*

Examples of Smart Cities come in many variants, sizes and types. This is because the idea of the Smart City is relatively new and evolving, and the concept is very broad. Every city is unique, with its own historical development path, current characteristics and future dynamic. The cities which call themselves 'Smart', or are labelled as such by others, vary enormously.

The evolution of the Smart City concept is shaped by a complex mix of technologies, social and economic factors, governance arrangements, and policy and business drivers. The implementation of the Smart City concept, therefore, follows very varied paths depending on each city's specific policies, objectives, funding and scope.

Any useful working definition of a Smart City needs to incorporate these highly diverse circumstances while still enabling improved understanding of good practice, the potential for scaling and the development of relevant policy frameworks.

There is also considerable overlap of the Smart City concept with related city concepts[16] such as:

- 'Intelligent City'
- 'Knowledge City'
- 'Sustainable City'
- 'Talented City'
- 'Wired City',
- 'Digital City'
- 'Eco-City'.

However, the Smart City concept has become predominant among these variants, especially at city policy level, globally as well as in Europe, so here we concentrate on the specific definitions and characteristics of the Smart City.

Many definitions of the Smart City focus almost exclusively on the fundamental role of ICT in linking city-wide services. For example, one suggestion is that a city is smart when: 'the use of ICT [makes] the critical infrastructure components and services of a city – which include city administration, education, healthcare, public safety, real estate, transportation, and utilities – more intelligent, interconnected, and efficient'[17].

Similarly, another approach states, 'We take the particular perspective that cities are systems of systems, and that there are emerging opportunities to introduce digital nervous systems, intelligent responsiveness, and optimization at every level of system integration[18].

Other definitions, while retaining ICT's important role, provide a broader perspective, such as the following wide working definition: 'a city may be called 'Smart' 'when investments in human and social capital and traditional and modern communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance'[19].

Such definitions tend to balance different economic and social factors with an urban development dynamic. They also serve to open the definition potentially to encompass smaller and less developed cities which are not necessarily able to invest in the latest technology. This latter point is also emphasised by a number of sources: 'While megacities [defined as over 5 million inhabitants] have captured much public attention, most of the new growth will occur in smaller towns and cities, which have fewer resources to respond to the magnitude of the change.'[20].

The broader approach suggested above also emphasises sustainability, quality of life and urban welfare creation through social participation, for example by addressing societal challenges like energy efficiency, environment and health [21].

We have seen that what makes a city a Smart City is the use of ICTs, which are used tooptimise the efficiency and effectiveness of useful and necessary city processes, activities and services. This optimisation is typically achieved by joining up diverse elements and actors into a more or less seamlessly interactive intelligent system. In this sense, the concept of a Smart City can be viewed as recognising the growing and indeed critical importance of technologies (especially ICT) for improving a city's competitiveness, as well as ensuring a more sustainable future, across networks of people, businesses, technologies, infrastructures, consumption, energy and spaces.

In a Smart City, these networks are linked together, supporting and positively feeding off each other. The technology and data gathering used in Smart Cities, should be able: constantly to gather, analyse and distribute data about the city to optimise efficiency and effectiveness in the pursuit of competitiveness and sustainability

- to communicate and share such data and information around the city using commondefinitions and standards so it can be easily re-used
- to act multi-functionally, providing solutions to multiple problems from a holistic city perspective[22].

Finally an important, but often overlooked, additional dimension of the Smart City concept

is city networking supported by ICT. Such networking is beyond immediate city governance

control, but allows for crucial communications within the same region, within the same

country and as part of European and global city networks.

Overall, ICT enables a Smart City to:

- make data, information, people and organisations smart
- redesign the relationships between government, private sector, non-profits, communities and citizens
- ensure there are synergies and interoperability within and across-city policy domains and systems (e.g. transportation, energy, education, health and care, utilities, etc.)

- drive innovation, for example through so-called open data, ‘hackers marathons’, living labs and tech hubs[23].

While ICT is a definitive component, Smart Cities cannot simply be created by deploying sensors, networks and analytics in an attempt to improve efficiency. Indeed, at worst, this can lead to a one-size fits all, top-down approach to sustainability and economic development.

In Japan, cooperation between government and industry, involving large Japanese conglomerations (such as Sumitomo and Mitsubishi Electric) has been leveraged to support smart city initiatives focusing on increasing the quality of life of citizens through green ICTs and smart grids[24].

In short, such a strategy focuses on the city as a single entity, rather than the people and citizens that bring it to life. Any adequate model for the Smart City must therefore also focus on the Smartness of its citizens and communities and on their well-being and quality of life. In so doing, it can encourage the processes that make cities important to people and which might well sustain very different – sometimes conflicting – activities. Thus, the ‘Smartness’ of Smart Cities will not only be driven by orders coming from unseen and remote central government computers which try to predict and guide the population's actions from afar. Smart Cities will be smart because their citizens have found new ways to craft, interlink and make sense of their own data and information, changing the behaviour of people and organisations. For example, many cities monitor air quality down to neighbourhood scale and make this data available. But how can citizens use this information?

Most people are unable to move house just because their neighbourhood has polluted air.

Rather, a citizen-led air quality monitoring system which complements the official statistics would see measurements taken in places they choose, such as at the height of a child’s push-chair, in playgrounds or different parts of a park.

In this example, people could choose their walking or cycling routes, measure the impact of their car, and experiment with community inspired initiatives to improve air quality, such as planting trees or setting up car-free zones[25]. Without the engagement of stakeholders, a city can never be Smart, no matter how much ICT shapes its data.

To sum up, this study defines ‘Smart City’ initiatives as multi-stakeholder municipally based partnerships aimed at addressing problems of common interest with the aid of ICTs, which underpin ‘Smart’ classification. ‘Smart City’ initiatives address problems of common interest with the aid of ICTs. To be classified as a Smart City, a city must contain at least one initiative that addresses one or more of the following characteristics: Smart Governance, Smart People, Smart Living, Smart Mobility, Smart Economy and Smart Environment. ICT initiatives based on these characteristics aim to connect existing and improved infrastructure to enhance the services available to stakeholders (citizens, businesses, communities) within a city.

### 1.2.1 Working definition of a Smart City

Working definition: As a result, this study’s working definition of a Smart City is ‘a city seeking to address public issues via ICT-based solutions on the basis of a multistakeholder, municipally based partnership’.

Here a summary overview of the main Smart City definitions.

Technology focused definitions

- The use of ICT [makes] the critical infrastructure components and services of a city – which include city administration, education, healthcare, public safety, real estate, transportation, and utilities – more intelligent, interconnected, and efficient.Washburn and Sindhu (2009)

- Cities [should be seen as] systems of systems, and that there are emerging opportunities to introduce digital nervous systems, intelligent responsiveness, and optimization at every level of system integration. MIT (2013)

- In a Smart City, networks are linked together, supporting and positively feeding off each other, so that the technology and data gathering should:be able to constantly gather, analyse and distribute data about the city to optimise efficiency and effectiveness in the pursuit of competitiveness and sustainability; be able to communicate and share such data and information around the city using common definitions and standards so it can be easily re-used; be able to act multi-functionally, which means they should provide solutions to multiple problems from a holistic city perspective. Copenhagen Cleantech Cluster (2012)

Broad definitions

- A city is smart when investments in human and social capital and traditional and modern communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance. Caragliu, Del Bo and Nijkamp (2009)

- A [smart] city is where the ICT strengthens freedom of speech and the accessibility to public information and services. Anthopoulos and Fitsilis (2010)

- [Smart Cities are about] leveraging interoperability within and across policy domains of the city (e.g. transportation, public safety, energy, education, healthcare, and development). Smart City strategies require innovative ways of interacting with stakeholders, managing resources, and providing services. Nam and Pardo (2011)

- Smart Cities combine diverse technologies to reduce their environmental impact and offer citizens better lives. This is not, however, simply a technical challenge. Organisational change in governments – and indeed society at large – is just as essential. Making a city smart is therefore a very multi-disciplinary challenge, bringing together city officials, innovativesuppliers, national and EU policymakers, academics and civil society. Smart Cities and Communities (2013)

- [a city may be called ‘smart’] when investments in human and social capital and traditional and modern communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance. Schaffers et al. (2011)

- Any adequate model for the Smart City must therefore also focus on the Smartness of its citizens and communities and on their well-being and quality of life, as well as encourage the processes that make cities important to people and which might well sustain very different – sometimes conflicting – activities. Haque (2012)

## *1.3 Smart City characteristics*

As we have described, the wealth of initiatives in the dynamic socio-economic, technical and policy environment in the EU potentially gives rise to a wide variety of Smart City characteristics. These can be associated with different objectives (general, specific and operational, for example) and with different patterns of actor roles and relations, policy instruments and implementation methods. Each of these qualities may, in turn, be mapped against different locations, city sizes, funding arrangements and framework conditions andoutcomes.

In order to capture as many of these circumstances as possible, we propose a framework of characteristics. This will enable us to identify relevant projects and initiatives which, when implemented, contribute to the formation of a Smart City. We will then use these projects and initiatives identified in this study to populate a structured evidence base. We can thereby analyse possible correlations among characteristics, attempt to draw causal inferences and on this basis develop recommendations concerning good practices and strategies.

Taking our working definition of a Smart City, supplemented by the additional evidence presented above, we can summarise the Smart City concept as firmly anchored in the enabling power of ICT, which interconnect systems and stimulate innovation to facilitate a series of policy goals. Given the needs of cities to compete, such policy goals include economic growth, which is in turn underpinned by well-developed human capital.

There is also a need to make economic development sustainable in environmental terms.

This could involve ICT-based 'Smart Networks' to reduce energy transmission costs and improve the resilience of utility networks by matching demand and supply dynamically.

Such networks would have the additional advantage of allowing local cogeneration to meet local power demand. They could also provide individual utility users with accurate and timely information to enable them to take costs and environmental impact into account when choosing and using appliances.

Another class of examples is provided by city mobility systems that use sensors, processors and ICT-driven traffic controls to provide Smart and efficient arteries. As we have made clear, however, other aspects (social, welfare, cultural, quality of life) are also critical for balanced Smart City development. Underpinning each of these features is the need for new modes of bottom-up and top-down holistic governance, which also enable and encourage broad participation and engagement by all stakeholders in all aspects of a city's life.

Building on the work of the European Smart City Project[26], as well as numerous other sources[27], there are proposed six Smart City characteristics:

- Smart Governance
- Smart Economy
- Smart Mobility
- Smart Environment
- Smart People
- Smart Living

These same six characteristics are deployed by a number of studies to develop indicators and Smart City development strategies[28].

This type of characterisation framework is well justified and documented, and already used in practice by an increasing number of cities and policy makers.

The framework aims to capture the key dimensions of European Smart Cities described above while retaining simplicity through specifying a relatively small number of characteristics which define these initiatives and cover the range of existing projects. When defining a Smart City in the present study, at least one of the six characteristics must be present in a given Smart City project or initiative. This is a baseline, however, and we must also keep in mind the Smart City definitions and summary outlined above. These point to the deployment of multi-dimensional strategies, which consist of many components and projects designed to be synergistic and mutually supportive. Indeed, the most successful Smart City strategies might be expected to adopt a multi-dimensional approach to maximise such synergy and minimise negative spill-over effects, as might happen, for example, if a Smart Economy strategy were prioritised which was detrimental to the environment. For this reason, we might expect to see more than one characteristic present in the most successful Smart Cities. The six characteristics of Smart Cities are described in more detail below.

Smart Governance

By Smart Governance we mean joined up within-city and across-city governance, including services and interactions which link and, where relevant, integrate public, private, civil and European Community organisations so the city can function efficiently and effectively as one organism. The main enabling tool to achieve this is ICT (infrastructures, hardware and software), enabled by smart processes and interoperability and fuelled by data. International, national and hinterland links are also important (beyond the city), given that a Smart City could be described as quintessentially a globally networked hub. This entails public, private and civil partnerships and collaboration with different stakeholders working together in pursuing smart objectives at city level. Smart objectives include transparency and open data by using ICT and e-government in participatory decision-making and co-created e-services, for example apps. Smart Governance, as a transversal factor, can also orchestrate and integrate some or all of the other smart characteristics.

Smart Economy

By Smart Economy we mean e-business and e-commerce, increased productivity, ICT-enabled and advanced manufacturing and delivery of services, ICT-enabled innovation, as well as new products, new services and business models. It also establishes smart clusters and eco-systems (e.g. digital business and entrepreneurship). Smart Economy also entails local and global inter-connectedness and international embeddedness with physical and virtual flows of goods, services and knowledge.

Smart Mobility By Smart Mobility we mean ICT supported and integrated transport and logistics systems. For example, sustainable, safe and interconnected transportation systems can encompass trams, buses, trains, metros, cars, cycles and pedestrians in situations using one or more modes of transport. Smart Mobility prioritises clean and often non-motorised options. Relevant and real-time information can be accessed by the public in order to save time and improve commuting efficiency, save costs and reduce $CO_2$ emissions, as well as to network transport managers to improve services and provide feedback to citizens. Mobility system users might also provide their own real-time data or contribute to long-term planning.

Smart Environment

By smart environment we include smart energy including renewables, ICTenabled energy grids, metering, pollution control and monitoring, renovation of buildings and amenities, green buildings, green urban planning, as well as resource use efficiency, re-use and resource substitution which serves the above goals. Urban services such as street lighting, waste management, drainage systems, and water resource systems that are monitored to evaluate the system, reduce pollution and improve water quality are also good examples.

Smart People

By Smart People we mean e-skills, working in ICT-enabled working, having access to education and training, human resources and capacity management, within an inclusive society that improves creativity and fosters innovation. As a characteristic, it can also enable people and communities to themselves input, use, manipulate and personalise data, for example through appropriate data analytic tools and dashboards, to make decisions and create products and services.

Smart Living

By Smart Living we mean ICT-enabled life styles, behaviour and consumption. Smart Living is also healthy and safe living in a culturally vibrant city with diverse cultural facilities, and incorporates good quality housing and accommodation. Smart Living is also linked to high levels of social cohesion and social capital.

## *1.4 The relationship between characteristics and components*

The characteristics used to classify Smart Cities include the areas addressed by Smart City initiatives, and illustrate the variety of projects and Smart Cities across the EU Member States.

They are, put simply, the ends to which stakeholders participate in an initiative. We call the means by which those ends are achieved components. If, for example, the characteristic of an initiative is Smart Environment, the components may be various environmental technologies.

The term 'components' covers a wide range of activities, resources and methods; some are pre-existing, while others are assembled or even created for specific projects. In order to interpret the design and potential contributions of Smart Cities and the portfolio of initiatives they host, it is useful to analyse how the characteristics and components of their initiatives align to Europe 2020 targets.

This section discusses the relationship between characteristics and components. In practice, components and characteristics are often difficult to distinguish; components, in particular, are not systematically identified. The central thesis of this section is that they cannot easily be separated and that they should therefore be analysed together.

Components can be conceptualised as the building blocks of Smart City initiatives.

They comprise the inputs, technologies and processes of specific initiatives, as well as the norms or standards deployed. In discussing the relationship between Smart City components and characteristics, some scholars argue that the components can be loosely stratified by the six characteristics, which in turn are used to identify whether a city is 'Smart'[29]. Cohen treats Smart City components as key drivers of specific characteristics, based on the specific challenges and needs a city faces with respect to that characteristic[30]. However, we observe in our sample (see Annex 10) that while some components pertain to a specific characteristic (e.g. 'green buildings' and 'energy sensors', which are specific to the Smart Environment characteristic), others are of a horizontal or enabling nature (such as 'open data' and monitoring technologies) and cover several characteristics.

Because Smart City initiatives go beyond the development and application of technology –in attracting participants and delivering impacts – we must take into account human or social factors, such as education and social capital, or institutional factors surrounding the role of stakeholders and funders. Only in this way may we arrive at a workable conceptualisation of the relationship between components and characteristics. Nam and Pardo adopt a holistic approach, categorising Smart City components within three core factors [31]:

- Technology factors
  - Physical infrastructure
  - Smart technologies
  - Mobile technologies
  - Virtual technologies
  - Digital networks
- Human factors
  - Human infrastructure
  - Social capital
- Institutional factors
  - Governance
  - Policy
  - Regulations and directives

The relationship between characteristics and components is summarised in Figure 1.2. The outer ring shows the components, and the inner ring the characteristics. Rather than each component mapping onto a specific characteristic, a range of technological, human and institutional factors underpins all characteristics.

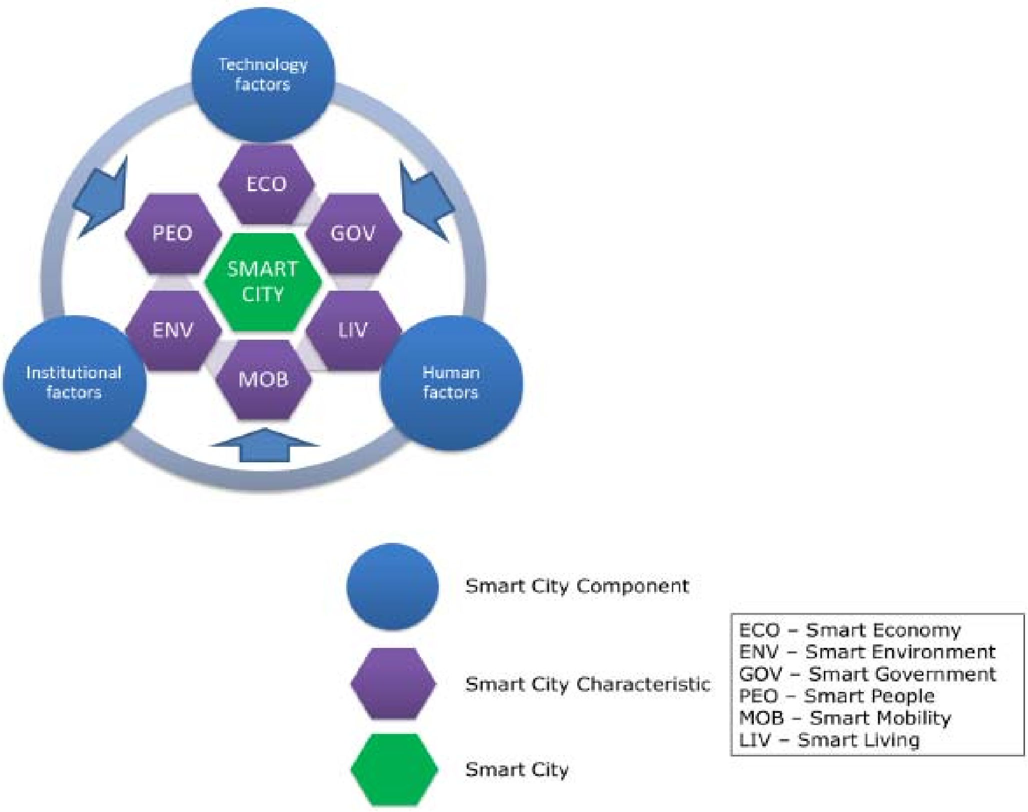



figure 1.2 : smart cities characteristics

This allows us to understand the relationships between components and characteristics as both direct and indirect. In some cases, the characteristic fully describes the initiative by displaying what the initiative is about and the priorities of its participants and direct beneficiaries.

In other cases, the characteristics are a vehicle for the components; the initiative is primarily a way to bring people together and create new ways of collaborating. This is the case when the primary contribution is to the Smartness of the city itself.

In some cases, the linkage from objectives to characteristics to components is direct; an objective is furthered by a specific initiative with an associated characteristic that necessitates and justifies the use of a particular component. Take, for example, the objective of improving energy efficiency within the city. This objective may be associated with an environmental initiative (characteristic), which makes use of Smart buildings (component) to permit energy network managers to adjust load in order to make efficient use of existing supply capacity. The linkage may also be indirect, if a specific component contributes to more than one characteristic, altering the way those characteristics are pursued across other initiatives and their associated components and objectives. We can see this type of linkage in the above example. Here, the use of Smart meters can help individual energy users to optimise their demand patterns (contributing to the environmental characteristic).

Furthermore, this information will raise their awareness of the price implications of their behaviour, leading them to factor energy considerations into their appliance purchase (economy) and residential and job location (mobility) decisions.

It is important to recognise the dual role of components in this conception. First, the availability of existing components can make it easier to mobilise and complete Smart City initiatives.

Second, they can also be regarded as desired (or even essential) by-products of such initiatives, to the extent that they are developed or improved during the course of initiatives. The relationship between components and characteristics is inherently complex.

Moreover, given the absence of information on the outputs or outcomes of Smart City initiatives, it is difficult to allocate components to individual initiatives and to attribute success or failure to the presence or absence of specific components.

Pre-existing components are generally not mentioned in the description of the initiatives, but are taken for granted, even if they are central or essential to the initiative’s success.

Therefore, characteristics associated with shortlisted initiatives will be aggregated and used in our analysis as a proxy for the profile of a given city. While it is important to note that the presence of specific characteristics is not enough to determine success of the outputs of an initiative or a Smart City, they do reflect the thematic objectives of an initiative. These can be aggregated for a given Smart City to characterise its portfolio of initiatives. This profile can then be then used to assess alignment with wider objectives, such as Europe 2020 targets.

## *1.5 Mapping smart cities of Europe*

The comprehensive mapping of European Smart Cities was based on a database of all 468 cities with a population of at least 100,000 within the 28 Member States of the EU[32]. This entailed three steps:

1. Data and other information on all 468 cities was drawn from the following sources:

- general sources including websites[33] and references cited in the bibliography.

- specific city sources, including their websites where available, together with other city-specific sources were used to identify Smart City characteristics in (for example) articles describing strategies, visions, plans, initiatives, city projects.

- Smart City project websites, including those funded or otherwise supported at EU level by the Competitiveness and Innovation Programme (CIP)[34], Future Internet Public Private Partnership (FI-PPP)[35], Eurocities[36] and other networks of European cities[37].

2. These sources were then analysed in depth to determine whether each city in the sample could be defined as a Smart City based on the definition and characteristics developed in the previous paragraphs. Specifically, this involves the presence of at least one of the Smart City characteristics (Smart Governance, Smart Economy, Smart Mobility, Smart Environment, Smart People and Smart Living). In looking for such evidence, we examined elements such as city strategies, projects, initiatives, programmes, networks, platforms, components and solutions. These elements could be either planned or in the process of being implemented. Initially, the search focused on cities using the exact words 'Smart City' or 'Smart'. Other types of city designation (including Intelligent City,

Knowledge City, Sustainable City, Talented City, Wired City, Digital City and Eco-City), as well as general city development policies, strategies and plans, were also examined to determine whether the city might be a candidate for Smart City designation. A Smart City also needs to have its characteristics at least partially enabled or supported by ICT.51 Using these criteria, 240 Smart Cities were identified.

3. The 'maturity level' of the identified Smart Cities was then examined using the following

categorisation:

- maturity level 1: a Smart City strategy or policy only
- maturity level 2: in addition to level 1, a project plan or project vision, but no piloting or implementation
- maturity level 3: in addition to level 2, pilot testing Smart City initiatives
- maturity level 4: a Smart City with at least one fully launched or implemented Smart City initiative.

Cities that do not attain maturity level 1 did not qualify as 'Smart': clearly there would also be no evidence of them having any of the six characteristics.

Where projects or initiatives in a Smart City have different maturity levels, the city as a whole was designated at the highest maturity level.

In summary, the research team compiled a database which includes all 468 EU-28 cities with at least 100,000 inhabitants. This database indicates each city's country location and population totals, and classifies 240 of them as Smart Cities.

For each Smart City, the database also records which of the six Smart City characteristics are present, as well as the overall maturity level. Finally, links to specific city website URLs with information on their Smart City activities are provided where available.

Overall, slightly over half (51%) of the 468 cities in the main sample meet our Smart City criteria, indicating how prevalent the Smart City movement has become in Europe in the last few years. Some significant Smart City trends observed in the database are analysed in this section.

First, all but six of the 52 cities in the EU-28 with more than 500,000 inhabitants have some form of Smart City (see Figure 4); this is very clearly a large city phenomenon. The incidence of Smart Cities decreases with city size. This does not mean, however, that smaller cities are not engaging in Smart City development. As Figure 1.3 shows, 43% of cities with between 100,000 and 200,000 inhabitants are involved.

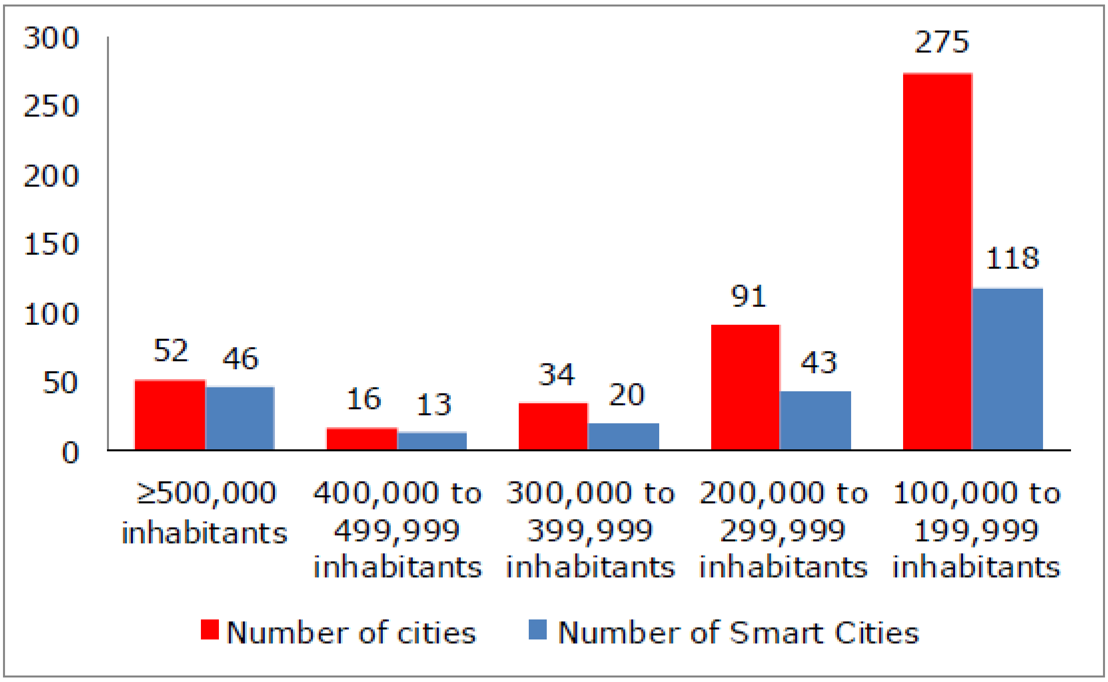



figure 1.3 : cities vs smart cities

Figure 1.4 shows the distribution of maturity levels, which is relatively even; just over 50% have not yet started pilots or implementation. It may be unsurprising that many cities are using the relatively new Smart Cities concept as a tool for self-promotion or are at an early stage of development. However, by the same token, almost 50% of cities that we consider Smart are already engaged in some form of active implementation.

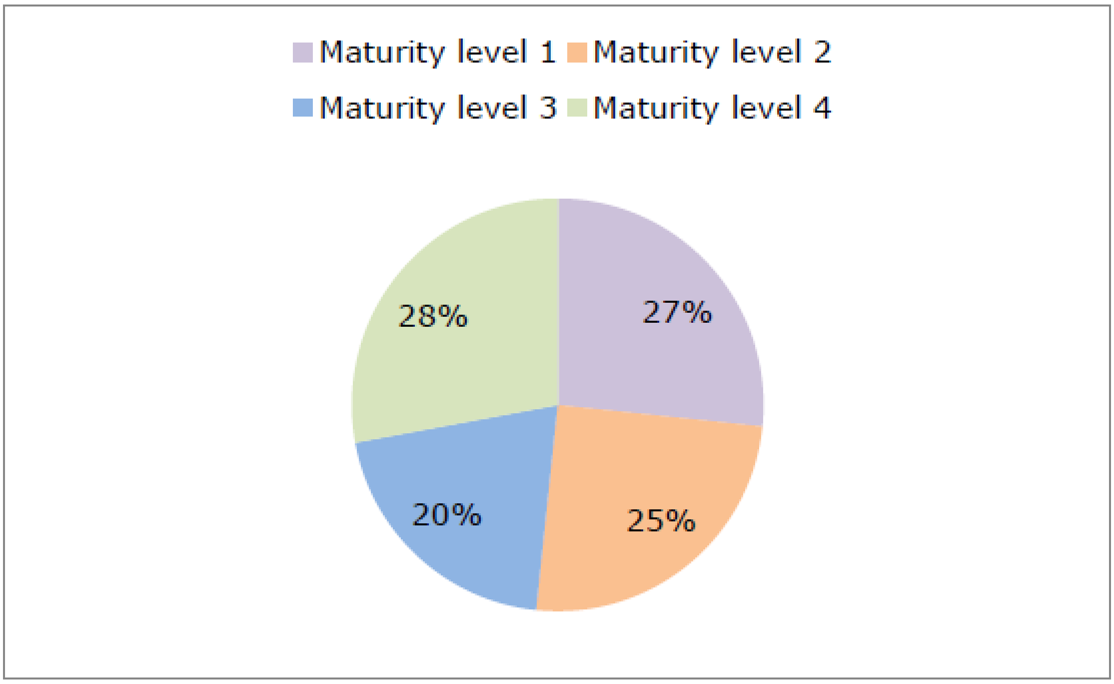



figure 1.4 : smart cities maturity levels

Figure 1.5 shows the number of the Smart Cities studied containing each of the six Smart City characteristics. Smart Environment has significantly greater representation than the other characteristics, followed by Smart Mobility. The remaining characteristics are more or less evenly distributed (around 10% coverage by all cities). This resonates with the overall impression that issues of congestion and the need to improve the overall city environment are among the foremost drivers of European Smart City policy.

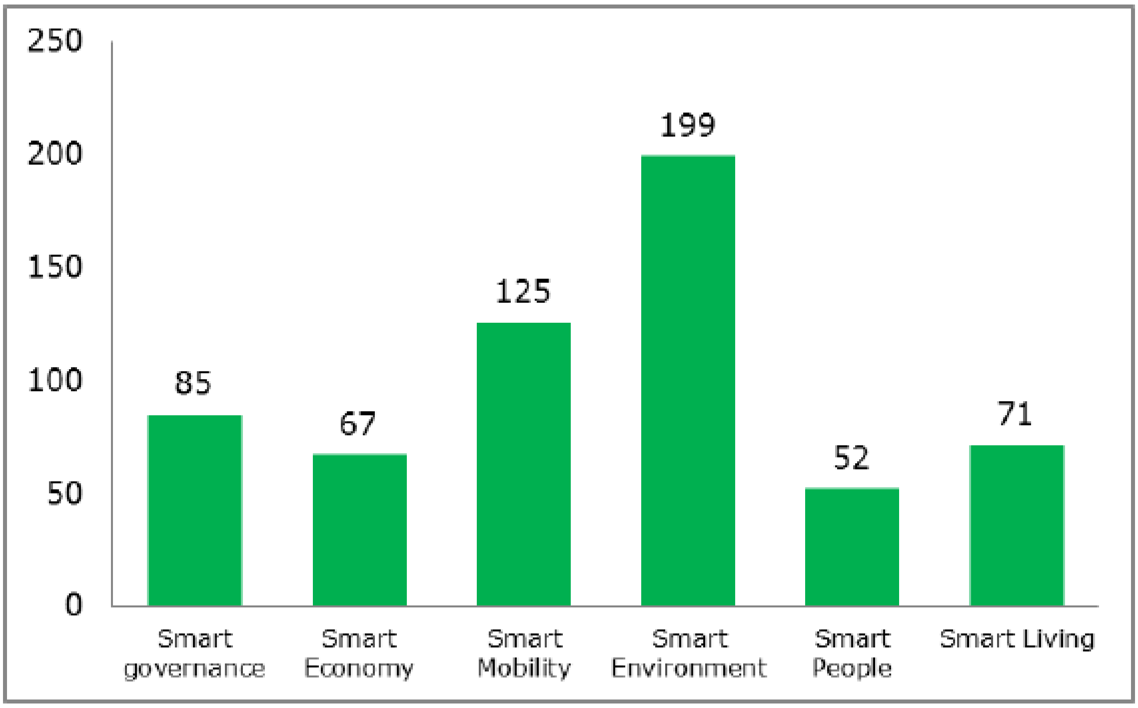



figure 1.5 : smart cities topics breakdown

These two characteristics – environment and mobility – may also be more easily identifiable than the others, and therefore attract political attention (there may be some quick political gains despite the potential need for a more long-term approach to all characteristics).

The decision to pursue specific Smart City initiatives is broad and complex, and reflects the priorities, capabilities and concerns of interested actors and stakeholders. The prevalence of environmentally orientated initiatives may reflect the common nature of the associated issues. All cities experience environmental problems to some degree, and these issues rank high on the agendas of civil society groups and businesses (whether in relation to corporate social responsibility or as a result of soaring energy prices and the related consequences of environmental degradation). This prevalence is also likely to reflect an emphasis coming from the community level, and other national and international sources. The transnational nature of all environmental issues also suggests that it is a key area in which European institutions can add value. The emphasis on Smart Environment across the majority of cities may, therefore, reflect the significant role of large, multi-city initiatives focusing on this characteristic.

Environment initiatives are relatively straightforward to identify, but some kinds of Smart initiative are more difficult to localise at the city level. The asymmetry of characteristic coverage may reflect this difficulty.

Cities involve fundamental networks, infrastructures and environments related to their key functions: city services, citizens, business, transport, communication, water and energy[38].

While systems related to transportation, communication, water and energy are underpinned by hard (and physically localised) infrastructure, issues affecting public services, business and social networks may be less tangible and harder to link to an individual city. In this instance, Smart Governance and Smart Economy projects may be more likely to be pursued at a national level; the associated issues may be harder to frame as 'municipal problems'. Examples of Smart City initiatives at national level include Italy's project 'Burocrazia! Diamoci un taglio!' (Let's cut the red tape!)[39], a national initiative aimed at encouraging citizens to use digital tools. Similarly, Portugal's national version of the project 'Fix my street'[40] allows citizens to report problems in public spaces to a central government portal[41]. Therefore, the relative lack of coverage of Smart Governance and Smart Economy characteristics in the sample of cities may, to a degree, reflect the lack of initiatives framed at a city level rather than a lack of problems or awareness of the associated issues.

The data show that 82 (34% of) Smart Cities have only one characteristic.

Figure 1.6 demonstrates that there is a clear correlation between city size and the number of Smart City characteristics a Smart City has. This supports the notion that larger cities tend to have the greatest resources and more ambitious Smart City policies.

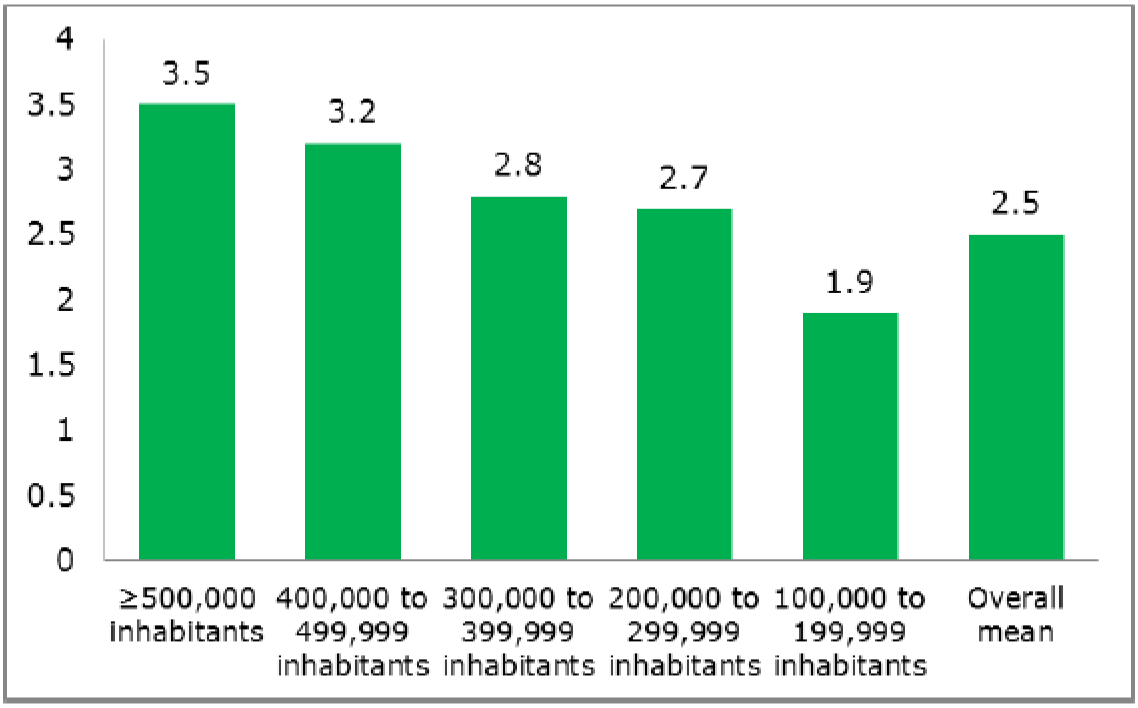



figure 1.6 : city size vs smart cities

Figure 1.7 compares Smart City size with maturity. It demonstrates a very strong tendency for cities of over 500,000 inhabitants to have the most mature Smart City initiatives (implementation beyond the planning and any pilot stages). Clearly, such cities tend to have the greatest resources and political clout. However, the data do not show any other clear relationship between city size and maturity level.

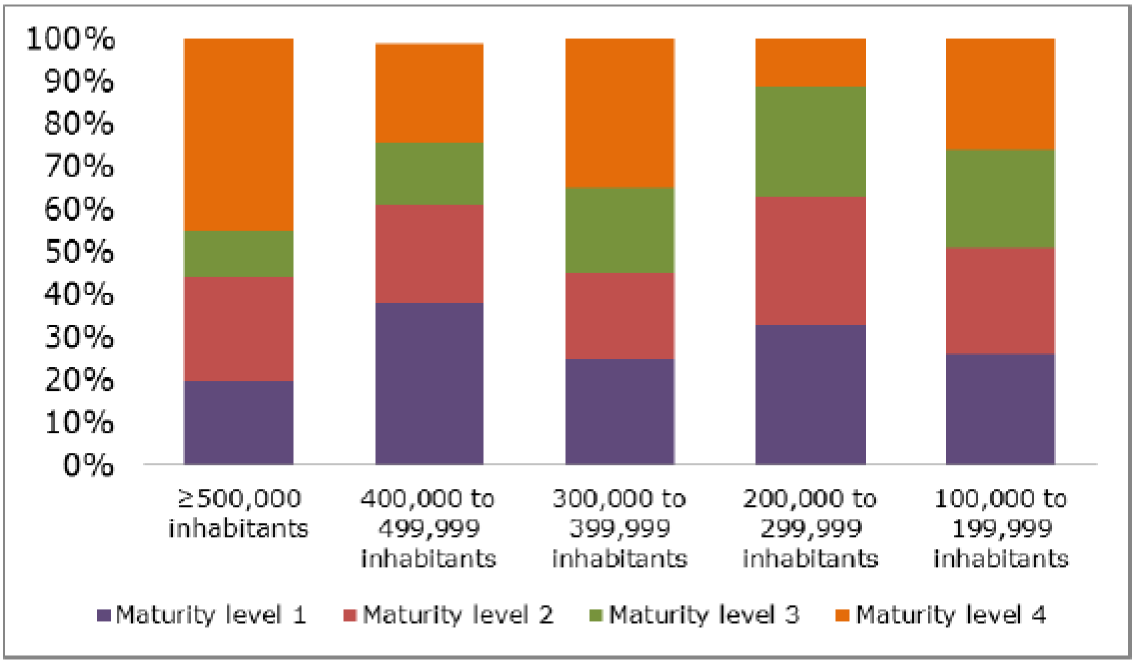



figure 1.7 : smart city size vs maturity level

As we see in Figure 1.8, comparing Smart City size with Smart City characteristics does not show any highly significant trends. The largest cities tend to have a more even distribution of characteristics than the average, while the smallest cities tend to focus on the two most common characteristics: environment and mobility.

Perhaps this again supports the notion that the largest cities are more ambitious given their resources and political influence, while the smallest are more likely to focus more exclusively on the most common characteristics.

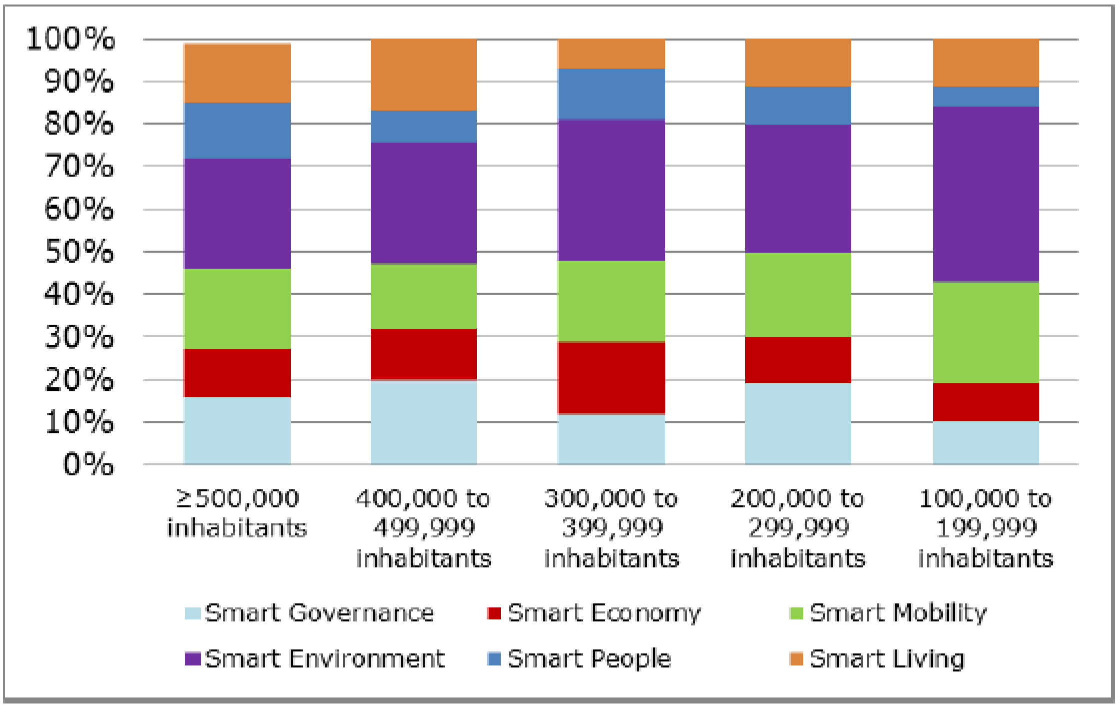



figure 1.8 : smart city size vs smart cities characteristics

This part presents detailed maps of the location of Smart Cities within the EU Member States, depicting all European cities of at least 100,000 inhabitants and those which we identify as Smart Cities (Figure 1.9, Figure 1.10 and Figure 1.11). These are followed by Figure 1.12 which illustrates the distribution of Smart Cities according to each of the six Smart City characteristics.

In Figure 1.12 cities in blue are the designated Smart Cities and those in red are cities with a population of over 100,000 for which we did not find sufficient information online to categorise as a Smart City. It shows that Smart Cities are widely spread across Europe and exist in almost every country within EU-28. As Cyprus, Luxemburg and Malta do not have any cities with a population over 100,000 they are outside the scope defined in this study.

It is important to note that virtually all Nordic Member State cities can be characterised as Smart Cities, as can the majority of cities in Italy, Austria and the Netherlands, and approximately half of British, Spanish and French cities.

Germany and Poland have relatively few Smart Cities. Eastern European countries generally have a lower incidence of Smart Cities than the rest of EU-28.

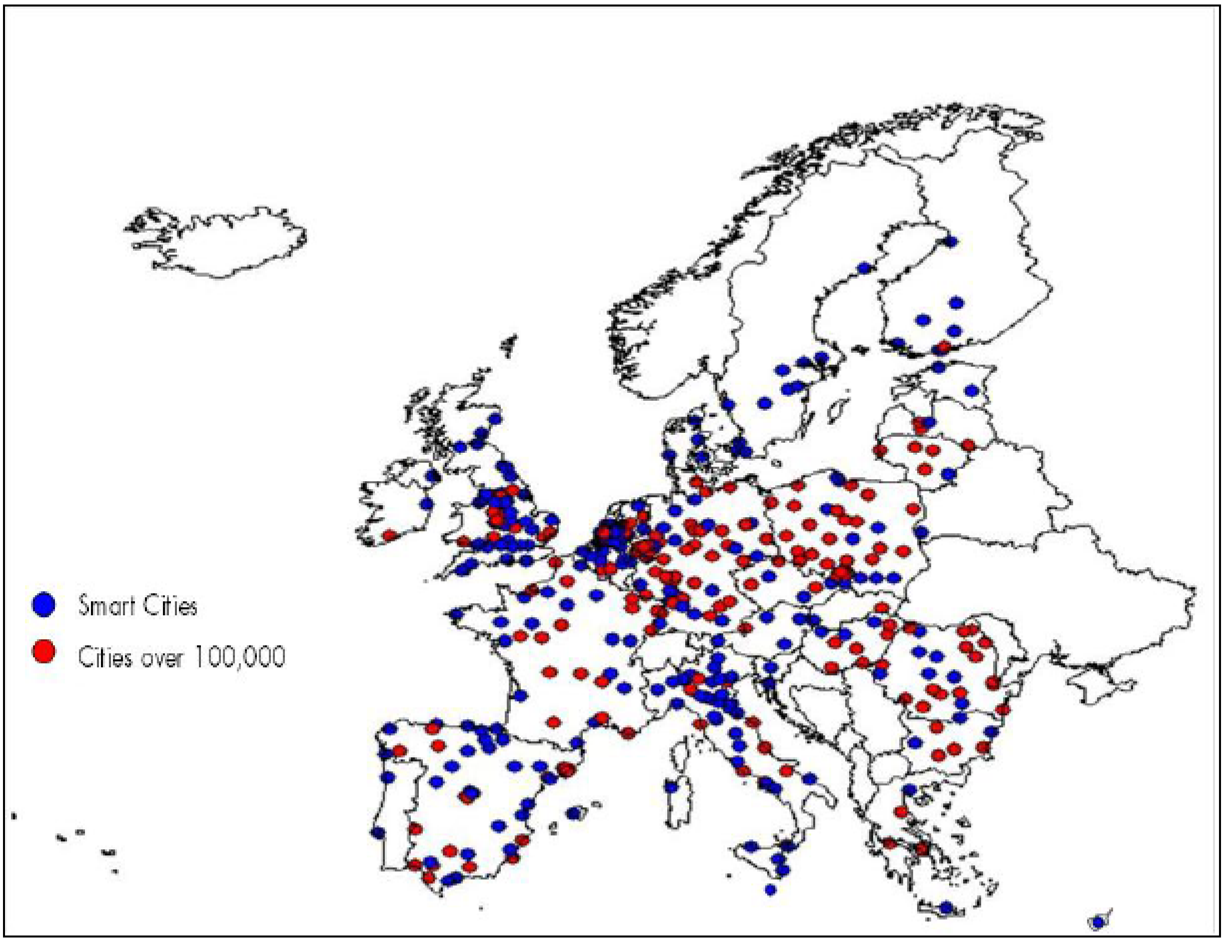



figure 1.9 : smart cities mapping

Figure 1.10 shows the total number of Smart Cities in the EU-28. It is clear that the larger countries, especially the UK, Spain and Italy, have the largest number of Smart Cities – more than 30 each. However, this is not universally true; large countries such as Germany and France have fewer Smart Cities overall. As would be expected, the smaller countries have absolute lower numbers of Smart Cities.

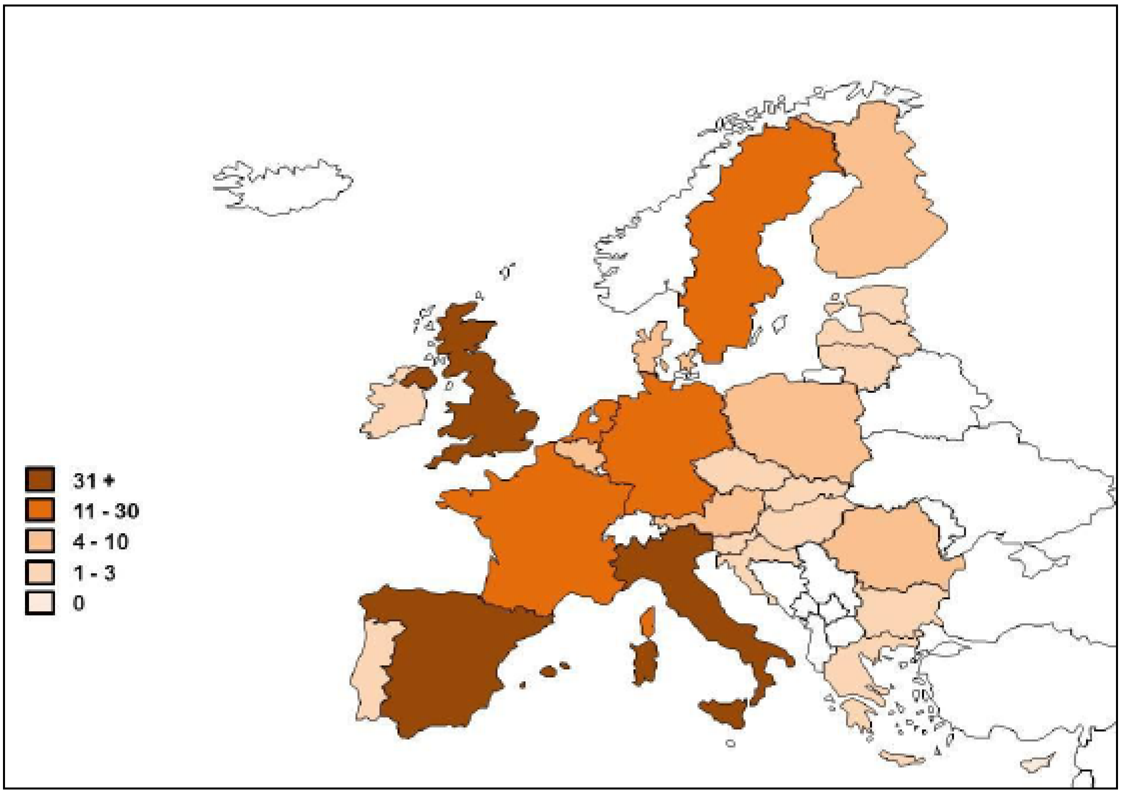



figure 1.10 : smart cities mapping by country

The trends shown are confirmed by Figure 1.11, which shows the proportion of cities (of over 100,000 inhabitants) in each country meeting the Smart City criteria. The leaders are Italy, Austria, the Nordic Member States, Estonia and Slovenia; they are followed by the UK, Spain, Portugal, the Netherlands and Belgium.

Lower percentages of Smart Cities to overall number of cities are seen in Ireland, France and Germany, most Eastern European countries and Greece.

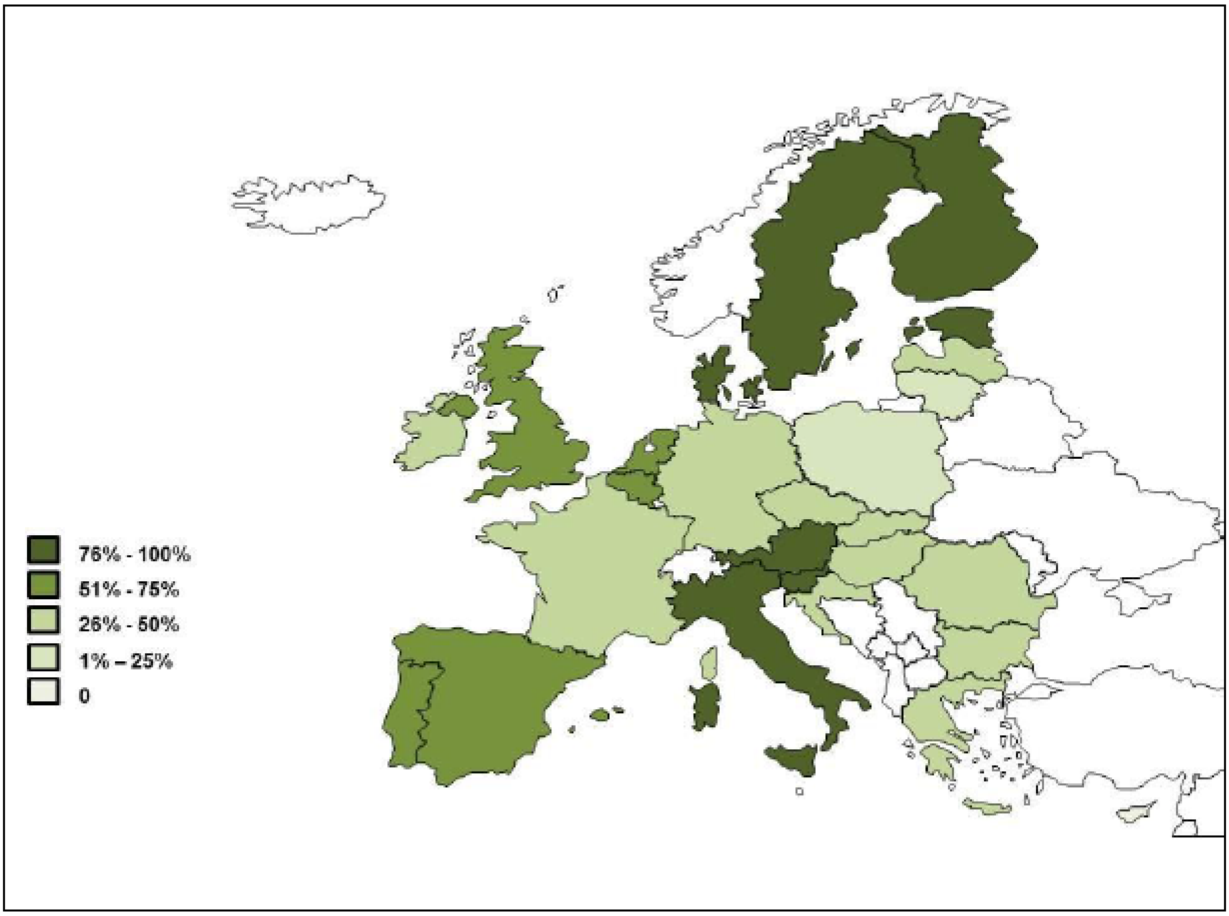
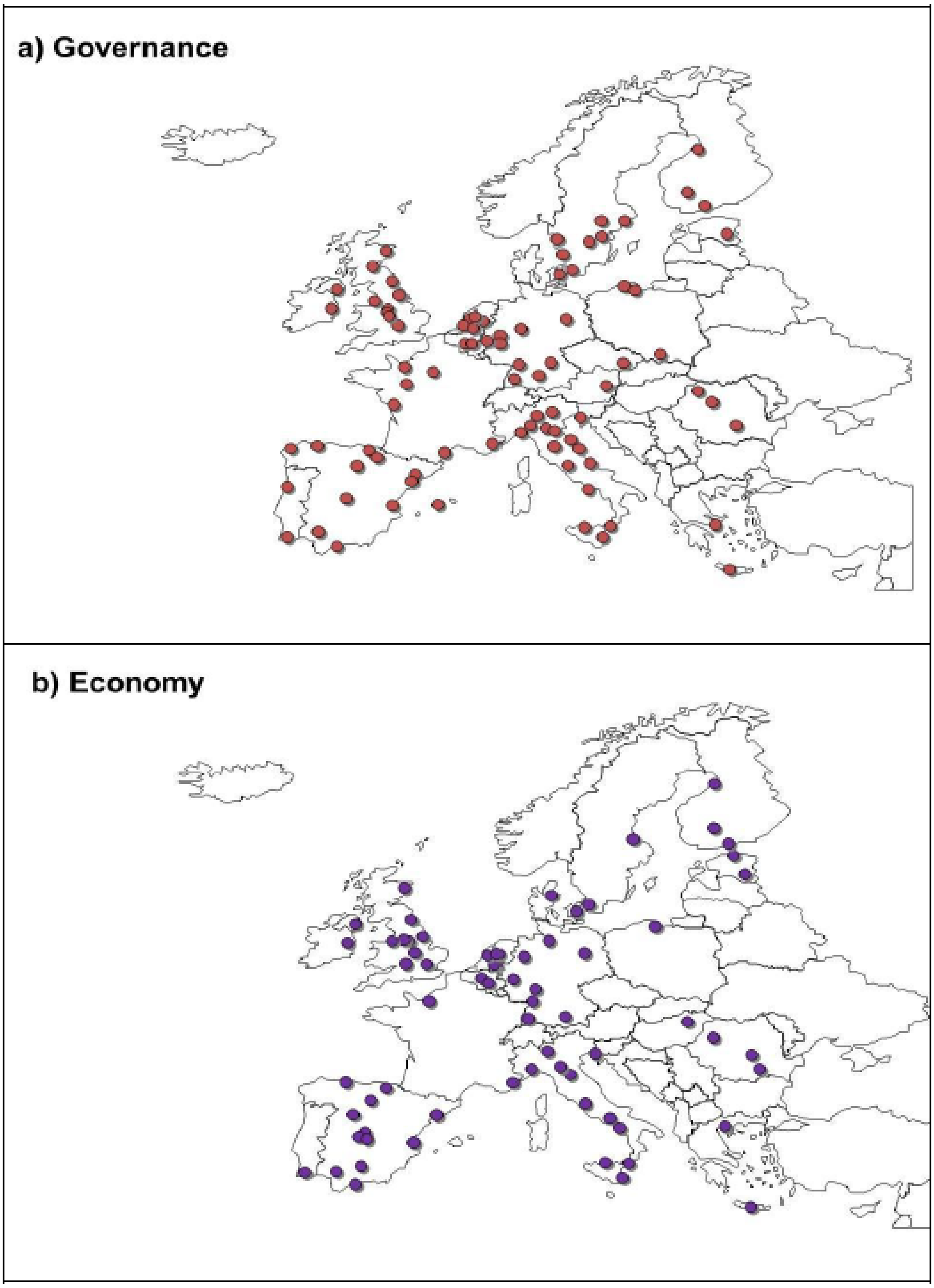
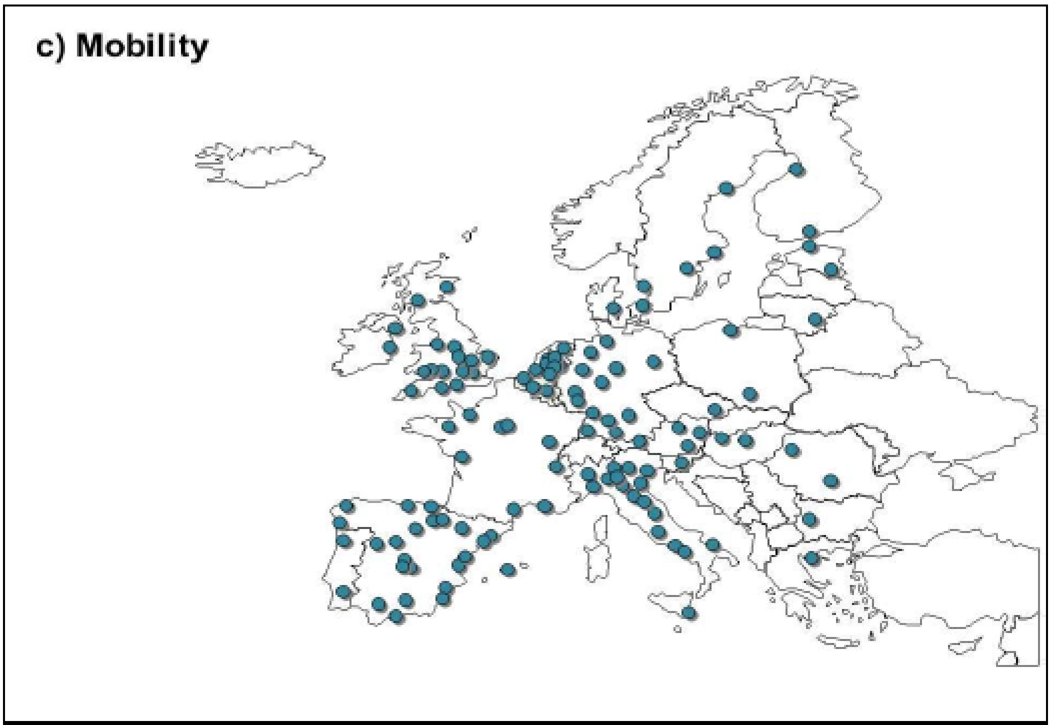
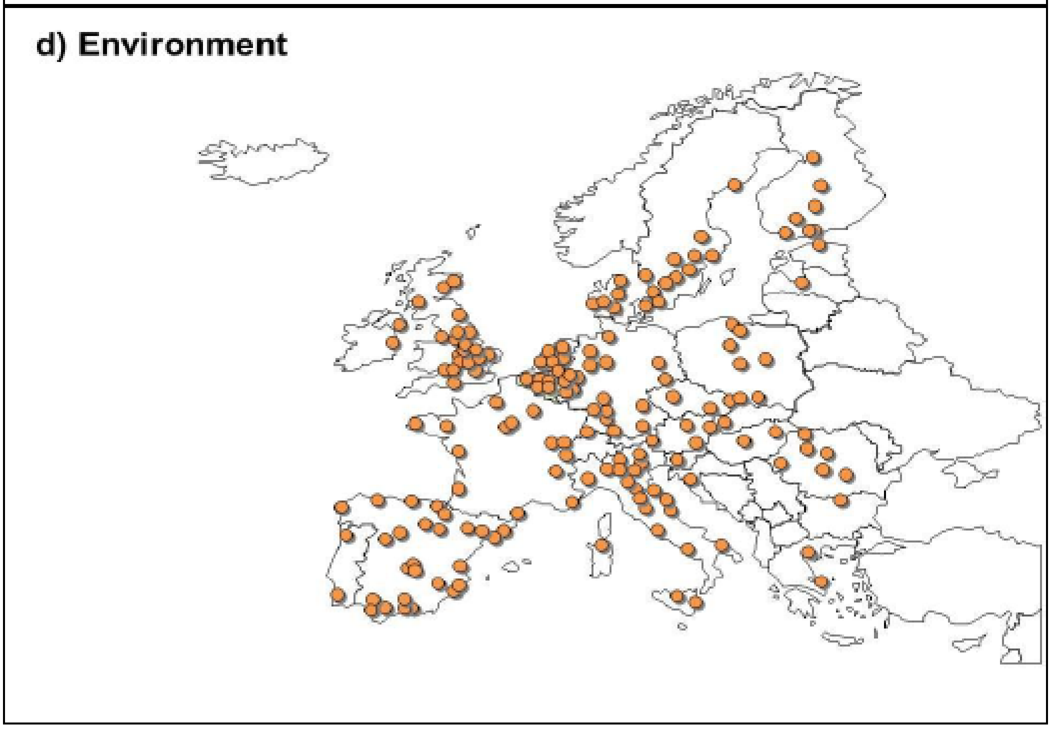



figure 1.11 : smart cities mapping by country

Figure 1.12 shows the incidence and geographic distribution of Smart Cities according to each of the six characteristics. As described above, (Figure 7) two-thirds of the Smart Cities focus on more than one characteristic with an overall average of 2.5 characteristics per Smart City. There is a clear correlation between city size and the number of Smart City characteristics; Smart Cities with only one characteristic are, to a great extent, smaller cities with between 100,000 and 200,000 inhabitants. In most of these cities, that single characteristic is Smart Environment or Smart Mobility. These two characteristics are also the most common overall; where a Smart City has two or more characteristics they are often found in combination, typically as traffic management solutions. Furthermore, in the two-thirds of Smart Cities with two or more characteristics, the most common combinations are Smart Environment and/or Smart Mobility, with one or more other characteristics.


a) Governance
b) Economy


c) Mobility


d) Environment

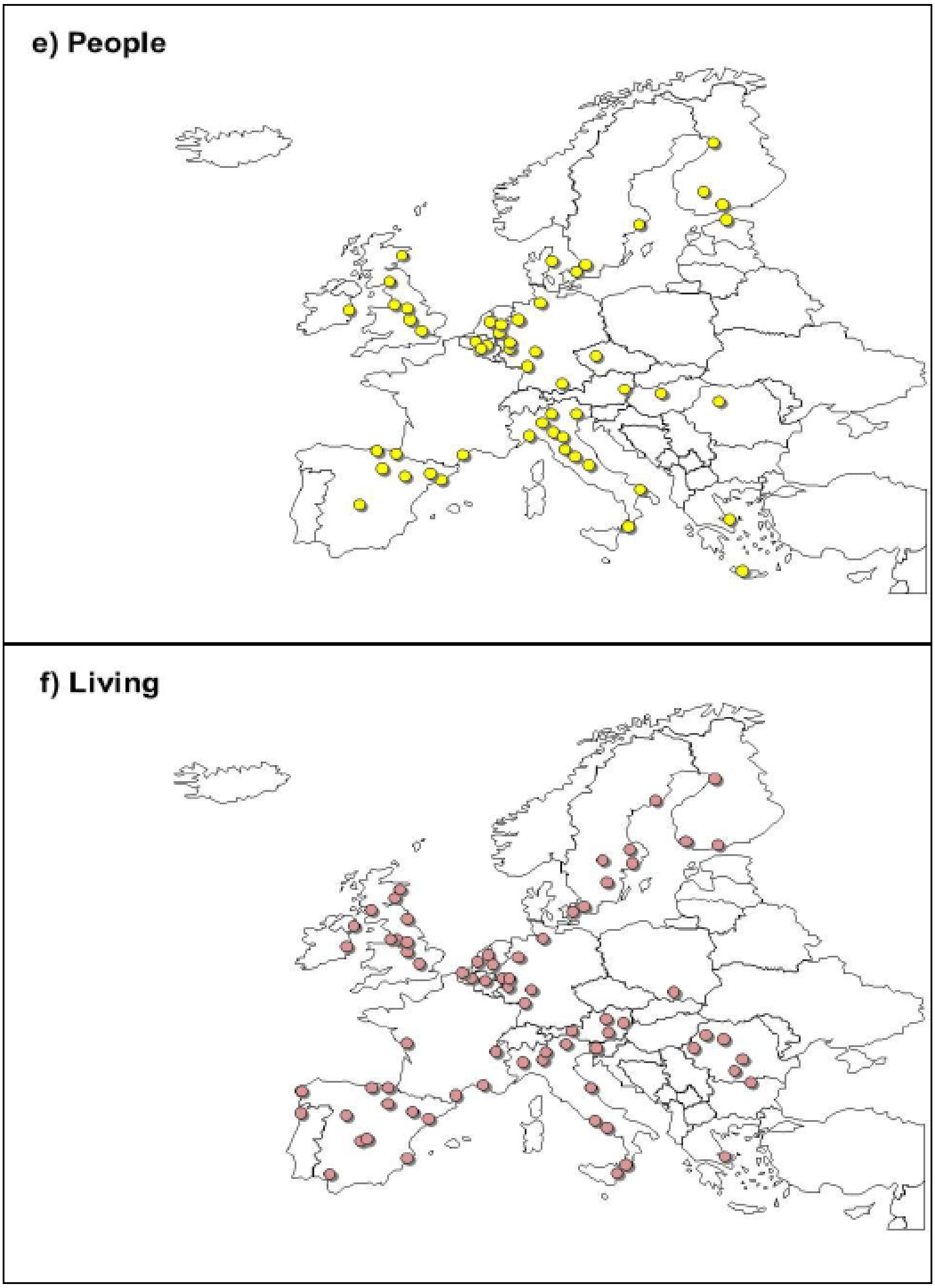



figure 1.12 : incidence and geographic distribution of Smart Cities according to each of the six characteristics

## *1.6 Description of work*

In this context, the work described in this document basically refers to one of the six Smart City characteristics, which is Smart Environment and in particular to two smart energy topics which are smart buildings and street lighting.

These two topics have both been handled by the same principle : citizen oriented enegy on demand. It means that energy has to be managed in a way that it is provided in the place and time that is actually needed and requested. The goal is to achieve energy saving in order to reduce the carbon footprint of our cities by keeping the citizens needs at the center of it. It means, for instance, that on streets safety must alwais be guaranteed and in buildings that users comfort must be properly taken into accont. Thus, this document is structured as follows.

Chapter 2 depicts the national Smart City projects in which the work has been carried out.

Chapter 3 describes the smart street lighting approach and shows experimental results from a real urban application.

Chapter 4 explains the diagnostics method for the detection of thermal energy faults and shows experimental results of a smart building network sharing the same thermal network.

Chapter 5 illustrates the multi-objective approach for the optimal thermal energy management in smart buildings and shows simulated results referring to two real life buildings.

Chapter 6 proposes an economic evaluation concerning the financial feasibility of the actual realization of smart buildings which might include the features described in chapter 4 and 5.

Lastly, in chapter 7 conclusions and future directions of this work are drown out.

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# Chapter 2. Projects

At present, more than two-thirds of sampled Smart City projects are still in the planning or pilot testing phases.

A sample of 50 Smart City projects across 37 Smart Cities in the EU was identified on the basis of maturity, availability of information, size and geographic location.

The projects in this sample were clustered into five characteristic types: neighbourhood units, testbed micro infrastructures, intelligent traffic systems, resource management systems and participation platforms.

**Smart Neighbourhoods**

Smart Neighbourhoods are neighbourhood-sized complete infrastructures. They are ICTenabled carbon-neutral and sustainable, and are designed to support Smart Environment, Smart Mobility, Smart Economy and Smart Living. Examples include the London suburb of Hackbridge (UK), Hafencity in Hamburg (Germany), Nordhavn in Copenhagen (Denmark), Stockholm Royal Seaport (Sweden), Oulu Arctic City (Finland), Lyon Smart Community (France) and Aspern in Vienna (Austria). These neighbourhood-scale Smart Cities, typically built for 10,000 to 40,000 inhabitants, are implemented either on green field (i.e. completely new) sites or as retrofitted development projects. They are usually used to expand city capacity and boost economic development by showcasing the city as a tech and sustainability frontrunner. The projects are holistic, representing complete visions of a future Smart City on a smaller scale. They are, therefore, intended for scaling up to city level at least.

The environmental objectives include the reduction of energy consumption and the provision of a complete, reliable and integrated energy infrastructure (including smart meters and grids, alternative and renewable energy, and water and waste management).

All the sampled projects emphasise Smart Living (enhancing residents' quality of life) and Smart traffic infrastructures (Smart Mobility) for public transportation and cycling.

**Testbed micro infrastructures**

Testbed micro infrastructures are small city demonstration and testing pilots for Smart City technology. They emphasise Smart Environment, Smart Mobility and Smart Economy. The infrastructures are created by connecting as many things as possible (in the sense of the 'Internet of Things' – systems, sensors and physical objects). Operational overlay systems are then implemented, to manage communication among these interconnected things with minimal direct human involvement. In most cases the scope of these infrastructures is limited to a so-called Smart Street or climate street; such smart streets can be found in the Barcelona suburb of Sant Cugat (Spain), Milan (Italy), Amsterdam (the Netherlands) and Cologne (Germany). Other examples operate on a larger scale such as the Greenwich Peninsula Operating System (OS) in London (UK) or the Glasgow intelligent street light system (UK).

The technology involves sensor monitoring systems for a range of city functions, most typically in combination, including intelligent energy management, parking, mobility, garbage, environmental (temperature, humidity and pollution) conditions, street lights, use of free Wi-Fi and demand for electric vehicle charging stations.

These are real-life laboratories for companies to demonstrate technology, understand the complex behaviour (resilience and fragilities) of such systems and learn how to integrate, manage and monitor their behaviour. The Sant Cugat Project (Spain), for example, aims to achieve efficiency and avoid traffic jams. To this end, sensor network monitoring systems are deployed in parking areas and outdoor areas of commercial buildings and mobility sensor systems are in operation for vehicles. Solar energy allows automatic garbage compaction to reduce the volume of waste to a fifth, and volume sensors allow efficient garbage collection. Environmental sensors (temperature, humidity and pollution) provide additional information on waste collection and the management of the irrigation system for intelligent urban green areas. Meanwhile, the presence of sensors controls lighting intensity in pedestrian areas.

All the testbed micro infrastructure cases sampled here have a multiplicity of objectives (e.g. to reduce CO2 emissions, save money, foster economic development and strengthen the technological base of local businesses and increase exports).

Most importantly the cases seek to find ways to expand and scale these micro infrastructures to a city level.

**Intelligent traffic systems**

Traffic management Smart City projects focus on Smart Mobility and Smart Environment.

They are ICT-enabled systems, typically based on road sensors or active GPS81 (i.e. while users have them 'on').

The objective is to monitor real-time traffic information in order to manage city traffic in the most efficient and environmentally friendly way possible. Examples include the Zaragoza traffic monitoring system (Spain), Dublin Road Congestion System (Ireland), Eindhoven Traffic Flow System (the Netherlands), Enschede Vehicle Inductive Profile (the Netherlands), and the Thessaloniki Mobility Project (Greece).

This objective is to be achieved by speeding up the resolution of road network issues, reducing congestion and improving traffic flow. Although the general and specific objectives are very similar across projects, the technological solutions employed are very different. For example, Zaragoza employs a sensor-based solution to obtain real-time city traffic information. The system supports efficient traffic management decisions and provides citizens with relevant information so that they can make their own choices. With 150 'urban' sensors over the urban grid of Zaragoza, 90% of all urban routes are monitored, and 30% of all traffic is audited daily. Travel time information goes directly to the Traffic Management Centre of Zaragoza City Council and is displayed on a web interface specially intended for management purposes.

In Eindhoven, on the other hand, participating pilot cars are equipped with a device containing a telematics chip 'ATOP', which gathers data from the central communication system of the car (CAN-bus). Sensor data (e.g. indicators of potholes or icy roads) is collected in-vehicle and transmitted to the cloud-enabled traffic centre. The Enschede system collects actual travel times of vehicles by means of Smart detection loops of traffic lights. The test installation covers three main roads in Enschede. Travel time savings are stored in a database, processed and shown on four dynamic route information panels on Highway 35. The city of Enschede aims to use this technology to optimise the use of the available infrastructure.

In Thessaloniki (Greece) two different systems have been put into place. First, a new traffic control centre manages incidents with real-time information, dynamically estimates traffic for the rest of the day, assesses and confirms estimated travel times, and dynamically manages traffic lights. The second system is a mobility planner that provides citizens with real-time traffic condition data, enabling them to choose between the shortest, most economical and most environmentally friendly route.

**Resource management systems**

Many Smart City projects within the EU-28 – and therefore a substantial proportion of our sample – address ICT-enabled resource management systems such as Smart grids, Smart meters, Smart energy and solar, wind and water management systems.

Resource management initiatives primarily involve Smart Environment, but Smart Governance, Smart Economy and Smart Living are also important characteristics. Examples include Smart Power Hamburg (Germany), Barcelona Smart grid and solar hot water ordinance (Spain), the Copenhagen wind power and Smart grid system (Denmark), the Copenhagen waste water management system (Denmark), Cologne Smart metering (Germany), Mannheim E Energy (Germany) and the Gothenburg managed Celsius Project (Germany).

**Participation platforms**

These projects involve the participation of citizens through ICT-enabled platform. Examples in our sample include: open data strategies and platforms, crowdsourcing and co-creation platforms, and other forms of citizen participation and ideation. The open data projects include citizen or user competitions to develop apps and other digital services (often reusing public data) to improve the quality and level of participation of public services. The open data projects currently under deployment are regarded by participants and government officials as providing better Smart Governance and Smart Economy outcomes than conventional approaches. Because citizen and business participants set the agenda, the degree to which other characteristics are reflected depends on the project scope, as well as the preferences and capabilities of participants.

Cities developing ICT-enabled citizen participation platforms include Amsterdam (the Netherlands), Helsinki (Finland) and Florence (Italy) among others, while EU backed projects include Periphea, Citadel and CitySDK.

Overall, the strategic objective of these projects is to develop better public services. This is based on input from citizens obtained by providing ideation platforms to develop a better city (e.g. the Amsterdam Smart City Platform), or competitions to take advantage of open public data to develop apps, useful data mash-ups or new services. For example, the city of Helsinki, Finland, is looking for new ways to encourage developers to exploit open data in order to create digital services and useful applications for citizens. The underlying themes of the Helsinki project are transparency of city decision-making and enabling better feedback from citizens to civil servants. Smart City services are thereby tested in the Helsinki Metropolitan area as part of people’s everyday life.

In this context the work carried out in this period has seen the application in three main national ‘Smart City’ projects placed in Rome, Bari and L’Aquila :

- Smart Village
- Res Novae
- City2.0

## *2.1 ‘Casaccia’ Smart Village*

The Smart Village project was funded by the Ministry of Economic Development within the Electric System Research framework. It has started on october 2012 and has finished on october 2014, although it will go on for three more years with a new research program.

The experimental facility known as Smart Village is located at the ENEA ‘Casaccia’ Research Centre (located in Cesano di Roma about 30 km north of Rome, extension 140000$m^2$) and in these three yaers has became a living lab to develop Smart City methods and technologies. In particular, it has been set up for Smart Lighting, Smart Buildings Network, Smart Mobility and ICT platform.

The objective is to demonstrate in a real case, the performance and robustness of the technology developed, its innovation and economic competitiveness, the ability to produce energy-saving and environmental. The base consists of the latest technologies available on the market, on which are grafted more advanced features in particular to the use of the technologies of computing intelligence. Following the approach of Smart Cities, all applications communicate with a central system of supervision of the Smart Village that provides to merge the data to a higher level. The common theme of all applications is the approach of ‘energy on demand’ : provide energy and resources where and when they are actually required.

The decision to build a demonstration at the ENEA Casaccia is connected to the identification of a particular market segment related to homogeneous urban districts. Thus, it is necessary to carry out first a reference example before placing in a city a critical technology and it should be that all the control and integration technology had passed the experimental stage showing to be able to meet constraints of urban reality.

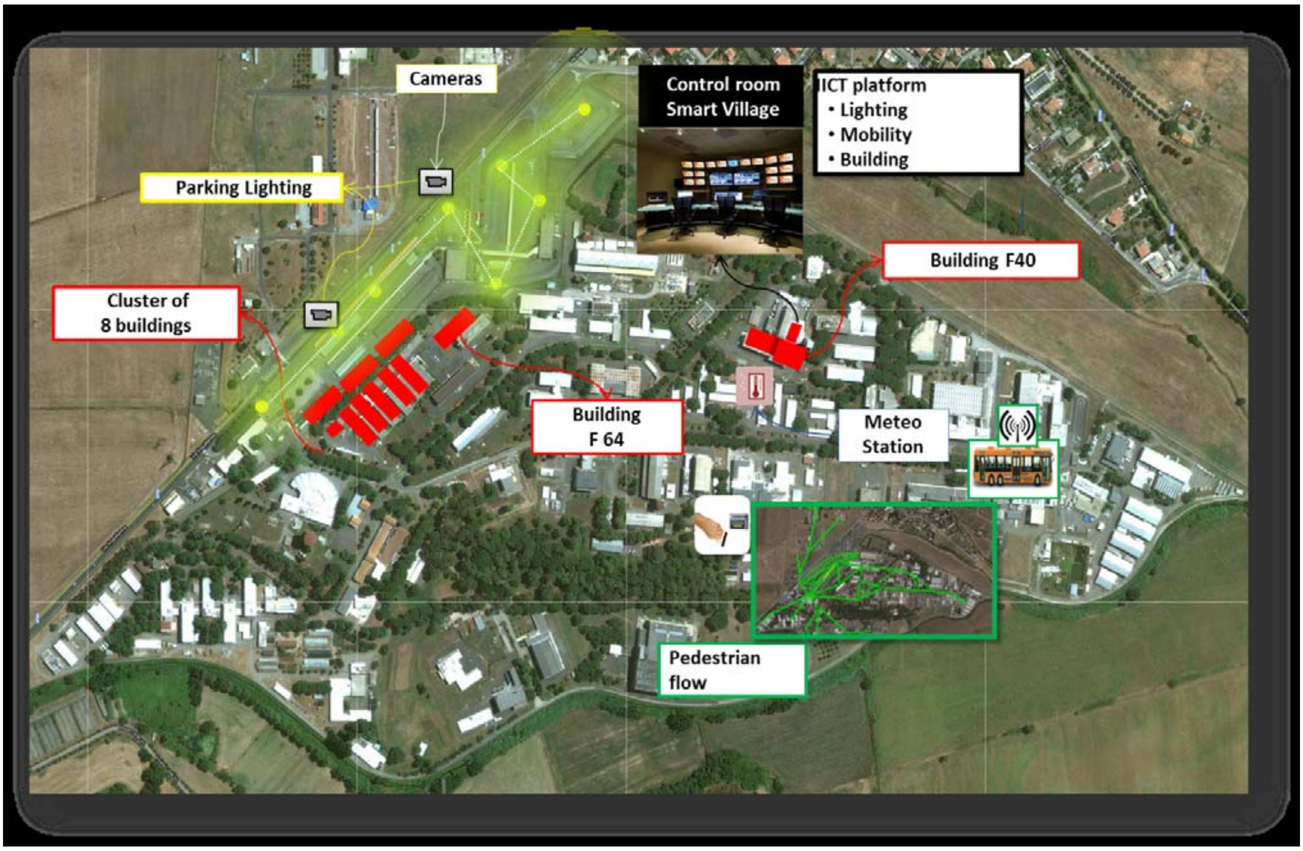


Figure 2.1 : smart village 'Casaccia' overview

Not least, the opportunity to study a "Smart" project applied to a smaller area as that of a research center to analyze and experience the technological innovations but having complete availability of data and more precise than a city.

Energy savings are achieved through the development of models for the optimization of energy supply commensurated to dynamical requests (energy on demand: supply energy only when and to the extent that it serves). To feed such models there are required detection methods, modeling of the user and the development of a sensor structure that can "measure" the demand for energy in real time, a network of transport of the data and a set of intelligent systems that are able to optimize the supply, to communicate with external adjustment systems and interact with users.

Smart applications considered for the Smart Village are based on innovative technologies available on the market, but include more advanced features, in particular the use of the technologies of computing intelligence approach with a "resource on demand", namely provide the service in exactly place, time and intensity required. The architecture of smartvillage has as a basic infrastructure on which the system of public lighting integrates smart services, such as management of internal mobility and building networks to remote control, all managed from a platform located in an integrated ICT control room.

### 2.1.1 Smart Lighting

The *Smart Lighting* vertical application is based on visual sensors for the reconstruction of the demand for lighting on the basis of which it is adjusted the light energy. The methodology consists of the processing of the images from cameras positioned on poles intelligent in order to reconstruct continuous vehicular and pedestrian flows, environmental conditions and possibly abnormal; subsequently implements a prediction hourly activity indices (steps of people and vehicles) on the basis of the data processed in order to determine the "user request" in the immediate future (15, 30 and 60 minutes). Finally it intervenes a system of optimal adjustment of the power supply of entire road sections via the remote management point-point of the single light point.

The dynamic adjustment of the power of the lamps of the poles has the dual purpose of increasing the level of road safety by providing service delivery lighting proportional to the amount of traffic detected (energy on demand) and in each case in line with the current regulations regarding the illuminance level road. Ultimately it achieves a significant gain in terms of energy savings and road safety, finally offering a quality service.

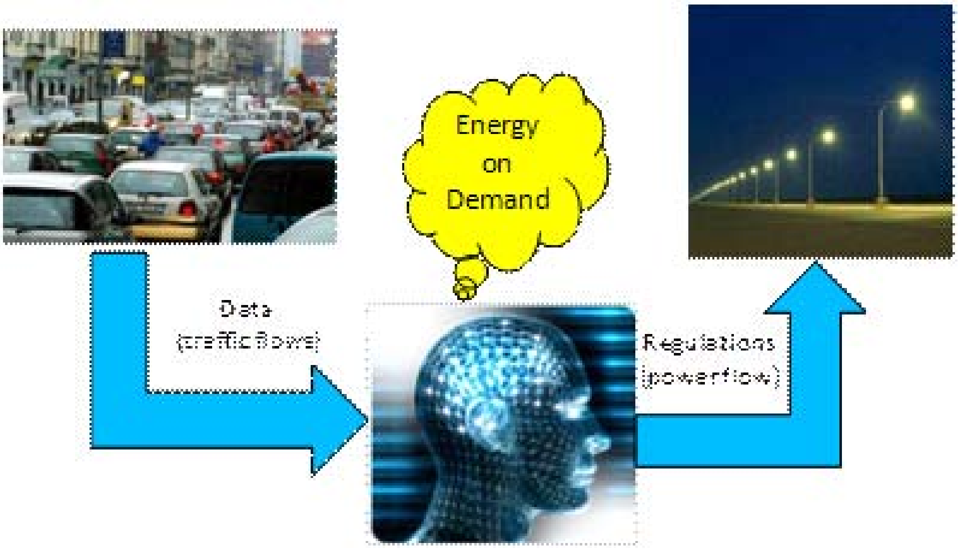


figure 2.2 : smart lighing approach

Smart Lighting was applied on some roads inside and in the parking lot of the Casaccia using the best technologies to reduce energy consumption and to provide services on smart smart lampposts. They include features LED lighting, remote management with point-to-point digital network and PLC (Power Line Communication Broadband), adaptive functionality with video detection and reconstruction of the profile of users (people and cars).

figure 2.3 : smart-eye sensors

| lat | lon | date | time | counter | carCounter | busCounter | pedestrianCounter | elapsedTime | flow | meanSpeed |
|---|---|---|---|---|---|---|---|---|---|---|
| 42.34927 | 13.40571 | 2014-03-18 | 13:12:43 | 179 | 131 | 14 | 22 | 300 | 17.9 | 19.6852 |
| 42.34927 | 13.40571 | 2014-03-18 | 13:22:43 | 131 | 100 | 7 | 16 | 300 | 13.1 | 19.5879 |
| 42.34927 | 13.40571 | 2014-03-18 | 13:32:44 | 151 | 115 | 11 | 18 | 300 | 15.1 | 20.2305 |
| 42.34927 | 13.40571 | 2014-03-18 | 13:42:45 | 148 | 127 | 5 | 14 | 300 | 14.8 | 18.2685 |
| 42.34927 | 13.40571 | 2014-03-18 | 13:52:45 | 151 | 126 | 8 | 15 | 300 | 15.1 | 21.3452 |
| 42.34927 | 13.40571 | 2014-03-18 | 14:10:35 | 100 | 76 | 4 | 15 | 300 | 10 | 19.2681 |
| 42.34927 | 13.40571 | 2014-03-18 | 14:20:36 | 127 | 98 | 17 | 10 | 300 | 12.7 | 18.1272 |
| 42.34927 | 13.40571 | 2014-03-18 | 14:30:37 | 118 | 96 | 6 | 13 | 300 | 11.8 | 17.5808 |
| 42.34927 | 13.40571 | 2014-03-18 | 14:40:37 | 91 | 72 | 7 | 8 | 300 | 9.1 | 21.4545 |
| 42.34927 | 13.40571 | 2014-03-18 | 14:50:38 | 111 | 95 | 7 | 8 | 300 | 11.1 | 14.5312 |
| 42.34927 | 13.40571 | 2014-03-18 | 15:00:39 | 79 | 66 | 8 | 4 | 300 | 7.9 | 17.7968 |
| 42.34927 | 13.40571 | 2014-03-18 | 15:10:40 | 76 | 71 | 3 | 1 | 300 | 7.6 | 16.9155 |
| 42.34927 | 13.40571 | 2014-03-18 | 15:20:41 | 69 | 55 | 6 | 4 | 300 | 6.9 | 18.4263 |
| 42.34927 | 13.40571 | 2014-03-18 | 15:30:42 | 58 | 43 | 7 | 5 | 300 | 5.8 | 23.6689 |
| 42.34927 | 13.40571 | 2014-03-18 | 15:40:42 | 101 | 81 | 10 | 3 | 300 | 10.1 | 19.0918 |
| 42.34927 | 13.40571 | 2014-03-18 | 15:50:43 | 88 | 62 | 21 | 1 | 300 | 8.8 | 23.3404 |

figure 2.4 : smart-eye outcome

*Smart Mobility* application's main idea is to elaborate presence data retrieved trough employees badge, estimate pedestrian flow inside the R.C. and showing estimations on a oriented graph.

### 2.1.2 Smart Building

The *Smart Building* application aims to build a network of smart buildings (9 buildings) that are equipped with sensory systems whose data are taken in real time by the supervision system of the Smart Village. The supervision system of intelligent applications developed by ENEA provides advanced diagnostics and optimization of management. The results are sent to the actuators for the implementation of control strategies and, in relation to the targets, towards the energy manager of the network or towards the users.

These buildings are equipped with sensors power consumption (electrical and thermal) and connected in real time to a server where they reside internet remote diagnostic programs (computation intelligence), whose results consist of failure indication, management of low quality, or deficiencies of the building equipment or automation systems, incorrect behavior from the point of view of energy management. The system provides information on dialogative progressive optimization of building management and in some cases may initiate a reset of the parameters of the systems of local control.

The energy management of buildings aims to optimize energy consumption, making them more efficient; is based on a system diagnostic and optimization centralized that could lead to significant energy and cost savings with investment costs being based mainly on automation and intelligence.

### 2.1.3 ICT integrated platform

All the control logics are managed through the ICT Smart Town Platform (STP).

The *ICT platform* is housed on the ENEA grid computing facility and its main goal is to develop a solution hw-sw ICT for the integration of data from various vertical applications; in particular the integrated platform has the function of collecting, organizing and processing the data and their redistribution to the various applications for the management of the various services (eg: interaction between mobility and access to buildings with the management of lighting).

Each facility can be seen as a vertical structure, since data coming from sensors are acquired and analysed in order to implement control procedure of the system, without analysing data generated from other systems. Instead, the platform is a horizontal structure allowing communication among vertical systems, so as to improve efficiency of the systems under energetic, monetary and citizens welfare point of view. Platform is able to redistribute to researchers and operators data it has collected, and aggregated data, as indexes of interest and analysis of probable diagnosis, after fault occurrence. Currently, platform has been designed to capture data from three facilities: the public lighting, the building network and the mobility infrastructure. Platform has been realized more generic as possible, such that code refactoring in case of addition of other infrastructure is limited. This platform was inspired by the structure of existing Supervisor Control And Data Acquisition (SCADA) systems. A SCADA is a system largely diffused in industrial control for retrieving and on-line data analysis. It also manage failures, alarms and provides a Human Machine Interface (HMI) for visualization. It is mainly composed by a Database, remote terminal Unit (RTU), a communication system and eventually many other modules. Analogously, the platform consists of a central Database, several modules, which perform functions such as data acquisition, actuation, alarms management, and a web interface that allows authorized users to have services, as consultation of sensors data, visualization of time series, graphs and histograms. The platform has been designed to acquire and process heterogeneous types of sensors, whereby Databases and tables are characterized by a generalized structure, in order to extend the platform to future upgrade. Heterogeneity of the monitored data has suggested additional functionality to the system: the ability to execute data fusion algorithms in order to carry out a situation assessment. This module is a process that extracts high-level information on the system state thanks to aggregation of low-level data. In order to maintain the platform robust to malfunction, acquisition and actuation modules are independent from other modules. Alarm monitoring is handled by a dedicated module, which checks periodically if the sensor values are within the thresholds. At implementation level, the platform is divided into two sections: one purely devoted to reporting data and monitoring alarms, other purely dedicated to web interfacing and to web services. At logic level, the platform is divided into four layers: presentation, application, data and sensor layer.

- Presentation Layer. User interface web application (servlet, html, jsp).
- Application Layer. In this layer, business intelligence activities are processed. In particular, building diagnostics and optimisation processes, data fusion, control logics and anomalies handling.
- Data Layer. Datawarehouse layer where heterogeneous data is stored.
- Sensor/Actuator Layer. In this layer, modules interfacing Database with sensor are developed. Each module is independent and dedicated to a particular sensor category.

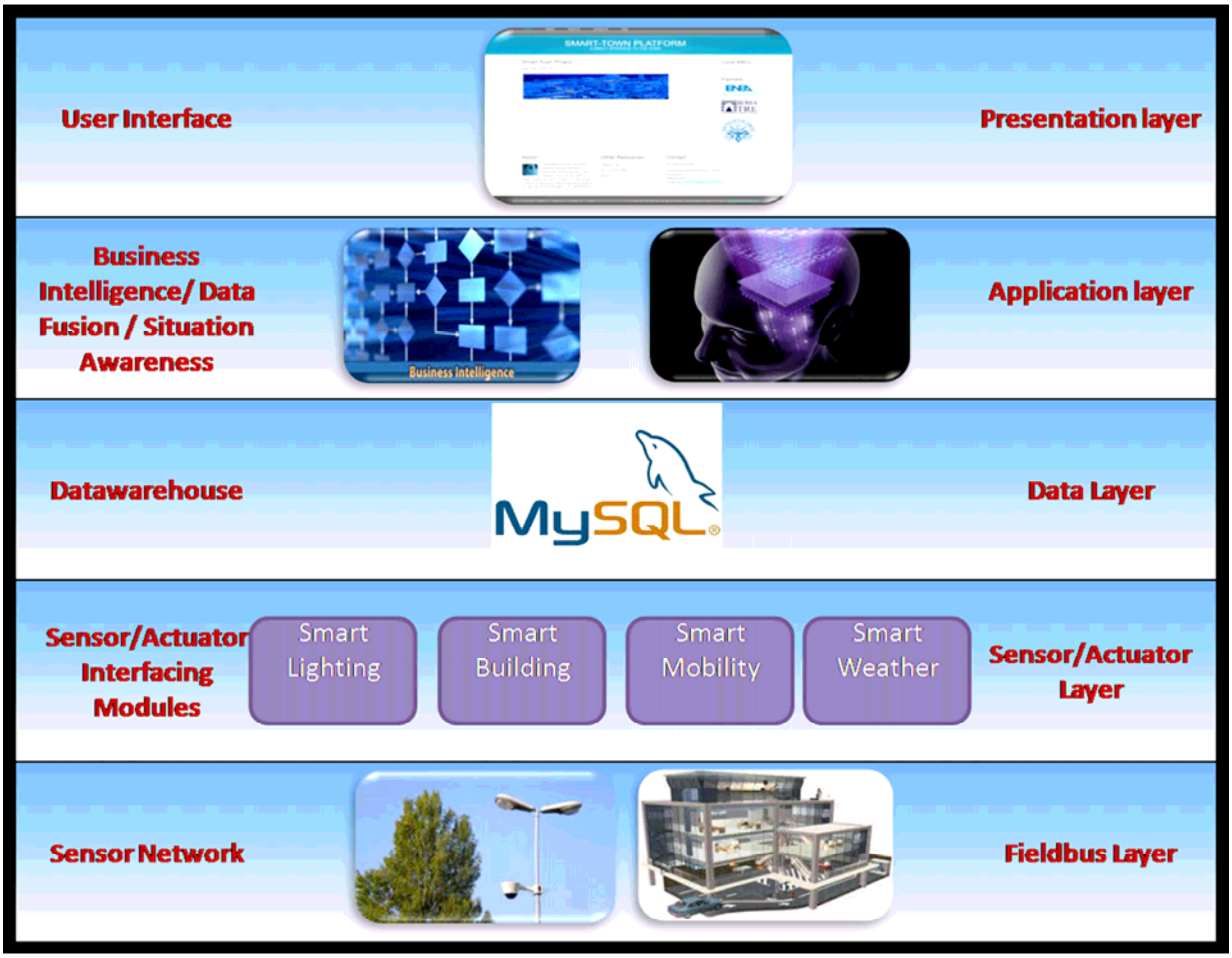


Figure 2.5 : ICT-Scada layer view

Smart Building Module interfaces field sensor installed on buildings to Database. In particular it interfaces with two proprietary BEMS, in one case, through parsing an eXtensible Markup Language (XML) retrieved through HyperText Transfer Protocol (HTTP) request, in the other one, directly through Open DataBase Connectivity (ODBC) connection. Actuation is carried out through a cycling thread reading desired actuation on DB and then forwarding packages to BEMS through Web Service (WS).

Smart Lighting module structure is similar to Smart Building, it interface to a BEMS dedicated to lamps dimming and consumption retrieving. Data are retrieved through a Secure File Transfer Protocol (SFTP) Push XML parsing. As in the building module, actuation are processed through WS. Through this module we can measure electric total consumption and dim lamps of the parking lot.

Smart Mobility module is dedicated to employees badges information retrieving, the module simply interfaces to R.C. main employee database and trough ODBC connection acquire data. Since each employee is linked to a working room, data elaboration provides information about estimated occupancy on the buildings, moreover pedestrian flow in the R.C. can be estimated through a connected oriented graph connecting each building and main paths.

Smart Weather module acquires weather data from Meteo Station through HTML parsing, retrieved through File Transfer Protocol (FTP) connection to Meteo Station data logger. Measures retrieved are:

- External temperature;
- External humidity;

- Pressure;
- Wind speed and direction;
- Rain level;
- Global solar radiation.

Communication system is summarised in next figure

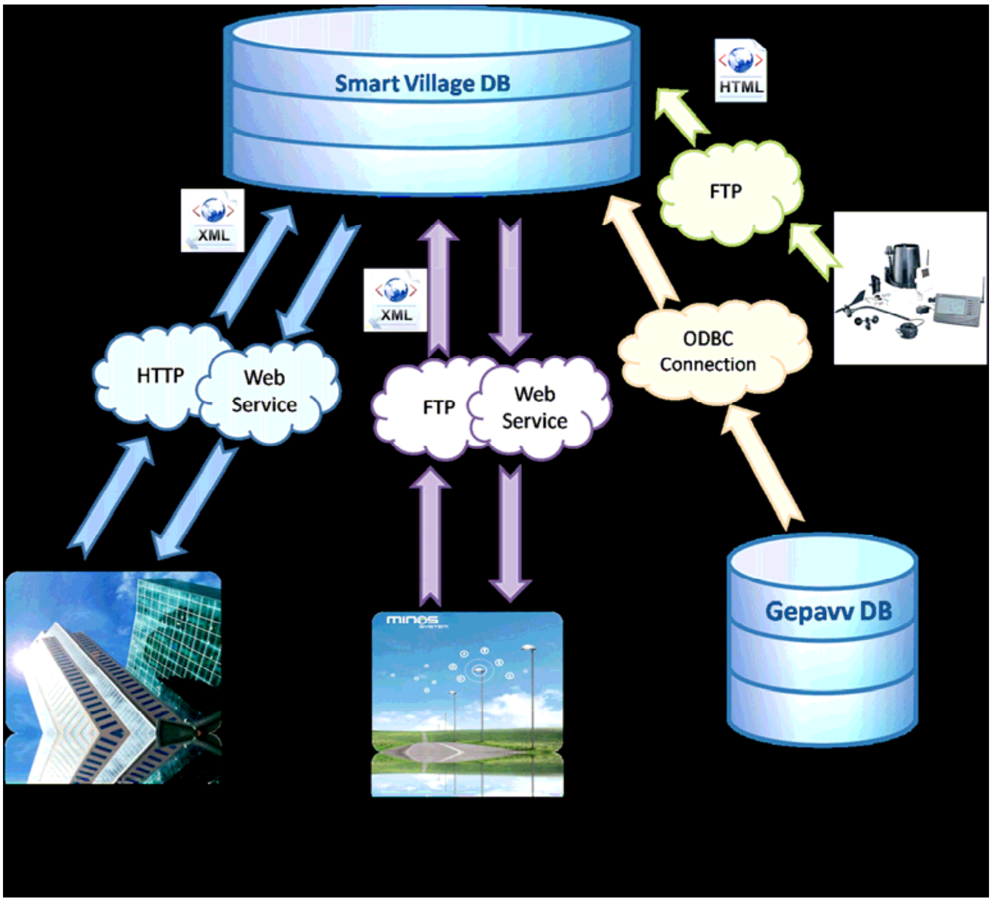


figure 2.6 : ICT communications

At implementation level, the platform is divided into 5 projects:

- Communication. Java Application. Handle connection between DB and sensor interfacing modules layer, error logs and shared variables.
- DataAcquisition. Java Application. Manage data retrieving from multiple local or remote BEMSs and DB insert.
- BuildingDiagnostics. Java Application. Processes data fusion for building diagnostics evaluations.
- BuildingControl. Java Application. Dedicated to control logics and actuations.
- ServerSmartTown. Java Web Application. Web interface for data retrieving and visualization.

Figure 2.7 shows MySQL DB developed in the Smart Town Platform. The detailed description of tables is out of the scope of the dissertation, but it is worth to distinguish principal sections characterizing relationship schemas.

- Diagnostics. Is the major frame of the DB. The main tables are preprocessing, processing, situation and causes, correlated by junction tables. Such structure reflects diagnostics process designed each phase has a dedicated historical table. Preprocessing table is used for preparing data before diagnostics process (e.g. normalisation, discretisation...).

- Actuation contains tables for actuation logics such as thresholds, comparing rules, scheduling. Moreover a historical table has been introduced for both high level and low level controls

- KPI tables report global analysis about performance of the assets monitored

- Alarms tables provides failures and alarms management given by low level diagnostics.

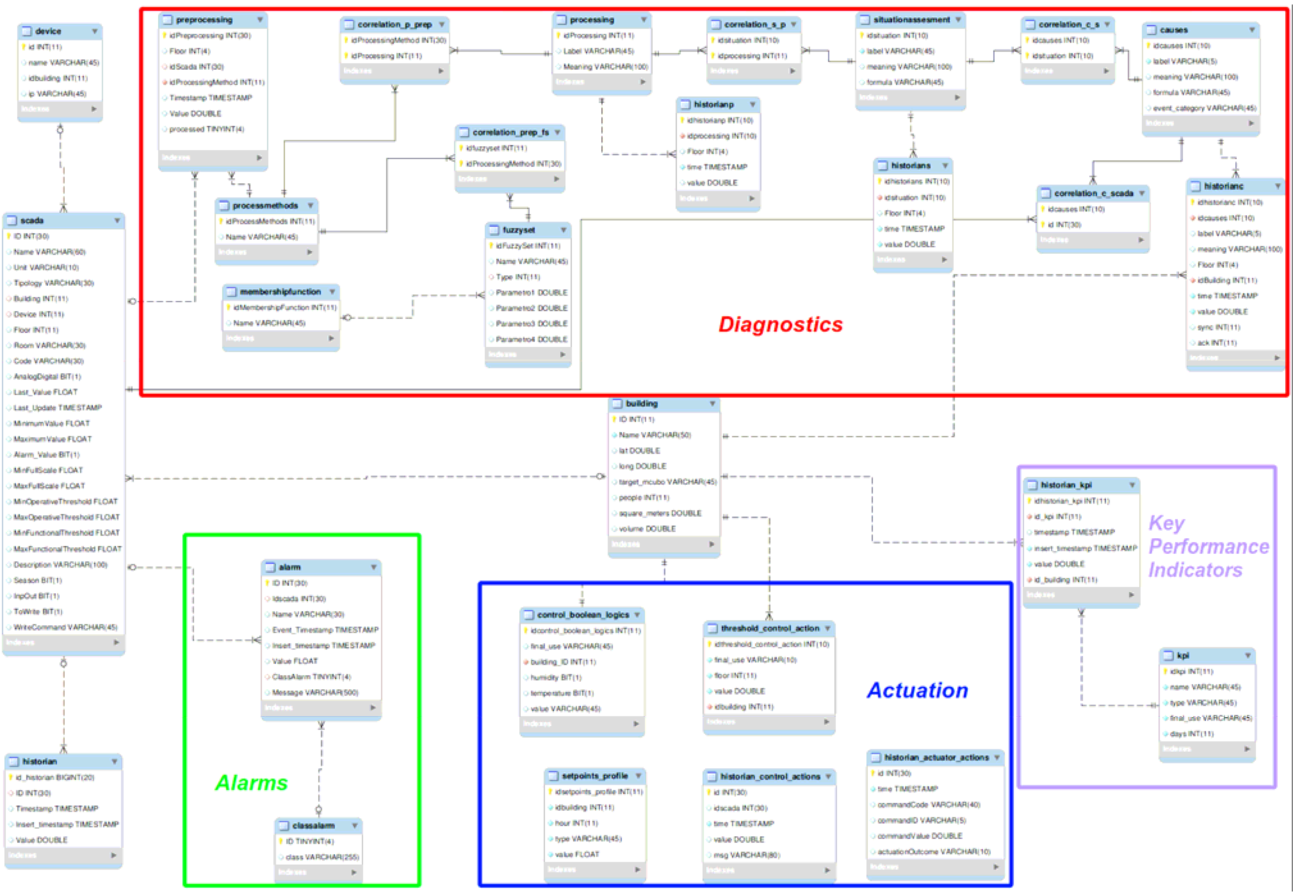


Figure 2.7 : DB layout

## *2.2 RES NOVAE – Reti, Edifici, Strade – Nuovi Obiettivi Virtuosi per l'Ambiente e l'Energia*

This project was developed by the Italian Ministry of Reasearch, Education and University within the "Smart Cities and Communities" national research work program.

It has started on october 2012 and has finished on october 2015.

The ambitious sustainability goals (increasing energy efficiency, reducing emissions of climate-altering gases, delivery of new value-added services and the overall improvement quality of life) set by the italian municipal Energy Plans and in particular the Sustainable Energy Action Plan (PAES), requires a national context in which the infrastructure, and in particular energy systems and ICT infrastructure, are able to provide "awareness" of the system status and of its most critical components, ability to evolve and adapt quickly to changing external conditions through integrated and interconnected solutions.

The project aims to seek, model and experiment on demonstration scale a complex and dynamic advanced management of energy flows at the municipal level, based on the integration of technologies in the energy and information technology in order to reduce energy costs, strengthen the multi-generation of energy from renewable sources, contain the environmental impact and raise awareness of energy and environmental issue in each individual actor of the community. As for energy (Renewable energy and smart grid) project promotes innovation through the development of technological and managerial solutions that promote and strengthen recovery, production and integrated management of the various renewable energy sources and related distribution systems, taking into account the need to enhance relations between the urban dimension and rural policies in the energy, environmental and climate of smart communities. As regards the scope of energy efficiency (Energy efficiency and low-carbon technologies), the project activities are intended to improve the energy and environmental performance of urban areas, through the development of technologies and management models integrated, able to reduce energy consumption and promote the rational use of natural resources.

The project, whose total duration is 32 months, is focused on the regions of Calabria and Puglia and split an experimental phase to be implemented in the final quarters of the cities of Cosenza and Bari, where they will implement the salient aspects of the research by subjecting them to occur in two contexts substantiallydifferent.

The research has the ambitious goal to deepen the issues related to the transformation of the model of supply and management of energy resources. The harmonized management, in a unique context that would give greater and more immediate value to citizens and its leaders, first and foremost can ensure the information and tools necessary to start slow, but necessary, evolution culture to a more conscious management of energy resources in the urban environment.

In this sense, it will is studied and implemented a "Urban Control Center" to provide energetic-environmental information to public administration, citizens and other interested players. This new tool will help the planning of energy and environmental city needs , will support the management of critical local operations and will lead the cultural development of citizens in relation to a careful management of limited energy resources, while respecting environmental quality.

The "Urban Control Center" is the final element of tangible and numerous lines of research, each essential and interdependent as a whole, which are designed to detect, enable and govern profound transformation that aims the ability to manage in a more efficient way energy resources :

1) Research and development of new applications for Smart Grids, related to the management of the distribution electric network, mainly low voltage, measures to foster the networking of renwable energy sources (RES), the improvement of customer service and energy efficiency. Between these applications, those designed to enable new value-added services to end-users, to increase the awareness on energy consumption, and other related to the most suitable storage solutions, are sought.

2) Research and development of new technical solutions and applications enabling innovative services in the field of building (Smart Building). By monitoring, coordinating and modulating in time the energy requirements at the level of single house, building or building networks, optimizing the management of energy sources and integrating plants to RES through innovative solutions (heat storage, solar cooling), they will experience new services aimed to increasing energy efficiency in buildings.

3) Research and development of new techniques of management of urban elements to impact energy and environment (Eg street lighting, storm water, carport, energetic characterization of public building e.g., monuments). By modeling smart objects, where physical objects are equipped with detection, calculation and communication capabilities and which are able to perceive and interact with the environment and with other intelligent objects, it will be possible to monitor in real time the use of energy and there will be the ability to define and rational use of self-regulating public goods in urban open areas (Smart Street).

These three lines of research feed, both with aggregated data, both with significant details, the system "Urban Control Center", in support of a growing public awareness and support control and coordination mentioned above.

It should be noted here as the "Urban Control Center" is be designed and developed in order to incorporate information also from other systems external to the project thus increasing the multidisciplinary perspective critical to the governance of complex issues such as the environmental quality in urban areas.

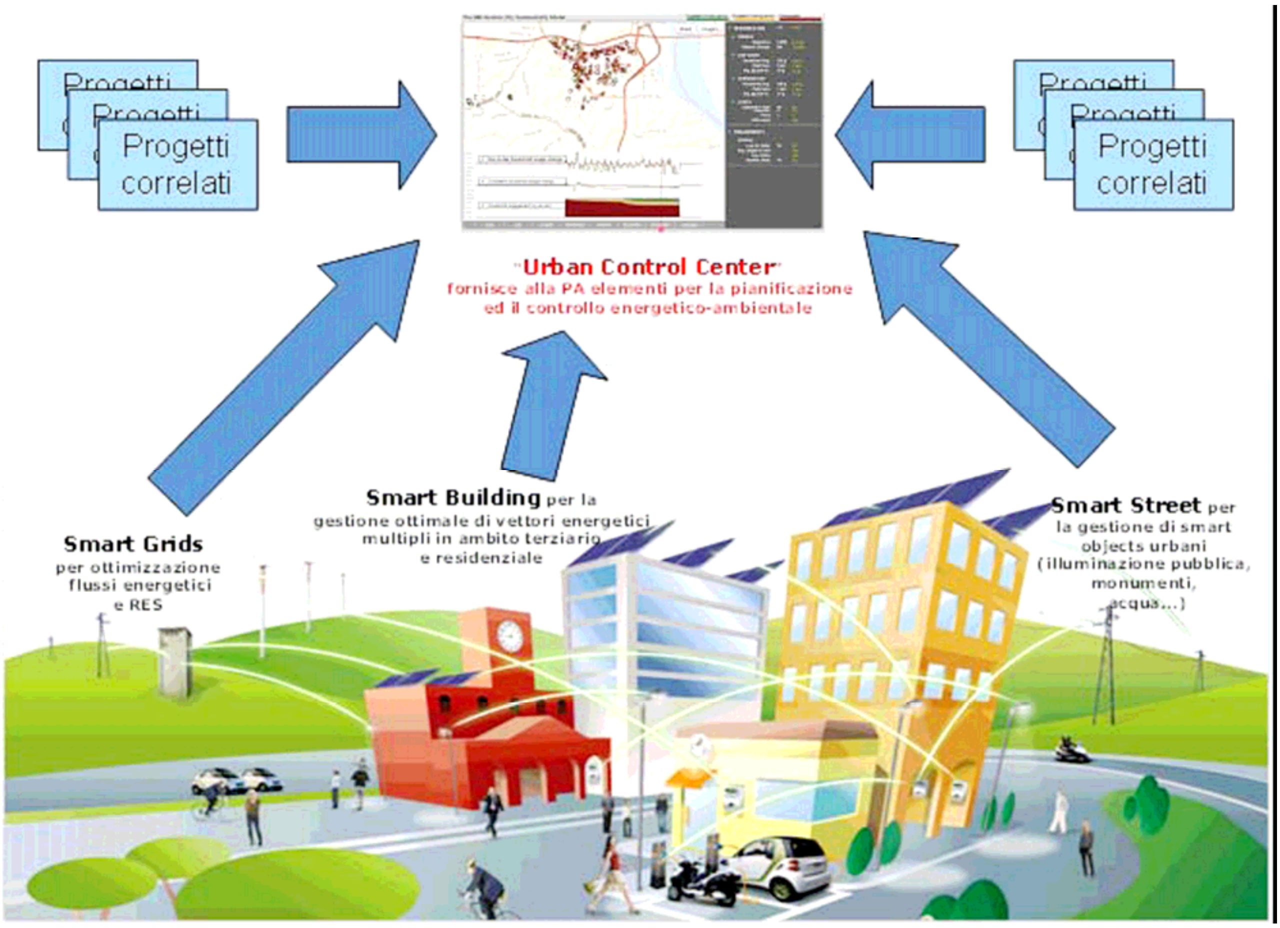


figure 2.8 : project overview

A system so detailed and complex can not be separated by a significant research support at the level of basic technologies and in the information management systems. In this sense activities are aimed at the study and evolution the use of various types of renewable sources, application of the electric storage, to innovation in advanced sensors, to design managers HW / SW which the Service Hub, the Pervasive Computing Engine, the BEMS, the Energy Box, monitoring for complex modeling and dynamic consumer needs energy of public property cadastre Energy. The strong innovative value of many of the elements mentioned will be essential for the successful integration into an effective urban interventions, offering tangible returns for the local community, an enabling platform for energy services and innovative social, a new way to consider the goods and public spaces in a scenario of limited resources.

The project requires for the elements, the models, equipment and, more generally, the hardware and software components developed in the research activities to be applied and tested in practice on the field. The part of the experimental development implements, in limited areas of the City of Bari and Cosenza, demonstrators pilot aimed to create efficient and sustainable urban contexts in which the energy distribution systems, networks of buildings and production facilities from renewable energy source, the ICT infrastructure communication are able to provide solutions that ensure integration and interconnection, "awareness" of the state of the system and its most critical components, ability to evolve and adapt quickly to the changing external conditions. However, due to the attributes of the absolute replicability of project activities and considering the continuing needs and obligations for policy makers to invest in interventions for energy efficiency and the development of "smart technologies", the project will be adaptable and repeatable in other territories and non-urban (cities, local districts, etc.), as well as the city of Cosenza and Bari.

In order to create efficient and sustainable urban contexts through the integration of innovative technologies and different systems and taking into account the economic-social-cultural substantially differences of the two cities, the experimental development involves the implementation of a structured information platform, called "Service Hub", to enable the provision of new value-added services to citizens, as example Active Demand, and for the collection and processing of energy data from the field. This information, provided to decision-makers through the "Urban Command Center", will support them in the definition of energy-environmental policies more suited to the local context. The "Service Hub" is the pivotal element onto which a whole series of complementary services for the two areas focusing to address and solve the different requirements / needs of the contexts in which they operate.

A major source of data for the "Service Hub" is represented by the distribution network MV / LV of the electrical energy. In the pilot demonstration of Bari the LV network will be managed with a Smart Grid approach aimed at monitoring and controlling network parameters and the application of the new equipment developed during the research project. This will then be feasible by means of the delivery and installation in the cabins along the LV network of the equipment for monitoring and network control. In a complementary manner, in Cosenza it will be installed in the secondary cabin a storage solution by carrying out special research activities, always according to Smart Grids, and new features aimed to stabilize the grid voltage and thus providing a better level of service to customers, while ensuring greater integration networking capabilities of the production systems and distribution.

Innovations in energy infrastructure, electrical and thermal properties, development of ICT platform "Service Hub" and the installation in some buildings, both public and private, of new products developed during the research phase, including the Energy Box, the Building Energy Management System (BEMS) and smart objects, allow to enable functionality, technology and value-added services in a Smart District view.

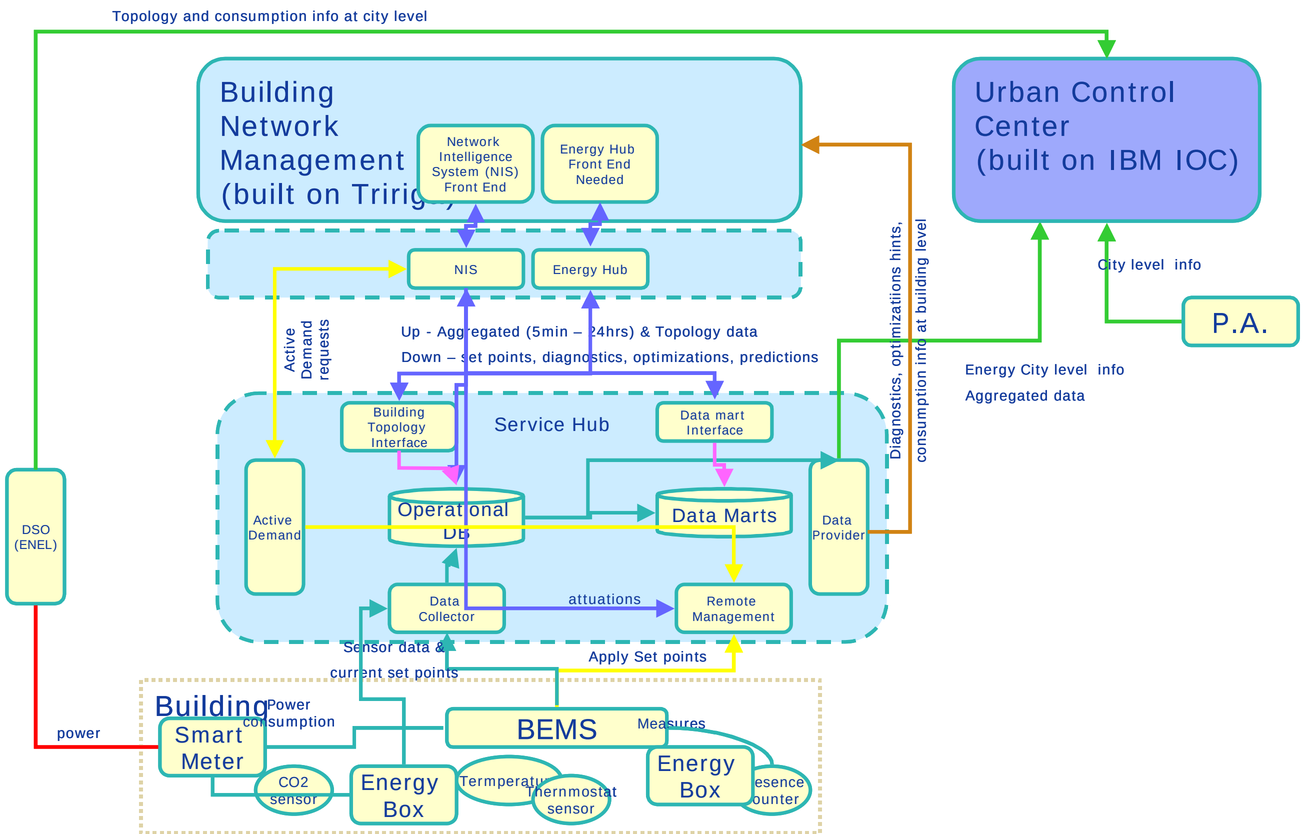

Figure 2.9 : ICT project layout

One of these is the Active Demand, practical response to the integration of distributed generation and optimization of energy consumption, at the level of individual dwelling but also for complexes of public and private buildings, with consequent economic advantages and comfort for users.

The consumer will be able to become active in the energy business being able to decide when and how to consume. The availability of users to modulate the energy consumption, as a function of economic incentives, lead to the creation of a new economic entity of the market, the Aggregator. The function of the Aggregator will be to manage a portfolio of private clients, public, commercial available to restructure their energy loads in the hours of the day having as counterpart an economic incentive. It will operate by exploiting the operational features of the "Service Hub" by which will have knowledge of the energy consumption of its customer and send commands to load modulation to individual actuator devices present in the building or apartments. For its work and for the service provided, the Aggregator will receive a financial reward. The greater the Aggregator portfolio, the better the services it can provide, and the greater the compensation that gets. This will lead to the creation of a competitive market based on innovative technologies which will take part in different business entities, local and national. The BEMS and the Energy Box guarantee a two-way flow of information: sending data (single building or apartment) to the "Service Hub" and implementing the controls to reschedule the loads according to the Aggregator signals to the home.

### 2.2.1 Objectives

The design idea tackles organically the size of the urban context, with the aim of improving

quality of life and create new services for citizens and for the Public Administration (PA), starting from the development of scientific expertise and regional integration and synergy of energy infrastructure, IT and logistics. The rationalization of flux and energy consumption, integration and renewable energy sources (RES), the development and implementation of new products, platforms and services and the launch of new innovative scientific and technological competencies to the local level, the priority objectives of the project idea, represent the basic element identified by the European Union for a Smart City, helping to achieve an efficient and integrated urban ecosystem. We start from the energy transport infrastructure: studied, analyzed and implemented in a smart grid view. Among the advantages there will be a greater capacity for connection of plants powered by renewable energy, with positive economic effects on the industry. The intelligent management of networks, or development of Smart Grids functionality together with the possibility to enable production from RES in the vicinity of the points of consumption, optimize the energy flows, resulting in a reduction of network losses. Innovations in energy infrastructure, development of ICT platforms and the creation of new products, including the Energy Box and the BEMS, allow to enable new value-added services, including Active Demand. In the future, consumers will be enabled to become active part in the energy business, being able to decide when and how to consume. The availability of the users to adjust their energy consumption will lead to the creation of a new economic entity of the market, called Aggregator, whose activities will be carried out by one or more entrepreneurial in the Active Demand service, enabling improved energy efficiency of the system and creating a new economic-productive territory. The Active Demand and Service Hub represents a concrete response to the integration of distributed generation and the optimization of energy consumption, at individual dwelling, but also for complexes of public and private buildings, with consequent economic and comfort advantages for users.

The environmental and energy data (energy, water, gas, KPI of pollutants) are integrated and exchanged in the "Urban Command Center" creating a modern system of control and management of energy resources available to the PA. This will provide the data in order to define and implement the best environmental policies and to evaluate the benefits. The information, in analytical form and graphics, it will be made available to citizens through monitors placed in strategic places and website, to raise awareness on issues of environmental sustainability.

The process of public involvement, PA, businesses, universities, research centers on the way to the Smart City is an element of the project; actors of smart cities will know which products / services help to positively change their lives. With the products / services they experience solutions to problems of metropolitan scale, which will be scalable at a regional level.

This is a prerequisite to attract capital in the territory that will allow you to activate a virtuous cycle of economic and social development long-lasting, with the creation of new services for the City, new business ideas, new jobs.

The development of the Service Hub will have the dual aim of ensuring the information exchange between the energy systems and networks of buildings, in order to enable new value-added services to end users and to provide the Public Administration, through the Urban Control Center, with data and aggregate information that can appropriately supporting the municipality in defining its energy policies. The Service Hub introduces a significant innovation compared to the experiences, mainly American, platforms for the Aggregator. It will handle not only the electric vector but also other energy carriers. To provide its services, the Aggregator will need instrumentation and innovative technologies integrated into public and private buildings, as well as sensors and actuators to monitor the consumption of its customers and act on them. With regard to energy optimization the network of planned buildings in the trial, the knowledge acquired from the research results are characterized by a strongly innovative and original: the actions of consumption optimization are not addressed on the construction of new buildings, but the behavior management energy of the building seen as nodes in a network. Most of the research work on the control of single buildings while there is still a well-stabilized approach that allows to operate on a urban scale. As regards the optimization and the integration of renewable energy in electricity grids and smart devices, it can not be ignored the advances in software.

Lastly, the use of solar energy in the climate can become a winning technology for the air conditioning. The use of solar collectors to the concentration for application to medium temperature allows further application fields of solar cooling currently little explored such the use of absorption machines. The use of sensor networks deployed in urban settings is a theme strongly innovative. The originality of the project idea on the advanced sensors for monitoring air quality is in the integrated approach of mature technologies for scalability in different scenarios applications, with the study and research of new technologies and intelligence.

### 2.2.2 Project structure

Partners : ENEL (coordinator), ENEA (scientific responsible), IBM, Politecnico di Bari, Università della Calabria, General Electric, CNR, Data Management, Elettronika

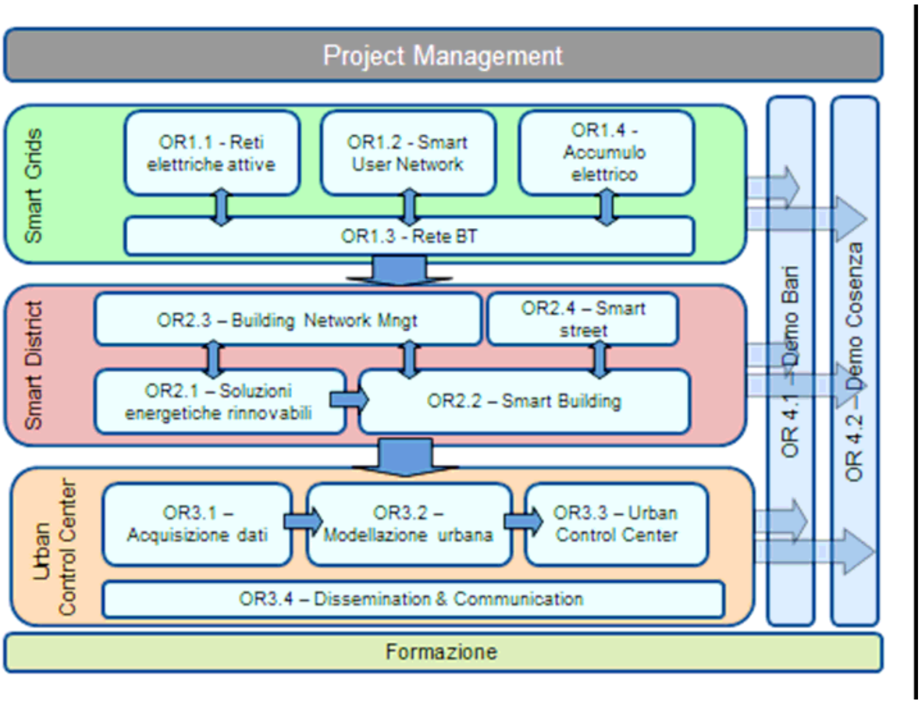


Figure 2.10 : project layout

The work carried out during the three years has focussed on the the OR2.3 (Building Network Mgmt) and in particular on the realization of the "Network Intelligence System" (NIS).

### 2.2.3 The Network Intelligence System

The OR2.3 Building Network Management aims to develop the methodology and the technology needed to support an operator of a network of buildings in order to shoot down all the sources of energy consumption within the network and interact with suppliers of energy (electrical or thermal) to implement policies to control application based on a advanced modeling that does not penalize the user comfort whilst minimizing detachments from the network.

The approach "building network management" can be applied on large stock of buildings (eg: neighborhood, city, country) also not connected to each other and in this case the attention is focused on reducing fuel consumption and to the active demand management. When in the condition of a shared thermal network (with the presence of generation distributed heat and / or electricity) the model is enriched by the optimized management of production systems of local energy. In this case it is realized the condition of the "Smart District" and the attention focuses on optimal management and synchronized production and energy loads. Finally, the approach can be generalized imagining a network of "smart district" (nodes) each with an autonomous intelligence but interconnected by a common policy for the management of demand and potential energy exchanges.

The development methodology is based on two main concepts: the " Energy Hub "which is the intelligence that allows to optimize the energy mix for the local production of energy dialoguing with generation systems and the "Network Intelligence System" (NIS) that allows the optimization of consumption and the application of the strategies of active demand control dialoguing with the control systems and interaction installed on buildings (BEMS: Building Energy Management Systems for commercial buildings; Energy Box for residential housing units).

The activity is on the development of management methodologies, simulation of complex network for the analysis and qualification of the strategic choices and evaluation of criticality, on the development of services that can be provided to users and ultimately on the development of a platform sw management able to communicate with the installations, buildings, operators of network management, distributors and vendors of energy (electricity and gas), the Urban Center (Structure of city government).

The Network Intelligence System focuses on the development of a library of models for diagnostics and remote optimization and active demand of a network of buildings. The System has the following objectives:

- providing services for modeling and predicting short of thermal and electrical consumption
- provide advanced data analysis services (diagnostic)
- provide guidance and set point for the optimal management of buildings
- provide guidance and set point in order to implement the demands of active demand

The activities will be the development of methods and algorithms and testing of existing database of buildings and networks. To accomplish this task, we developed the following steps:

- Development of predictive models of energy consumption of each building in order to obtain an "energetic imprint" on the basis of historical data collected during the first monitoring period. This model will do a prediction of the expected consumption given the time of day or week, climate data and the influx of users. The activity will consist of a part of development of the models through innovative methodologies and an implementation of sw libraries of these models.
- Diagnostics: the approach of the network of buildings can provide an effective response to the question about which buildings aremore efficient from the point of view of energy and which are less so, by means of a comparison between historical information refer to the individual building or through comparison with other properties similar to the structural characteristics and climatic through performance indices or "quality index management." In addition, for each building of the network will be developed diagnostic indicators (alarms) with their possible causes. Finally a system of dimensionless comparison of indicators allow them to compare between the performance of all buildings in the network to report any structural deficiencies (housing, facilities) or management (automation, behaviors) of buildings.
- Optimization: on the basis of performance indicators it is possible to optimize the objectives of a building where energy efficiency, comfort, the costs of management and maintenance through the connection with the other elements; this means that this module will provide guidance on the optimal set point to send to BEMS / energyBox, commands on, off and choking, the messages to the user. This activity will include a part of the development of optimization algorithms and an implementation of sw libraries.

## *2.3 City 2.0*

The main goal of this project, supported by the Italian ministry for education, university and research, is to carry out a ‘smart ring’ which includes and integrates several ‘smart cities & communities’ features.

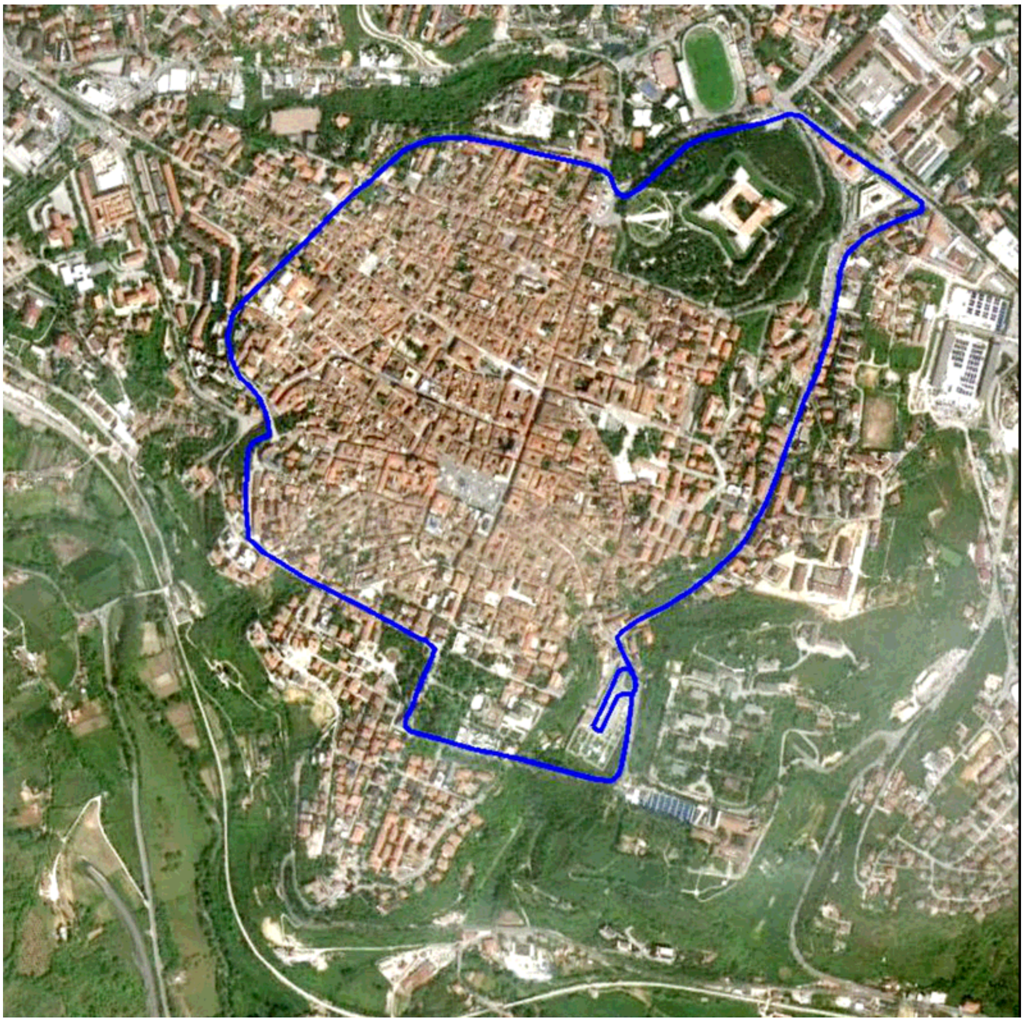

Figure 2.11 : overview of the experimental area

The main strategic objectives are :

Development of a Smart Street model based on the integration of public lighting, sustainable mobility and innovative management of building networks.

- Using the lighting network as the backbone of a network of sensors, the Data transmission to intelligent applications.
- large-scale technology demonstrator.

It will undertake a circular route in the vicinity of the historical center of the city (called "Smart Ring"), defined in accordance with the objectives and directions of the Centre's Reconstruction Plan where to apply in an integrated and synergistic way the following interventions:

  - public electric mobility;
  - Intelligent Lighting;
  - Diagnostic and energy analysis of buildings;
  - interactive communication systems available to the community;

- environmental monitoring and seismic monitoring.

Therefore, this is summary of actions on the territory

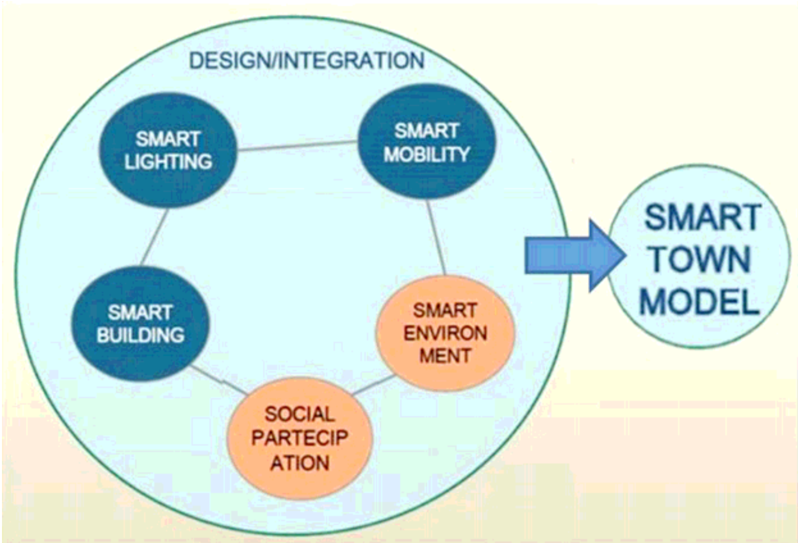


Figure 2.12 : project overview

SMART LIGHTING - INTELLIGENT LIGHTING

- Implementation along the ring of a public lighting system low consumption, also with the aid of LED technologies
- Installation of automatic detection systems and video traffic surveillance
- Installation of lighting remote actuation systems
- Installation of data processing servers

SMART MOBILITY - MOBILITY 'INTELLIGENT

- Definition and acquisition of a means of public transport traction power
- Definition and acquisition of on-board storage system
- Definition and construction of a station for quick charging of half
- Equipment of the medium with instrumentation necessary to Info-mobility applications

SMART BUILDING - INTELLIGENT BUILDINGS

- Provision of network and server as a service for all possible activities of analysis and energy audit of the buildings on the ring
- Definition of at least two public buildings on which to experiment with techniques of diagnosis and low level energy remote control

SMART PARTICIPATION

- Implementation of at least one network of environmental Wi-Fi in one of the zones most significant (Piazza Duomo, the Castle Park, Villa Municipal, Collemaggio, Parco Unicef)
- implementation of at least a "interactive kiosk" for the information users.

SMART ENVIRONMENT

- Positioning on the ring of at least 1 station, possibly mobile for air quality monitoring
- Creation of panels of information to users about the status of air quality.
- Provision of network and server as a service for all seismic monitoring activities present in the vicinity of the ring

### 2.3.1 Smart Lighting

Project objectives

- Realisation along the whole ring of a public lighting system with low power consumption, also with the aid of LED technologies
- Installation of automatic traffic detection systems and video surveillance
- Installation of lighting remote actuation systems
- Installation of data processing servers

Description of activities

The project aims to explore the type of "smart lighting" solutions where the network of public lighting (IP) plays a very significant role in the management of a number of municipal services that go beyond the same street lighting. Thanks to the ubiquity of the IP network, you can use it as a

digital infrastructure that covers the last mile (except the last 50 meters) of the city. In this way we study solutions to integrate power supply and digital network and applications that enhance such an opportunity in the contexts of the mobility system and energy management of buildings networks

using ICT technologies and computation intelligence.

For this purpose there are developed detection methods and modeling of the catchment and models for optimization of energy supply commensurate dynamically to the request (energy on demand) that require the development of a sensor structure that can "measure" the request of Real-time energy.

As part of this project it is identified in line with the provisions of the reconstruction Plan of the historic center of the city, a ring road to be used for the application of best technology currently available on an industrial scale.

The route has been preliminarily identified in the path that connects the Terminal bus Collemaggio, Via Strinella, Police Headquarters, Municipal Stadium Piazza Alpini Battalion, Viale Duca degli

Abruzzi, Viale Belvedere, Via XX Settembre, Viale di Collemaggio. It connects the parking lots of modality that will be of the belt to the future LTZ that will form the heart of the City. In this way the network data can be better integrated also with Smart Mobility activities of this project.

Along the way, they will be installed new street lighting systems, energy-saving, also with LED technology.

It will therefore be possible to install numerous types of sensors and actuators for a wide range of services to users.

To power the street lights will be used PLC technology (Power Line Communication) that allows traffic of broadband information via the power signal modulation.

In this way the lighting system becomes the enabling technology for many related services. The first of them is precisely the possibility of implementing the same lighting system (for low self consumption) with a variable intensity depending on the traffic of vehicles and people on the road network, allowing a significant additional saving of energy.

### 2.3.2 Smart Mobility

Project objectives

- Definition and acquisition of a means of public transport to electric traction
- Definition and acquisition of on-board storage system
- Definition and implementation of a station for the rapid charging of the medium
- Equipment of the medium with necessary instrumentation for info-mobility applications

Description of activities

Around the ring it is made a public transport service via an electric bus fast charging. At present the most interesting ring was identified in the track that intermodal parking lots according to the latest City Reconstruction Plan.

These means, particularly innovative, to provide, for the accumulation of electricity in that mode, to allow charging at high currents (supercapacitors and / or lithium-ion batteries), limiting the charging time to a few minutes, for distances of several kilometers.

Charging can be conductive (with plug-socket connections or unmanned air contact) or inductive (without contact).

### 2.3.3 Smart Building

Project objectives

- Provision of the network and servers as a service for all possible analysis and energy audit of the buildings in the coming of the ring
- Definition of at least two public buildings on which to test the diagnosis and Energy remote control.

Description of activities

Along or in the proximity of the ring there are present a number of services public buildings (offices andschools) and public and private management centers which, by their nature, constitute an element of electrical consumption with high energy savings potential, via the low-level automation systems.

In the implementation of the project the network of PLC communications and centralized servers provide utilities an energy audit service in the building and implementation of profiles consumption..

However, they are defined in partnership with the City and other local bodies, some public buildings on which test diagnosis and remote energy control, through the realization of a monitoring and control station ("control room").

The definition of the project 3 buildings owned by the town have been identified :

- Elementary School of the Tower;
- Nursery School of the Tower, with an adjacent station of the Police Station;
- Current Headquarters Council Chamber of the City at Villa Gioia

### 2.3.4 Smart Participation

Project objectives

- implementation of at least a network of environmental Wi-Fi in one of the most significant areas (Piazza Duomo, the Castle Park, Villa Comunale, Collemaggio, Parco Unicef)
- implementation of at least a "interactive kiosk" for the information to users
- implementation of a web portal (www.piazza100.it)

Description of activities

The network of PLC communications and centralized servers can be used interactively by local authorities and citizens. for example you can try out new ways of information to users through doors to the city constantly updated. Using the same tools will also enable direct communication systems with Administration and public consultation.

Given also the widespread presence of the park area near the ring, it can also help promote the availability zones to users of wireless networks (free or available for content targeted information) so that users can connect to the Administration through their smart-phones.

It will also be made at least one "interactive kiosk" characterized by a high level of interactivity and will leverage form the users useful information on the perception of the effect of the initiatives undertaken and the need of changes.

### 2.3.5 Smart Environment

Project objectives

- Positioning on the ring of at least 1 station, possibly the mobile monitoring of quality air
- Creation of panels of information to users on the state of air quality.

- Setting up the network and the server as a service available to all monitoring activities seismic present in the vicinity of the ring.

<u>Description of activities</u>

The network of PLC communications and the centralized server may also be used for the collection and processing (and related information to users) of data on air quality, by means of monitoring stations installed on the poles of public lighting.

At present the most promising choice seems to consist in the installation of a system of monitoring of air quality characterized by low response times. In this way it is installed directly on the electric vehicle in circulation in the ring and allow, through interaction with intelligent poles, processing of complete map of the area monitored, with frequent updating.

Such information could be made available in real time directly available to the citizenship in all the terms of the Smart Participation, in the access points distributed throughout the country, but also through web portals dedicated to the initiative.

The network will also be available for the data from the different seismic monitoring systems installed and being installed in the city on many of the most valuable buildings.

# Chapter 3. Smart lighting

Imagine a smart city where traffic flows naturally without any bottlenecks, where all people enjoy high speed Wi-Fi access in every park and public area and where electric cars align to charge directly from the streetlight poles. During the night, the street lights will be comfortably lit at all times, but automatically dimmed or even switched off when not needed. The city consumes less energy and resources, while people feel safer and businesses thrive. This is a city that cares more about its people and the environment.

Therefore, the main objective of this chapter is to show how new intelligent lighting systems can achive the goal of energy saving without affecting the safety of the citizens by means of a novel approach for street lighting management based on ‘energy on demand’. The main pillars of the proposed contribution are the predictive models aimed at forecasting the traffic flow rates and the control strategy based on the regulations which allow the dynamic street classification downgrade according to the previously predicted demand.

Thus, in the first paragraph it is introduced the overall scenario for street lighting, then it is described the proposed approach where predicted models are carried out and lastly real experimental resuts of the proposed control strategy are reported.

## 3.1 The street lighting scenario

Since the first international recommendations for the lighting of roads [1], power consumption and environmental aspects have become more and more important and at the same time, the improved performance of luminaires and lamps, and especially the introduction of electronic control gears, has made it possible to introduce adaptive lighting for motorised roads and pedestrians areas.

The legislation UNI11248: 2007 defines, by means of photometric requirements, class lighting reference of urban areas and identifies the lighting performance of lighting systems that would help, as far as relevance, safety of road users satisfying all requirements for vision. This legislation also takes into consideration the possibility of downgrades of category as a result of risk analysis (presence of intersections / conflicting conditions of slowing down, near pedestrian crossings), but also the environment and the surrounding visual traffic flow: and this is the aspect on which emphasis was placed and which was based on the analysis of energy consumption and theoretical estimates.

A structured model has been developed for the selection of the appropriate lighting classes [2] (M, C, or P), based on the luminance concept, taking into account the different parameters relevant for the given visual tasks. Applying for example time dependent variables like traffic volume or weather conditions, the model offers the possibility to use adaptive lighting systems with remarkable energy consumption savings and therefore high financial benefits for those municipalities [3] where street lighting is a high percentage of the electrical bill.

Today lighting control approaches ranges from simple on/off to regulation systems.

On/off systems include timers, twilight and astronomical clocks. The first one is a static system which turns on and off street lights always according to fixed times. The second one have light-sensitive photocells to turn them on at dusk and off at dawn [5], the third ones are GPS based street light controllers which operate the on/off of the street light according to the location features (longitude, latitude, sunrise, sunset times).

Regulations systems are based on dimmable LED or high pressure sodium vapor lights [4] and allow to schedule lights on or off and set dimming levels of individual or groups of lights.

All these systems have one common feature : they do not care about the real on-line demand and this is a source of high inefficiency.

Thus, in order to overcome the main lack of the current regulation systems, it has recently started the new Intelligent Street Lighting (ISL) approach which looks very promising [5,6]. Therefore, here we propose an ISL approach (Smart Adaptive Control) based on the concept of 'energy on demand', whose goal is to dynamically set the light intensity as function of the foreseen demand, namely the traffic flow rate 1 hour forecast.

Thus, in such context the demand model has a critical role and its accuracy strongly affects the performance of the regulation system.

In the last decade one of the most widely used method in order to solve modeling problems is that of Artificial Neural Networks (ANN) [7,8]. In particular, traffic flow forecasting has been faced since the nineties [9,10,11,12,13,14,15] up today [16,17,18,19] with ANN. As example, among the most recent work [19] focuses on traffic flow forecasting approach based on Particle Swarm Optimization (PSO) with Wavelet Network Model (WNM). [16] reviews neural networks applications in urban traffic management systems and presents a method of traffic flow prediction based on neural networks. [17] proposes the use of a self-adaptive fuzzy neural network for traffic prediction suggesting an architecture which tracks probability distribution drifts due to weather conditions, season, or other factors.

All the mentioned applications have one feature in common: they use one single global model in order to perform the prediction. A novel approach is to use not only one model but an ensemble of models.

## *3.2 The adaptive approach*

This study refers to the City 2.0 research project as part of the loan provided by the Finance Act 2010 (Article 2, Paragraph 44, Law 23 December 2009, 191), in favor of CNR and ENEA for the development of the productive fabric of the South. The city of L'Aquila has been selected as a pilot demonstration of the integrated development of innovative technologies and methodologies oriented savings and energy efficiency.

There are a number of integrated activities and synergies, according to a smart approach, in order to trigger a process of reconstruction and sustainable redevelopment of the city, through monitoring, diagnostics and optimization of different aspects, such as buildings, lighting public and mobility and also communication systems purely for the participation and social involvement.

With regard to public lighting, it has been made a Smart Ring of about 5 km, which includes the city's historic center. In particular, attention has been focused on the test field that insists on Via Strinella (1.2 km long), characterized by a single-carriageway and two lanes, one for each direction, a width of about 3 meters each. Here there are installed 53 LED light points and 3 SmartEye, the optical sensor which can directly analyze the scene, detecting and monitoring vehicular traffic (pedestrian) on the basis of which to implement policies and strategies of intelligent lighting (Smart Lighting).

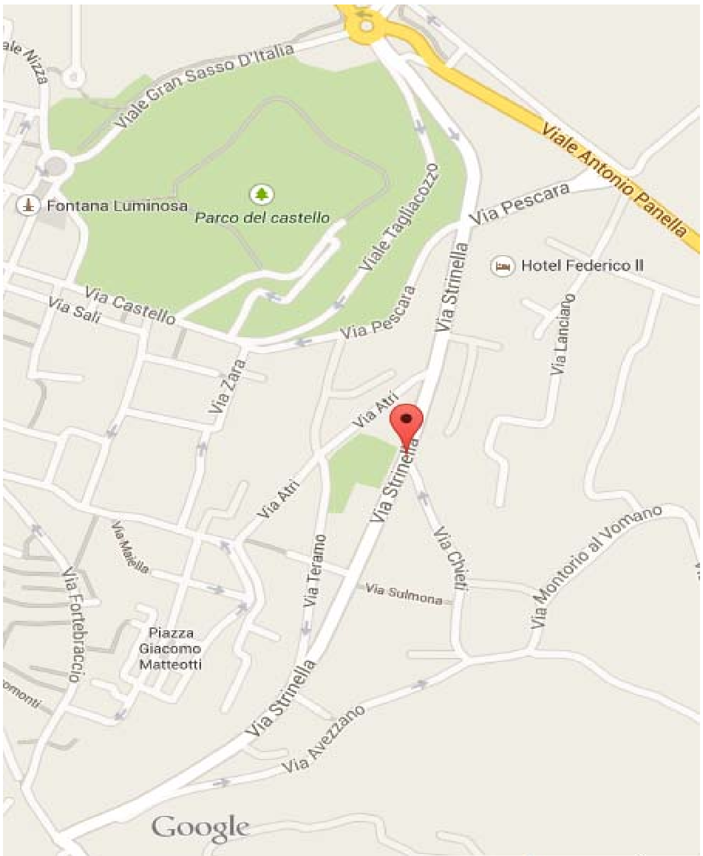


figure 3.1 : experimental field placement

For each of the three sensors the corresponding scenes are shown below


figure 3.2 : experimental field scene 1

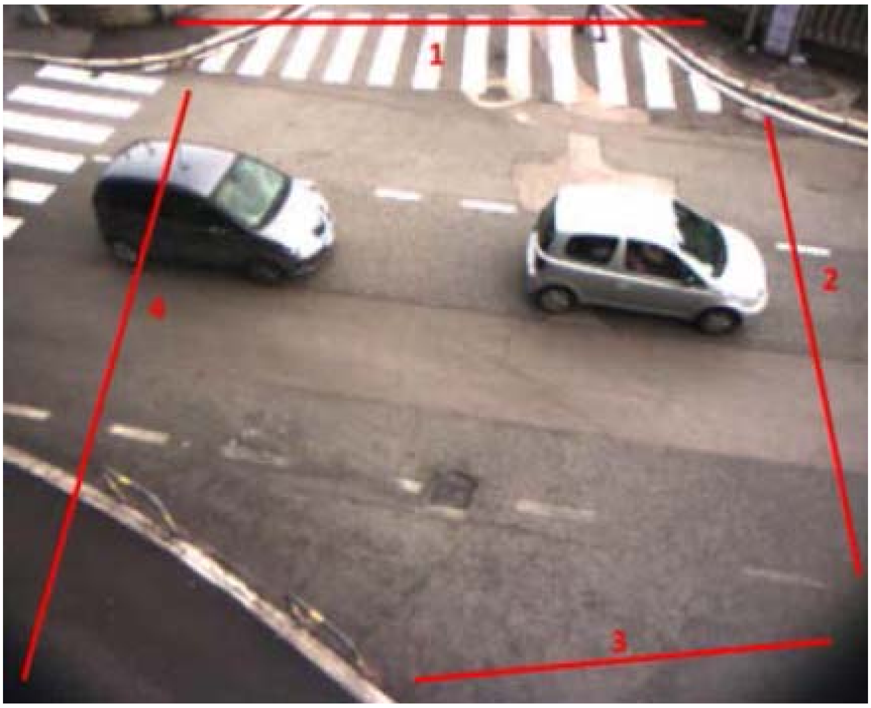

figure 3.3 : experimental field scene 2

figure 3.4 : experimental field scene 3

Because of the complexity of the scene at the crossing and the roundabout (and related issues in terms of security), no regulations can be made on the lights installed there. This is because of a greater difficulty for monitoring and management of the vehicular flows coming from different directions (involving several gates the input of the scene) that determine an increase of the possibility of collisions and criticality. Based on these considerations, the lights that insist along the straight stretch of road, flanked by the park, will be the subject of various analyzes, processing and subsequent actions.

The work carried out to date includes a series of steps, which will be described below in detail.

1. Acquisition and analysis of data traffic
2. Study and development of predictive models

### 3.2.1 Data acquisition and traffic analysis

The first activity, concerning the acquisition and analysis of traffic data, has started on September 2014 and took place in real-time with a 10 minutes sampling time. To remedy any problems of acquisition, the measurements were normalized on the basis on sample count actually detected during the 10 minutes. Below there is a graph which shows clearly the typical "saddle" trend, in which during the night there is a lower number of passing vehicles, which it is increasing in the central hours of the day and then have a small decline, due not to the fact that a few vehicles are passing by itself, but because of the traffic that reduces the viability and, consequently, the number of passing vehicles within the time interval analyzed.

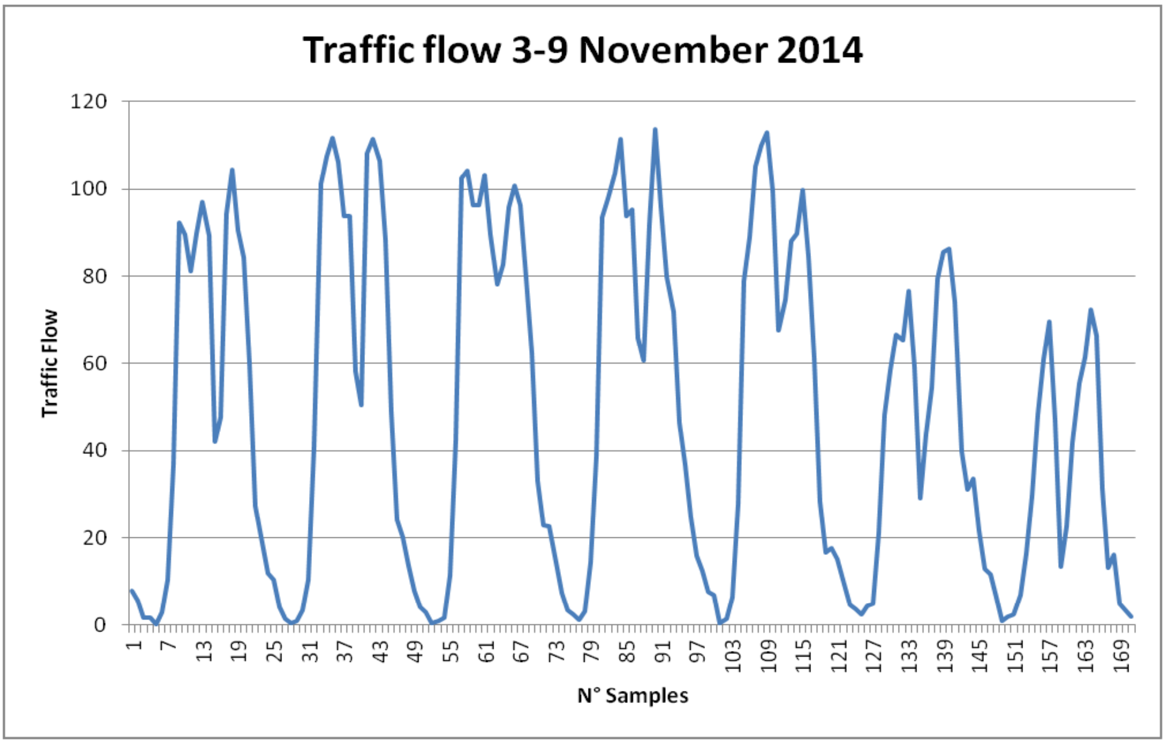


figure 3.5 : traffic flow profile

### 3.2.2 Modelling

This activity involved the study of predictive models of vehicular traffic on the basis of which to implement strategies for efficient management of public lighting dimming. Obviously, the adjustment can not be performed in real time: therefore we need to have available a priori a complete profile for each time slot of the relevant day which can be properly implemented.

In particular statistical methods, regressive and neural computing the MAPE (Mean Absolute Percentage Error) have been analyzed and implemented in order to validate the goodness in the calculation of the expected traffic for the following week.

Method 1: Forecasting the next week considering the days of the previous month.

The initial choice has considered the average of the passing vehicles by hour for every day of the previous month (30 days for November 2014). The model used was, therefore, the same for predicting each day of the first week of December: MAPE is 10.79%, a relatively high value, due to the fact that the user behavior is variable if you It is in the presence of different days and weekdays / holidays.

Method 2: Estimate the next week considering the days of the previous month by a regression model.

The regression model in matrix form, realized in Matlab using as input the passing vehicles during the 30 days of November, resulted in a MAPE of 9.65%

Method 3: Forecast of next week considering the days of the previous month by ARMAX model.

The ARMAX model (autoregressive moving average model), function taken from the System Identification Tool Matlab and using as input the passing vehicles during the 30 days of November, resulted in a MAPE of 8.83%.

Method 4: Forecast of next week considering the days of the previous month by NAIVE model.

The NAIVE model provides that, given the number of samples acquired, for each of them, at time t, x(t-k) = x (t) with k increasing: it is namely a shift of the series model that is compared with the real one. The increasing of k has determined a minimum MAPE of 12:08%, corresponding to the case x(t-1) = x(t).

Method 5: Estimation by neural model considering the days of the previous month.

The application of Feed Forward Artificial Neural Networks (FF-ANN) has had a preliminary analysis in order to have better training of the network (from March 2014 to November 2014) about the optimal number of input and hidden nodes: set the number of hidden nodes = 10, it has been investigated the number of inputs that from time to time has assumed values of 4,8,12,16,20,24.

In order to avoid overfitting the experimental data set has partitioned in two parts, training and testing and the 'Save Best' criterion has been applied. The training set is 75% (about 4800 records) of the whole data set and therefore the testing set is the remaining 25% of data (about 1600 records). This partitioning of the data is the same for all the modelling techniques considered in this study, therefore the comparison of the different models is coherent.

The ensambling that has been applied is the Basic Ensambling Method (BEM), ie by averaging five computations of neural networks.

The results in tables 3.1a and 3.1b show that as the nuber of input increases then the prediction error decreases. From these results the configuration with 12 inputs has been chosen as a good balance between accuracy and network complexity.

A subsequent analysis (table 3.2) concerned what was the best prediction horizon: as it is trivial to understand, the lower it is, the better the outcome in terms of average absolute eror, as shown in the table below which reports the results applied to the testing set. The training shows a similar behaviour.

| **FF-ANN BEM (training)** | | |
|---|---|---|
| **N° Input** | **MAPE** | **Max Error** |
| **4** | 4,20% | 71,49% |
| **8** | 3,68% | 71,68% |
| **12** | 3,05% | 71,74% |
| **16** | 2,97% | 68,45% |
| **20** | 2,83% | 49,81% |
| **24** | 2,85% | 49,19% |

table 3.1a : ANN modeling results

| FF-ANN BEM (testing) | | |
|---|---|---|
| **N° Input** | **MAPE** | **Max Error** |
| **4** | 8,07% | 49,83% |
| **8** | 6,60% | 54,04% |
| **12** | 5,67% | 42,51% |
| **16** | 5,52% | 43,40% |
| **20** | 5,40% | 43,03% |
| **24** | 5,25% | 41,76% |

table 3.1b : ANN modeling results

| INPUT: 12 | FF_ANN BEM | |
|---|---|---|
| **Prediction horizon** | **MAPE** | **Max** |
| **1** | 5,67% | 42,51% |
| **2** | 7,18% | 56,45% |
| **3** | 7,59% | 67,67% |
| **4** | 7,89% | 72,14% |
| **5** | 7,91% | 76,71% |
| **6** | 8,19% | 75,00% |

table 3.2 : ANN forecasting capabilities (testing results)

The table below shows graphically the comparison between real-time and predicted traffic flows with the above methods.

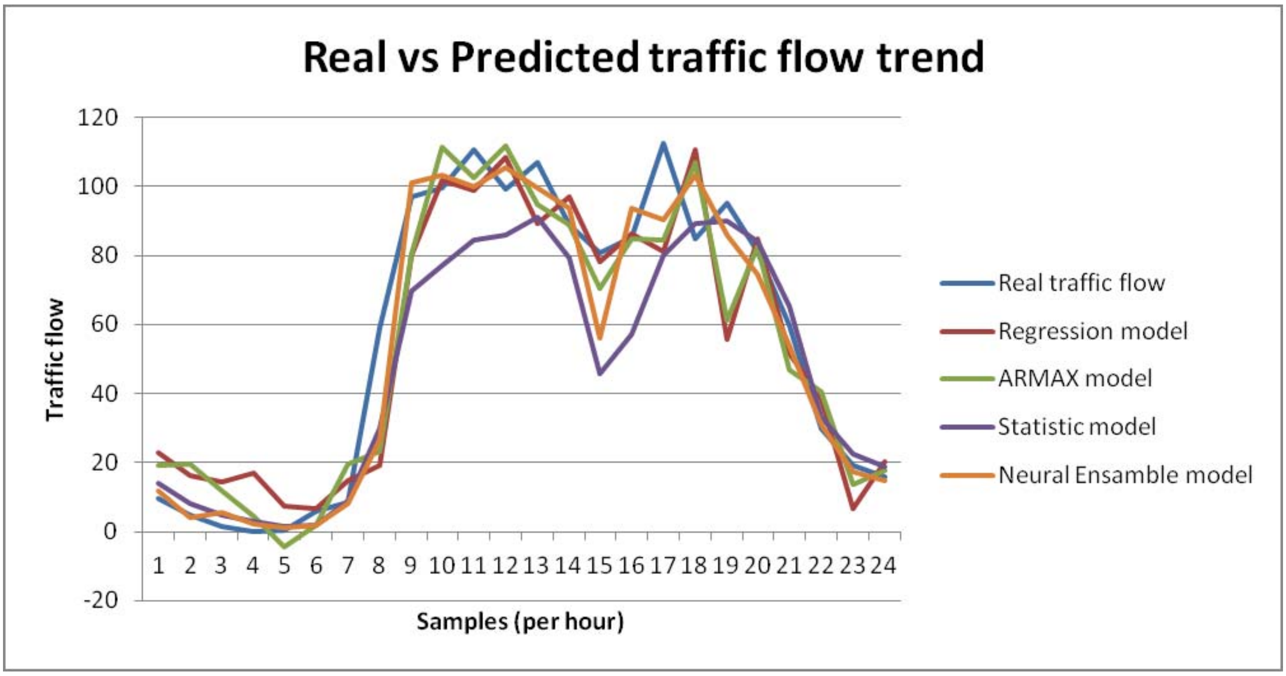


figure 3.6 : traffic flow forecast model comparison

| |
|---|
| **Statistic model (average)** |
| **10.79%** |
| **Regressive model** |
| **9.65%** |
| **ARMAX model** |
| **8.83%** |
| **NAIVE model** |
| **12.08%** |
| **FF-ANN model** |
| **5.67%** |

table 3.3 : modeling results comparison (testing)

The statistic model (simple hourly average over all the days) has been afterwards improved by splitting the single days into working / holidays.

Method 1.1: Forecast of individual days of the following week considering their position and the same day of the previous month.

The method adopted has calculated the average of their days in the month prior to the calculation of the same day of the following week, in the case of working days and holidays. As example, to predict the Monday of the first week of December it was carried out the average Monday in November, for the prediction of the Saturday of the first week of December it was carried out the average of the Saturday of November, and so on for the other days.

The MAPE obtained is reported in the following table.

This criterion is very effective if there is an almost constant behavior in the days considered, but in the case of events such as road closures, violent weather events, festivities or festivals, the situation of city traffic is highly variable going to affect negatively the prediction (see Monday, presenting a MAPE of 7.53% in contrast to Wednesday, when the MAPE is 3.92%).

| **Average MAPE – working days** | | | | |
|---|---|---|---|---|
| **Monday** | **Tuesday** | **Wednesday** | **Thursday** | **Friday** |
| 7,53% | 6,22% | 3,92% | 3,62% | 5,31% |

table 3.4 : ANN modeling results

| **Average MAPE – week-end** | |
|---|---|
| **Saturday** | **Sunday** |
| 4,25% | 3,26% |

table 3.5 : ANN modeling results

| **Average MAPE All working days** |
|---|
| 5.32% |
| **Average MAPE Whole week-end** |
| 3.75% |

table 3.6 : ANN modeling results summary

The average MAPE for all the days is 4.5% which is one point lower than the best of the previous models (FF-ANN : 5.6%).

<u>Method 1.2:</u> Estimate of weekdays/weekend of the next week considering the weekdays of the previous month.

Analyzing the average of passing vehicles per time slot for every working day of the previous month (20 days for November 2014) in order to predict the weekdays of the next week of December 2014: therefore, every weekday will have the same pattern.

Similar to the model for weekdays, it was developed a model that calculates the average of the passing vehicles per time slot for all holidays of the previous month (10 days for November 2014) in order to predict their holidays in the first week of December 2014. (Each holiday will have the same pattern). It is possible tosee from the following table, the MAPE is greater than in the case of the working days.

| MAE – Weekday Model |
|---|
| 5.29% |
| **MAE – Weekend Model** |
| 7,32% |

table 3.7 : ANN modeling results

The weekday model behaves in a similar day with respect to the previous one, but the week.end one is worse, therefore the the resulting best predictive model is 1.1 and it is the one used in the dimming model.

### *3.3 Assessment of energy savings*

Once defined and implemented the statistical model 1.1, the next step is the evaluation of energy savings resulting from the implementation of the proposed dimming strategy.

The roadway considered at the city of L'Aquila, Via Strinella, is classified as urban street district (ME3c), whose nominal capacity 800 vehicles hourly equivalent: as shown in the following table, extracted from the UNI EN 13201-2 the average luminance (minimum maintained) road surface in dry conditions of the roadway has a value of 1.0 cd / m2 and is the main parameter that should be considered.

In addition, given the absence of bumpers and conflict areas and consequently a reduction of, respectively, 50% and 25% of the nominal flow of vehicles, you will have a one level (ME4b) and 2 levels (ME5) derating lighting category, which correspond to luminance values equal to 0.75 cd / m2 and 0.5 cd / m2, as seen from table 3.9.

| Class | Luminance of the road surface of the carriageway for the dry road surface condition | | | Disability glare | Lighting of surroundings |
|---|---|---|---|---|---|
| | $\overline{L}$ in cd/m$^2$ [minimum maintained] | $U_o$ [minimum] | $U_l$ [minimum] | $TI$ in %[a] [maximum] | $SR^{2b}$ [minimum] |
| ME1 | 2,0 | 0,4 | 0,7 | 10 | 0,5 |
| ME2 | 1,5 | 0,4 | 0,7 | 10 | 0,5 |
| ME3a | 1,0 | 0,4 | 0,7 | 15 | 0,5 |
| ME3b | 1,0 | 0,4 | 0,6 | 15 | 0,5 |
| ME3c | 1,0 | 0,4 | 0,5 | 15 | 0,5 |
| ME4a | 0,75 | 0,4 | 0,6 | 15 | 0,5 |
| ME4b | 0,75 | 0,4 | 0,5 | 15 | 0,5 |
| ME5 | 0,5 | 0,35 | 0,4 | 15 | 0,5 |
| ME6 | 0,3 | 0,35 | 0,4 | 15 | no requirement |

table 3.8 : lighitng requrements by stree class

prospetto A.7 **Determinazione della categoria illuminotecnica per le strade urbane di quartiere e interquartiere**

| Parametri illuminotecnici | | | Categoria illuminotecnica |
|---|---|---|---|
| Dispositivi rallentatori | Flusso di traffico | Zona di conflitto | |
| Assenti | <25% | Assente | ME5 |
| | | Presente | ME4b |
| | <50% | Assente | ME4b |
| | | Presente | ME3c |
| | ≤100% | Assente | ME3c |
| | | Presente | ME2 |
| Nei pressi dei dispositivi | <25% | Assente | ME4b |
| | | Presente | ME3c |
| | <50% | Assente | ME3c |
| | | Presente | ME2 |
| | ≤100% | Assente | ME2 |
| | | Presente | ME1 |

table 3.9 : dynamic street lighting downgrade allowed by the italian law

By the reduction of the luminance limit to ensure it is therefore possible to reduce the power of the lighting points in a dynamic way, on the basis of the estimate of the profile of vehicular traffic. In this regard it has been developed an algorithm, albeit in simplified input variables, which replicates the basic functionality of the main calculation lighting commercial softwares (ex. dialux).

As result of these calculations, the use of the selected light source with 137 W power and luminous flux of 10275 lm (luminous efficiency of 75 lm / W) determines a value of average luminance (minimum maintained) Lm 1.02 cd / m2, that meets the limit set (≥ 1.0 cd / m2), as well as other photometric requirements.

The adaptation of the algorithm on the basis of these results gives a rough and conservatively indication on the percentage of power reduction in the above cases, the result is that for a downgrade of one level, the power can be reduced by 67% and for one of two levels of 45%.

For this assessment are taken into account parameters concerning :

- The road configuration
  - track width
  - inter-poles distance
  - type of road surface (taking the average coefficient of reflectivity)
- The enlightening bodies
  - height luminaire
  - installed power
  - luminous flux (or alternatively the luminous efficiency)
  - degrees opening fixture
  - performance or luminaire
  - outreach
  - tilt

However, in situ measurements show that the installed capacity of the actual piece of equipment is 113 W, compared with 137 W shown in the calculation.Without changing the matrix of adjustment factors used before, you get the value of the average luminance to ensure within the study area does not meet the lighting requirements of reference.

The table below performs the comparison between these two situations, which specifies the power required for the different values of average luminance to maintain, the ratio of this calculated power and the reference, the energy savings and the voltage to be applied to the single feeder luminaire:

| **reference power 137 W** | | | |
|---|---|---|---|
| | **Optimal power** | **Optimal vs. reference power** | **Saving** |
| **@ $L_m$ = 1.0** | 133 W | 0.97 | 2.9 % |
| **@ $L_m$ = 0.75** | 100 W | 0.72 | 27 % |
| **@ $L_m$ = 0.5** | 67 W | 0.48 | 51 % |

table 3.10 : lighing scenario 1

| **reference power 113 W** | | | |
|---|---|---|---|
| | **Optimal power** | **Optimal vs. reference power** | **Saving** |
| **@ $L_m$ = 1.0** | 133 W | 1.17 | -17 % |
| **@ $L_m$ = 0.75** | 100 W | 0.88 | 11.5 % |
| **@ $L_m$ = 0.5** | 67 W | 0.59 | 40.7 % |

table 3.11 : lighing scenario 2

For the same week, from 29 November 2014 to 5 December 2014, it was therefore carried out a comparison between the percentage of installed capacity provided for the time samples of each day, using real traffic data and according to the aforementioned statistical model adopted.

As can be seen from the following chart, detail of 29 November, there is a match of vehicles falling within specified ranges (the absence of the histogram in the middle reveals the fact that lighting in the hours from 7 to 17 during the month of December is off; for the other months these hours will be established on the considerations and sunrise and sunset, according to the astronomical timer).

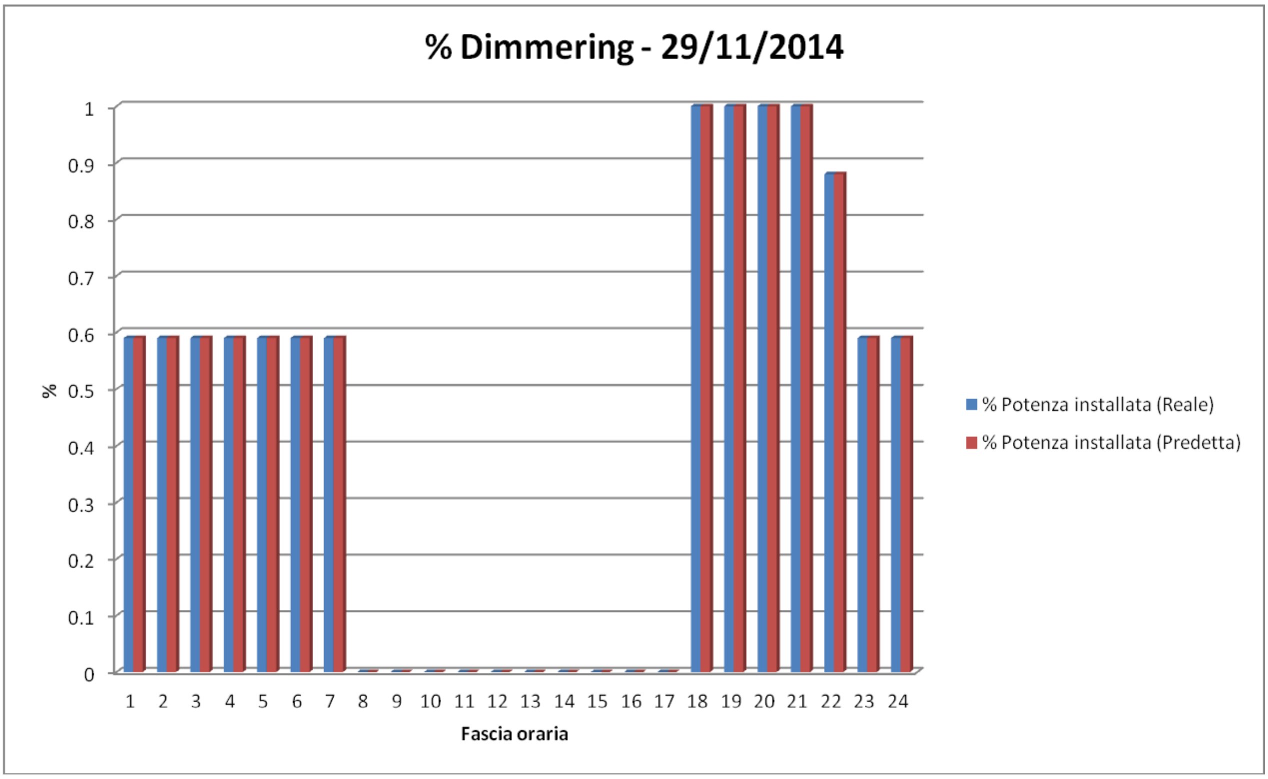


figure 3.7 : example of dynamic dyyming profile

However in some circumstances (see graph relative to November 30th), it may happen that the traffic forecast falls within a different range from the corresponding one of the real traffic flow within the same time interval (case which occurs mainly in relation to the transition day / night that there is a gradual decrease of passing vehicles): and if it is acceptable (even if you were using a power higher than needed, while ensuring regulatory limits) that

downgrading_class_forecast > downgrading_class_real

the same is not possible in the opposite situation for which it might be incurred in safety problems for road users.

Before applying profiles dimmering, engineers will have to ascertain and ensure that the provision of vehicles for the current month, compared with their actual data, are consistent with this aspect: if not, you will have to provide for the adjustment of the band downgrade to that for the corresponding real data. However any corrective action parameters and the percentage of power reduction will be, ultimately, subject to approval by the local administration.

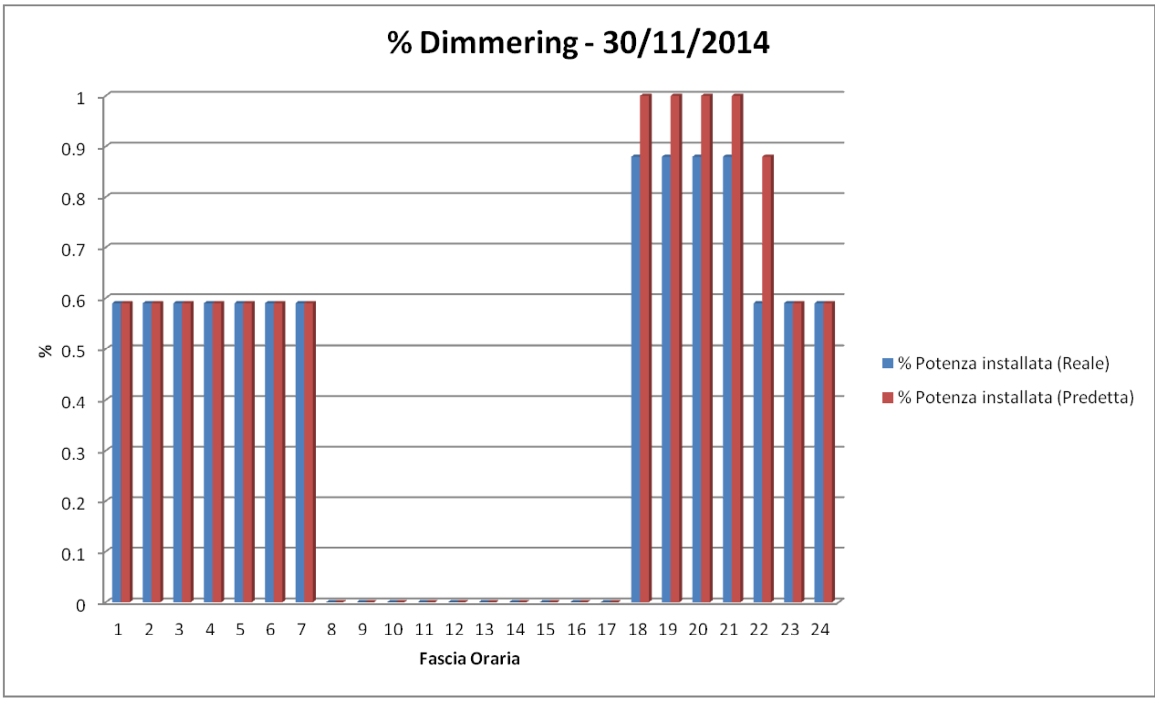

figure 3.8 : example of dynamic dyyming profile

In this sense, from the implementation point of view, it was decided to consider the thresholds of the vehicles for the downgrading changed, conservatively, at ± ε, that after a series of tests has been set equal to 10%, which minimizes such a situation.

The daily energy consumption, making use or not of reduction actions of the installed power of the apparatus in function of external variables, would be obtained using the following formula:

Dayly_consumption [kWh] = installed_power[kW] X working_hours[h]

So, regarding the day of November 29th 2014, for the individual lighting fixture you would have the situation below:

Energy_consumption_nodimming = 113[W] X 14[h] = 1,582 [kWh]

Energy_consumption_dimming = 113[W] X 4[h] + 100[W] X 1[h] + 67[W] X 9[h] = 1,15 [kWh]

with a resulting energy saving of 0,42 kWh

Given the conformation of the street (via strinella), the Smart-Eye sensor considered for the analysis of the scene covers a straight stretch of the road, without significant input from the residential streets, on which stand 18 appliances,then we would have a total energy saving equal to

0,42[kWh] X 18 = 7,56 kWh

At the end of the 6-month experimental period during which the algorithm has calculated the dimming profiles, in the table below we can see the theoretical energy savings which would be obtained for each month, for the 18 lamps object of the study, pointing out the indicative on / off system times. It is needed to specify that the savings for the spring will be inferior to others because of daylight saving time and the change of the sunrise and sunset time. In addition, the month of May is not considered until 31, but up to 29. The cost of energy has been recovered from the ENEL site and set equal to 0.17 € / kWh. For CO2 savings it is considered a value of 382 g / kWh.

| **Results** | | | | | | |
|---|---|---|---|---|---|---|
| | **Dec.14** | **Jan.15** | **Feb.5** | **Mar.15** | **Apr.15** | **May15** |
| **Switch on time** | 17 | 17 | 17 | 18 / 19 | 19 | 20 |
| **Swithc off time** | 8 | 8 | 7 | 7 | 7 | 6 |
| **Working hours [h]** | 465 | 465 | 392 | 400 | 360 | 290 |
| **Energy consumption (No Dimming) [kWh]** | 945.81 | 945.81 | 797.328 | 813.6 | 732.24 | 589.86 |
| **Energy consumption (Dimming) [kWh]** | 684.054 | 678.366 | 565.092 | 563.49 | 503.91 | 400.356 |
| **Energy Savings[kWh]** | 261.756 | 267.444 | 232.236 | 250.11 | 228.33 | 189.504 |
| **Energy Savings [%]** | 27,67% | 28,27% | 29,13% | 30,74% | 31,18% | 32,12% |
| **$CO_2$ Savings [kg]** | 100 | 102.2 | 88.7 | 95.6 | 87.2 | 72.4 |

table 3.12 : experimentation summary

In conclusion, the work of the City 2.0 project on Smart Lighting took place over 12 months, from 1 July 2014 to 30th June 2015, organized as follows:

- in the first months, the data acquired by the SmarteEye sensor on Via Strinella were analyzed and a series of computations, accompanied by diagnostic and data consistency;
- 6 months after, statistical, regression and neural prediction methods have been studied, tested and compared to determine the reliability in the long term;
- once selected and implemented the most performing predictive model, in consideration of the road configuration in situ, for the months from December 2014 to May 2015, there were defined dimming profiles at weekly level. At the end of the trial, there were evaluated fuel consumption with and without the application of intelligent strategies of adaptive reduction of the installed power, achieving energy savings of the order of 30%.

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# Chapter4. Thermal Fault Detection and Diagnosis in a Smart Building Network

Energy and economic efficiency are the main targets of modern Building Energy Management Systems (BEMS) , therefore looking for a valid method for fault detection and diagnosis (FDD) to instruct operation and maintenance is a main mission. At present FDD is mainly based on collecting signals whose analysis and interpretation is left to human experts. Unfortunately, the number of signals is often very high and the relations among them highly non-linear. Thus, human operators are often not capable to detect in time a fault. This is a very critical point, because the early detection of a fault may prevent the building from serious problems.

In the last decades the application research of artificial intelligence [1][2] has become one of the most important topics in fault diagnosis and theoretical study in this field is mainly focused on artificial neural networks [3][4] and fuzzy systems [4][5]. A number of papers on the application of Artificial Neural Networks (ANNs) for FDD have been published. [6] created and tested on field data a whole-building energy software for detecting energy use problems. The software uses ANNs models as energy end-use predictors to determine the ratio of measured energy use to expected energy use, accounting for the weather, time of day, and other features of building energy use that are time- and day-dependent. A separate energy ratio is computed for each energy end-use. The whole-building energy software generates detection messages according to categories "lower than normal" and "higher than normal" energy ratio. In [7] a fault diagnosis system of an automatic solar water heater was developed. This system consists of a prediction module, a residual calculator and the diagnosis module. In the prediction module an ANN is used, trained with values obtained from a TRNSYS model of a fault-free system and, consequently, able to predict the fault-free temperatures under different environmental conditions. The input data to the ANN are the time of the year, various weather parameters and one input temperature. The residual calculator receives both the current measurement data from the data acquisition system and the fault-free predictions from the prediction module. In the diagnosis module the residuals are compared against three constant threshold values. So, four categories are defined: normal, low probability of failure, high probability of failure, and failure. Each state of the system is decided from the magnitude of the residual, which classifies it to one of each category. The system can predict three types of faults, but it cannot, however, identify the exact cause of the fault in the solar collector. The system was validated by using input values representing various faults of the system. [8] developed a diagnostic tool for a supermarket using ANN models. This tool evaluates, on the basis of suitable explanatory variables, the energy consumption of each supermarket subsystems to provide the energy baseline, and then realizes the fault detection. The actual energy consumption of the store or the system is compared to the predicted consumption. In the first level of diagnosis, the performance is labelled as Bad/Average/Good depending on the actual value exceeds the predicted value by 10% or more/by 5% to 10%/by less than %5. If there are five or more consecutive points greater than the upper prediction bound or lower than the lower prediction bound, the likelihood of a fault occurrence is high (second level diagnosis). The tool cannot, however, identify the exact cause of the fault in each system. Once a fault has been detected, the maintenance team must be notified to examine the operation of the system more closely.

Fuzzy techniques are more appropriate for FDD as it allows the integration in a natural way of human operator knowledge into the fault diagnosis process and the formulation of the decisions taken is done in a human understandable way such as linguistic rules. In the energy application field these techniques were mainly used in FDD of energy production systems [9][10][11] and very little was carried out in the building energy consumption FDD. [12] developed a FDD strategy based on an Efficient Adaptive Fuzzy Neural Network to assist building automation systems for sensor heath monitoring and fault diagnosis of an Air-Handling Unit (AHU). [13] carried out a hybrid approach employing fuzzy sets and possibility theory where failure possibilities of vague events are characterized by fuzzy sets to translate expert subjective judgments, while fuzzy fault rates are derived from fuzzy possibility scores. Moreover, in [14][15] it is proposed an FDD approach based on fuzzy sets in order to detect electrical faults and bad management of the lighting and conditioning system.

In this scenario, this chapter takles the problem of Thermal Energy FDD in a network of smart buidings using fuzzy techinques. The main novelty of this work refers, not on the methodology itself which is quite well established and mature, but on its application on a cluster of building sharing the same thermal energy network.

The chapter is therefore structured in this way : the first paragraph introduces the general approach for building diagnostics, the second one describes how the diagnostics model has been implemented in five different situations with real data results.

## *4.1 The PSC model for building diagnostics*

The Preprocessing Situation Cause (PSC) model is a three-hierarchical levels rule based framework aimed to identify high level anomalies on the building and a two phases process has been carried out: design phase of building malfunction events was based on a top-down approach:

firstly, typical building abnormal events were classiffed, then a set of possible situations related to each cause were identified and, finally a set of aggregated measures have been correlated to each situation. Such structures is divided into three levels of information through data fusion model.

- Causes. Reasons of the anomalous status of the building, typical causes involves occupants behaviour, systems malfunction, structural design errors or exceptional events.
- Situations. Anomalous situations of the building, they include assumptions regarding abnormal behaviour of energy vectors related to working schedules, occupancy, weather or structural characteristics.
- Preprocessing. Sensor data eventually statistically aggregated, typical preprocessings are trends, outliers and mean values.

The second phase is based on a bottom-up approach: starting from sensors data collected, information is increasingly aggregated to higher levels such that starting from locally failure detected, original, high level causes are guessed. The following tables show a theoretical framework. Table 4.2 enumerates the list of preprocessings identified, table 4.3 situations and table 4.4 the causes. It is worth underlining that although such framework is designed to be as more general and scalable, it depends obviously on the building characteristics and monitoring system installed, hence, such lists are not, and not intended to be, an exhaustive set of possible anomalies. However, this framework can be continuously updated according to different data, systems and experts assumptions. Table 4.2 groups preprocessings according to data source typologies, for readability reasons, such typologies have been shortened, table 4.1 shows complete meanings. The structure of Preprocessing table regarding consumptions is logically divided into final uses and energy vectors:

- Electric consumption
  - Lighting
  - Emergency
  - Fancoil
  - E.M.F.
- Thermal heating consumption
- Thermal cooling consumption

Furthermore, preprocessing related to occupancy, weather, calendar, working schedule are listed. Situations table 4.3 reflects preprocessing division, therefore it is divided into final uses and energy vectors as well.

| Acronym | Meaning |
|---|---|
| LEC | Lighting Electric Consumption |
| EEC | Emergency Electric Consumption |
| EMFC | Electro Motive Force Consumption |
| CEC | Chiller Electric Consumption |
| CTC | Chiller Thermal Consumption |
| FCCE | Fancoil Electric Consumption |
| TFF | thermal Fluid Flow |
| HTC | Heater Thermal Consumption |
| IT | Indoor Temperature |
| IH | Indoor Humidity |
| EA | Equipment Availability |
| OB | Occupancy Badge |
| OS | Occupancy Sensor |
| WS | Working Schedule |
| WD | Weather Data |

table 4.1 : data source typologies

| Measure | | Preprocessing |
|---|---|---|
| LEC | $P_1$ | Outlier electric consumption |
| | $P_2$ | Anomalous trend electric consumption |
| | $P_3$ | Change of mean value of power absorbed |
| | $P_4$ | Cumulated consumption normalised |
| | $P_5$ | No consumption |
| EEC | $P_6$ | Outlier electric consumption |
| | $P_7$ | Anomalous trend electric consumption |
| | $P_8$ | Change of mean value of power absorbed |
| | $P_9$ | Cumulated consumption normalised |
| | $P_{10}$ | No consumption |
| EMFC | $P_{11}$ | Outlier electric consumption |
| | $P_{12}$ | Anomalous trend electric consumption |
| | $P_{13}$ | Change of mean value of power absorbed |
| | $P_{14}$ | Cumulated consumption normalised |
| | $P_{15}$ | No consumption |
| CEC | $P_{16}$ | Anomalous trend electric consumption |
| | $P_{17}$ | Anomalous difference between electric and thermal energy |
| | $P_{18}$ | Cooling Efficiency Anomalous |
| | $P_{19}$ | Change of mean value of power absorbed compared to nominal |
| | $P_{20}$ | Cumulated consumption normalised |
| | $P_{21}$ | No consumption |
| FCEE | $P_{22}$ | Outlier electric consumption |
| | $P_{23}$ | Anomalous trend electric consumption |
| | $P_{24}$ | Change of mean value of power absorbed |
| | $P_{25}$ | Cumulated consumption normalised |
| | $P_{26}$ | No consumption |
| CTC | $P_{27}$ | Outlier thermal energy consumption |
| | $P_{28}$ | Anomalous difference between electric and thermal energy |
| | $P_{29}$ | Cooling Efficiency Anomalous |
| | $P_{30}$ | Change of mean value of power absorbed compared to nominal |
| | $P_{31}$ | Cumulated consumption normalised |
| | $P_{32}$ | No consumption |
| GEC | $P_{33}$ | Cumulated consumption normalised |
| TFF | $P_{34}$ | Anomalous trend thermal fluid flow |
| HTC | $P_{35}$ | Outlier thermal energy consumption |
| | $P_{36}$ | Anomalous difference between electric and thermal energy |
| | $P_{37}$ | Cooling Efficiency Anomalous |
| | $P_{38}$ | Change of mean value of power absorbed compared to nominal |
| | $P_{39}$ | Cumulated consumption normalised |
| | $P_{40}$ | No consumption |
| IT | $P_{41}$ | Outlier indoor temperature |
| | $P_{42}$ | Indoor and outdoor temperature similar |
| | $P_{43}$ | Anomalous trend indoor temperature |
| | $P_{44}$ | Setpoint change frequency high |
| | $P_{45}$ | Thermostat value variance high |
| | $P_{46}$ | Setpoint mean value |

table 4.2a : theoretical preprocessing

| Measure | | Preprocessing |
|---|---|---|
| IH | $P_{47}$ | Outlier indoor humidity |
| | $P_{48}$ | Indoor and outdoor humidity similar |
| | $P_{49}$ | Anomalous trend indoor humidity |
| EA | $P_{50}$ | Communication interruption |
| OB | $P_{51}$ | Occupancy Room Percentage |
| | $P_{52}$ | Probability current room occupancy |
| | $P_{53}$ | Occupancy building level |
| OS | $P_{54}$ | Instantaneous room occupancy |
| WS | $P_{55}$ | Working schedule |
| WD | $P_{56}$ | Outdoor temperature |
| | $P_{57}$ | Outdoor humidity |
| | $P_{58}$ | Pressure level |
| | $P_{59}$ | Wind Speed |
| | $P_{60}$ | Wind Direction |
| | $P_{61}$ | Rain Level |
| | $P_{62}$ | Solar radiation Level |

table 4.2b : theoretical preprocessing

| | Situations |
|---|---|
| $S_1$ | Anomalous consumption on electric devices (lighting) |
| $S_2$ | Anomalous thermal consumptions on heating equipment (electric) |
| $S_3$ | Anomalous consumption on electric devices (e.m.f.) |
| $S_4$ | Uncontrolled external air incoming |
| $S_5$ | Local thermostat setpoint anomalous |
| $S_6$ | Anomalous thermal consumptions on cooling equipment (electric) |
| $S_7$ | Local electric consumption outside working schedule (e.m.f.) |
| $S_8$ | Lighting equipment turned on outside working schedule |
| $S_9$ | Thermal losses on distribution system |
| $S_{10}$ | Places illuminated without presence |
| $S_{11}$ | Energy consuming auxiliary devices turned on |
| $S_{12}$ | Insufficient thermal power of heating plant |
| $S_{13}$ | Insufficient thermal power of cooling plant |
| $S_{14}$ | Shading devices position modified |
| $S_{15}$ | Unexpected Emergency lighting turned on |
| $S_{16}$ | Electric devices turned on without presence (e.m.f) |
| $S_{17}$ | Electric circuits malfunction |
| $S_{18}$ | Electric energy supply interrupted |
| $S_{19}$ | Anomalous number of electric devices turned on (e.m.f) |
| $S_{20}$ | Unbalanced number of occupancy level compared to working schedule |

table 4.3 : theoretical situations

| | Causes |
|---|---|
| $C_1$ | Insufficient Lighting equipment installed power |
| $C_2$ | Malfunction of scheduled control in thermal plant |
| $C_3$ | Malfunction on heating plant pumps |
| $C_4$ | Malfunction on thermal plant AHU |
| $C_5$ | Malfunction on thermal plant chiller |
| $C_6$ | Thermostat control failure (heating) |
| $C_7$ | Thermostat control failure (cooling) |
| $C_8$ | Distribution system overload or maintenance |
| $C_9$ | Occupants open windows |
| $C_{10}$ | Occupants changes setpoint |
| $C_{11}$ | Occupants leave electric equipment turned on (lighting) |
| $C_{12}$ | Occupants leave electric equipment turned on (e.m.f.) |
| $C_{13}$ | Occupants leave electric equipment turned on (heating) |
| $C_{14}$ | Occupants leave electric equipment turned on (cooling) |
| $C_{15}$ | Insufficient insulation on thermal distribution system (heating) |
| $C_{16}$ | Insufficient insulation on thermal distribution system (cooling) |
| $C_{17}$ | Regulation system failure (heating) |
| $C_{18}$ | Regulation system failure (cooling) |
| $C_{19}$ | Thermal plant sizing wrong (heating) |
| $C_{20}$ | Thermal plant sizing wrong (cooling) |
| $C_{21}$ | Thermal plant degradation (heating) |
| $C_{22}$ | Thermal plant degradation (cooling) |
| $C_{23}$ | Insufficient light level in rooms |
| $C_{24}$ | Occupants dazzling sunlight |
| $C_{25}$ | Holiday |

table 4.4 : theoretical causes

The actual implementation is inspired by the proposed theoretical structure and it is described in the following tables taken from the real implementation on database.

| idProcessing | Label | Meaning |
|---|---|---|
| 1 | P1 | Power peak outlayer |
| 3 | P8 | Power trend not as expected |
| 5 | P51 | Working Time |
| 6 | P24c | Occupied Rooms % |
| 7 | P59 | % room points with > 500 lux |
| 8 | P60 | High residual |
| 9 | P61 | Conditioning Outlier (electric power) |
| 10 | P11 | Winter thermal consumption |
| 11 | P13 | Temperature supply water difference between setpoint and actual measure |
| 12 | P14 | Valve opening % |

| | | |
|---|---|---|
| 13 | P15_i | Room temperature difference between setpoint and actual measure |

table 4.5 : actual preprocessing implementation

| idsituation | label | Meaning | formula |
|---|---|---|---|
| 1 | S1a | High number of lights on | P1 OR P8 |
| 2 | S30 | High % presence out of working time | P51 AND P24c |
| 3 | S33a | Sufficient natural lighting | P59 |
| 4 | S1c | Consumption outlayer | P1 OR P8 OR P60 |
| 5 | S2a | High number of fancoils on | P61 |
| 6 | S10 | High heat consumption outside working hours | NOT P51 AND P11 |
| 7 | S11 | Low heat consumption during working hours | P51 AND NOT P11 |
| 8 | S12 | HIGH thermal Consumption with LOW occupation | NOT P24c AND P11 |
| 9 | S13 | LOW thermal Consumption with HIGH occupation | P24c AND NOT P11 |
| 10 | S14 | The valve does not mix when the difference between the flow temperature and the set-point is less than a benchmark value | NOT P13 AND NOT P14 |
| 11 | S15 | The valve mixture when the difference between the flow temperature and the set-point is greater than a value of the benchmark | P13 AND P14 |
| 12 | S16 | A room of a thermal zone has an internal temperature higher than the set-point value | P15_1 XOR P15_2 ... XOR P_n |
| 13 | S17 | More rooms of a thermal area have an indoor temperature higher than the set-point | P15_1 OR P15_2 ... OR P_n |
| 14 | S18 | All the rooms in a zone have a temperature higher than the set-point value | P15_1 AND P15_2 ... AND P_n |

table 4.6 : actual situations implementation

| idcauses | label | Meaning | formula | event_category |
|---|---|---|---|---|
| 1 | C13a | Lights on with no people | S1a OR S30a | BuildingLighting |
| 2 | C53 | Lights on during working time with high natural light | S1c AND S33a | BuildingLighting |
| 3 | C27 | Fancoil on with no people | S2a AND NOT S30 | BuildingCDZ |
| 4 | C30 | Malfunction in the central heating timer | S10 OR S11 | BuildingTherm |
| 5 | C31 | Improper heat management | S12 OR S13 | BuildingTherm |
| 6 | C32 | Incorrect operation of the mixing valve in the boiler | S14 OR S15 | BuildingTherm |

| | | | | |
|---|---|---|---|---|
| | | room | | |
| 7 | C33 | Malfunction of the room thermostat in the summer | S16 · (1 – α) + S17 · α | BuildingTherm |
| 8 | C34 | Defect distribution system | S18 | BuildingTherm |

table 4.7 : actual causes implementation

## *4.2 The thermal diagnostics model : definition, implementation and experimentation*

In [14][15] some applications of this approach to electrial anomalies have been applied. In this work and [16] it has been extended the approach to thermal faults identification of a cluster of buidings sharing the same thermal network.

Therefore, in this paragraph there are described the details of the approach based on fuzzy sets. The reason for choosing it is based on the fact that fuzzy techniques are very appropriate for FDD as it allows the integration in a natural way of human knowledge and that it is a well established and mature methodology, as described also in the introduction of this chapter, also in the energy related applications.

Moreover, the proposed diagnostics model defines some fuzzy sets used as indicators in the lattice [0,1] of the plausibility that a fault occurrs, it actually does not define any inference system based on rules in the Mamdani [17] form triggering some kind of consequences.

All the parameters of the fuzzy sets have been tuned in order to mark a priori known faults with a value higher than 0.5 and serious ones (acknoledged by experts) with a value higher than 0.8 (these are arbitrary choices) .

Stated the use of bottom-up diagnostic techniques, based on the principle of division in the pre-processing, situations and causes levels, there have been identified some causes related to an abnormal consumption of thermal energy. In particular:

1. Malfunction in the central heating timer: this case is designed to identify misconduct clock that regulates the switching on and off from the central heating boiler.
2. Improper heat management: that case aims to identify poor management of the system and is dependent on the occupation of the building.
3. Incorrect operation of the mixing valve in the boiler room: it aims to identify the malfunctioning of the valve fluid mixing.
4. Malfunction of the room thermostat in the summer: this cause is identified, if for a given area of the building is detected that one or more rooms have an internal temperature higher than the set-point value.
5. Defect distribution system: this happens because if, for a given area, is detected in all the rooms a temperature higher than the set-point value.

### 4.2.1 Malfunction in the central heating timer

This indicator tries to identify misconduct clock that regulates the switching on and off of the heating boiler room.

This anomaly is supported by two possible situations :

- S10 = High heat consumption outside working hours
- S11 = Low heat consumption during working hours

S10 is the situation when the timer does not switch off the heating at the end of the day, S11 is the opposite situation, when the timer does not switch on the heating at the beginning of the day.

The composition of these two provide evidence that the clock of the thermal room is out of order.

A possible modification of this indicator is the one which replaces the working time (which is connected to the clock) with the outside temperature in order to identify that the control system in charge of optimizing (see chapter 5) the water supply temperature is not working as expected.

The following table shows the fuzzy variables preprocessing used, evaluated through specific membership function. In detail:

- working time is fuzzyfied as a Gaussian function of time;
- thermal consumption is fuzzyfied as sigmoid.

| Label | Meaning | MembershipFunction | Parameters |
|---|---|---|---|
| **P51** | Working Time | $e^{\left(\frac{-(x-m)^2}{2s^2}\right)}$ | m = 12<br>s = 4 |
| **P11** | Winter thermal consumption | $\frac{1}{1+e^{\left(-\frac{(x-c)}{t}\right)}}$ | c = 6.5<br>t = 2.5 |

table 4.8 : preprocessing fuzzy sets

Subsequently, there were identified associated situations, obtained by relating the preprocessing proceeds, according to the logic of Boolean AND, OR, NOT (∧, ∨, ¬)

High heat consumption outside working hours:

S10 = ¬P51 ∧ P11

Low heat consumption during working hours:

S11 = P51 ∧ ¬P11

The cause is merged from the OR logic of the two situations:

C30 = S10 ∨ S11

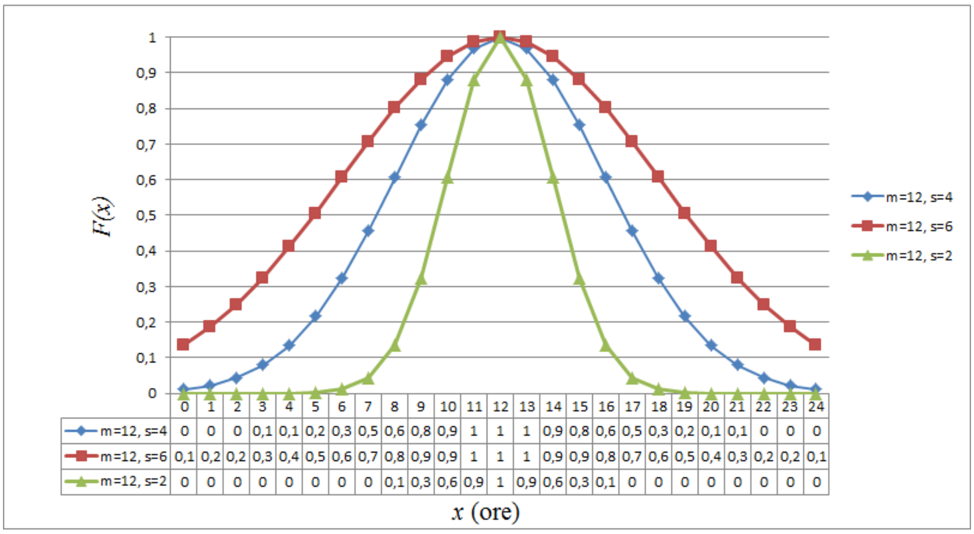
The implementation of the rule in Java, was made considering first of all the buildings of the Smart Village in which to apply that case, namely F40, F85 (corresponding to the thermal power plant on the cluster) and the cluster of buildings (F66, F67, F68, F69, F70, F71, F72, F73).

In order to do that, the SCADA identifiers, related to thermal winter consumption per building, have been identified in the database.

In order to obtain acceptable values of preprocessing, it was necessary to calibrate the membership functions with specific parameters, in relation to the values measured by the sensors. The rule in question were analyzed for two membership functions, respectively for the working hours and the heat consumption:

- Gaussian function;
- Sigmoid function.

Regarding the Gaussian function, it was decided to set the parameters, namely mean (m) and standard deviation (s), so as to have in the time period of 24 hours an appropriate clarification of the working time of the CR ENEA. For this reason have been set at m = 12, indicating mid-day, and s = 4, so that it reflects the working period during the day understood by now 8:00 to 16:00 hours, so that the function Gaussian to be higher than 0.5, in these hours. For the purposes of diagnosis, the setting described above is to be the most optimal. In fact, as it can be seen from the graph in Fig. 4.1, setting always m = 12 but changing the value assigned as you will get the values that do not represent the situation of working considered.




| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| m=12, s=4 | 0 | 0 | 0 | 0,1 | 0,1 | 0,2 | 0,3 | 0,5 | 0,6 | 0,8 | 0,9 | 1 | 1 | 1 | 0,9 | 0,8 | 0,6 | 0,5 | 0,3 | 0,2 | 0,1 | 0,1 | 0 | 0 | 0 |
| m=12, s=6 | 0,1 | 0,2 | 0,2 | 0,3 | 0,4 | 0,5 | 0,6 | 0,7 | 0,8 | 0,9 | 0,9 | 1 | 1 | 1 | 0,9 | 0,9 | 0,8 | 0,7 | 0,6 | 0,5 | 0,4 | 0,3 | 0,2 | 0,2 | 0,1 |
| m=12, s=2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0,1 | 0,3 | 0,6 | 0,9 | 1 | 0,9 | 0,6 | 0,3 | 0,1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

figure 4.1 : gaussian membership functions

In relation to the sigmoid function, it was decided to set the respective parameters, the center (c) and steepness factor (t), so it is executed a careful evaluation in the moment in which the heat consumption present a value above a certain threshold . Therefore, it is placed c = 6.5, to highlight that in correspondence with this value will start to have an high thermal consumption, and t = 2.5 to define a degree of steepness as to obtain the correct increment value of the function to a relatively greater heat consumption. Fig. 4.2 illustrates the situation just described, highlighting the differences produced by different settings of t.

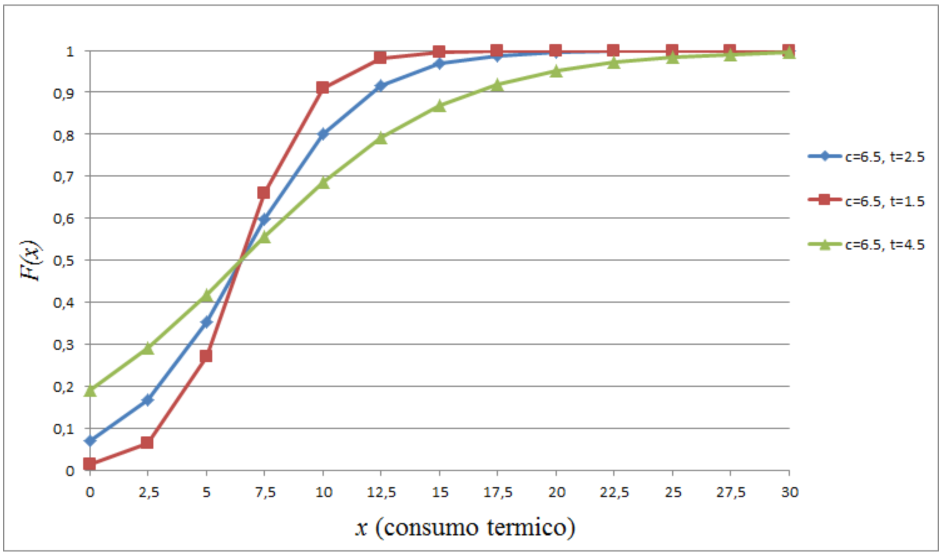



figure 4.2 : sigmoidal membership functions

Once the calibration step has been carried out, it was decided to run a simulation of the diagnostic rule, in order to assess the relative anomalies. Obtained the latter, for each specific building was carried out an analysis of the data as a function of:

- number of events per severity;
- number of events per time slot;
- number of anomalies subdivided by calendar month;
- value anomalies over a chosen time horizon.

The first two methods of observation are in reality in relation to what allow us to have a better clarity of the results obtained.

Before describing the findings, it is necessary to point out that:

- for the first type of analysis there were identified three bands of gravity: the first comprises values between 0.5 and 0.7, the second between 0.7 and 0.8 and finally the third includes values between 0.8 and 1;
- for the second analysis time bands of 4 hours have been chosen;
- Finally, the third type of investigation were considered the months of December 2014, January, February and March 2015.

First it was examined the building F40. As can be seen from the graphs shown in Fig. 4.3, 4.4 and 4.5, there is, first of all, a high number of anomalies in correspondence with a gravity index of between 0.8 and 1, such as to indicate a significant heat consumption due to the malfunction of the timer place in the central heat adjoining building. Another element that reinforces what we just said, appears to be the presence of major anomalies outside working hours, from which it emerges that the supply of heat is higher than it actually should be.

From this result it follows that the malfunction of the clock which regulates the switching on and off of the heating plant produces an important energy inefficiency, which can lead to negative consequences especially relevant in terms of management costs to be incurred.

Then analyzing the F40 based on the number of events per month, it is observed how there is a higher number of anomalies in the month of January, hypothetically due to winter temperatures lower that lead to a greater use of fancoils.

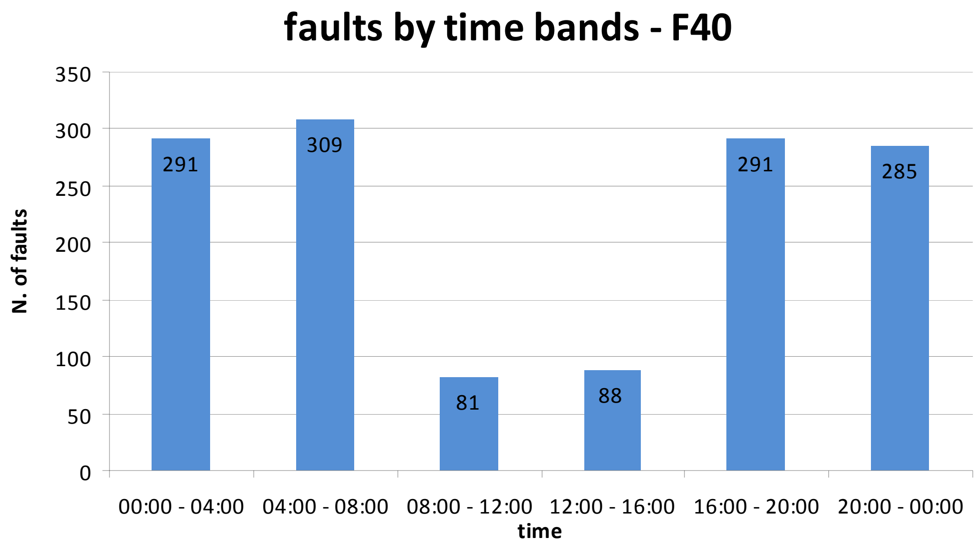



figure 4.3 : faults stats

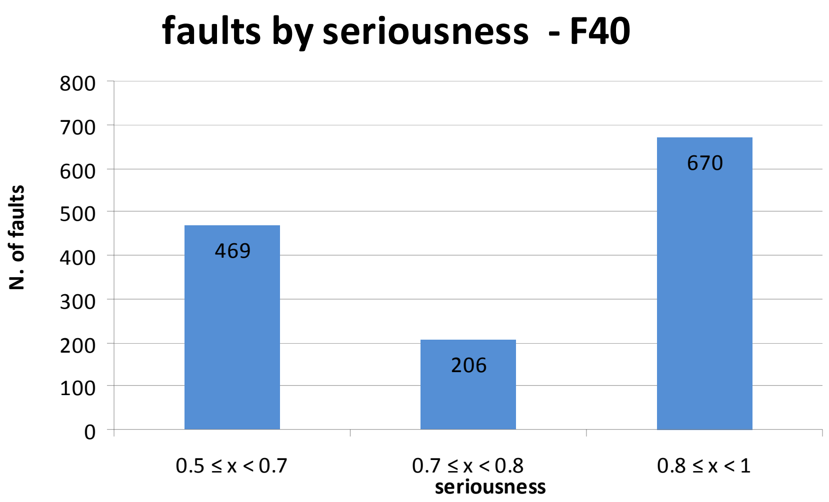



figure 4.4 : faults stats

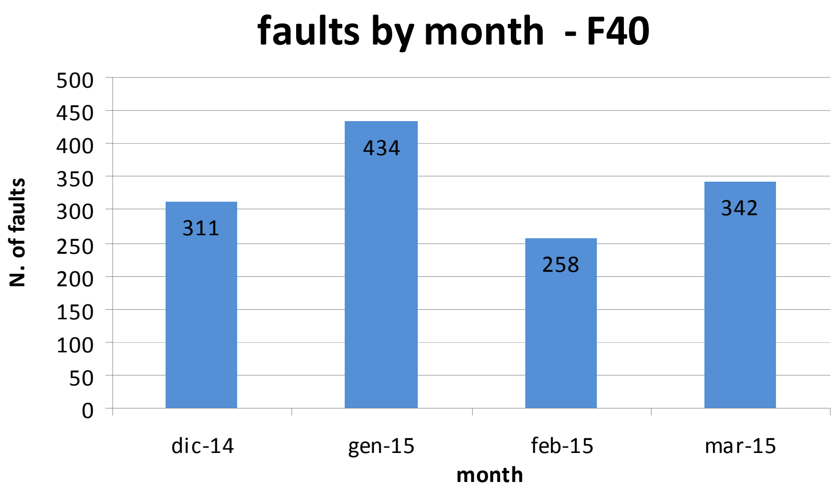



figure 4.5 : faults stats

As regards the analysis of the cluster of buildings and the thermal power plant annexed, it identifies the same pattern observed for the building F40. In fact, even if the thermal power plant is not the same, it still has a high number of anomalies with high degree of importance, to even more stress as one of the most significant causes, the origin of a thermal behavior atypical, it is precisely the prong thermostat. In Fig. 4.7 it is observed that the time slots in which are found several faults are always those outside of working hours, indicating a high thermal consumption that should not be present. It is clear, moreover, as the failure of the timer in the boiler obviously has an impact on the building energy behaviour connected to it, thus generating anomalies in cascade. From this situation it can be stated that, although the latter is a malfunction, it is consistent with the operation and the distribution of the system for the supply of thermal energy.

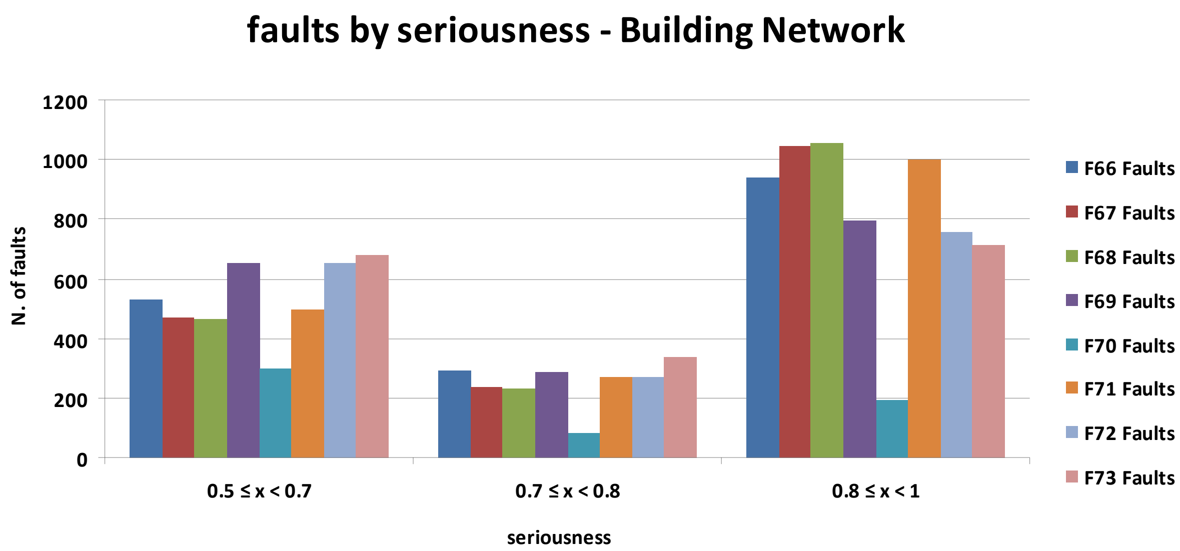



figure 4.6 : faults stats

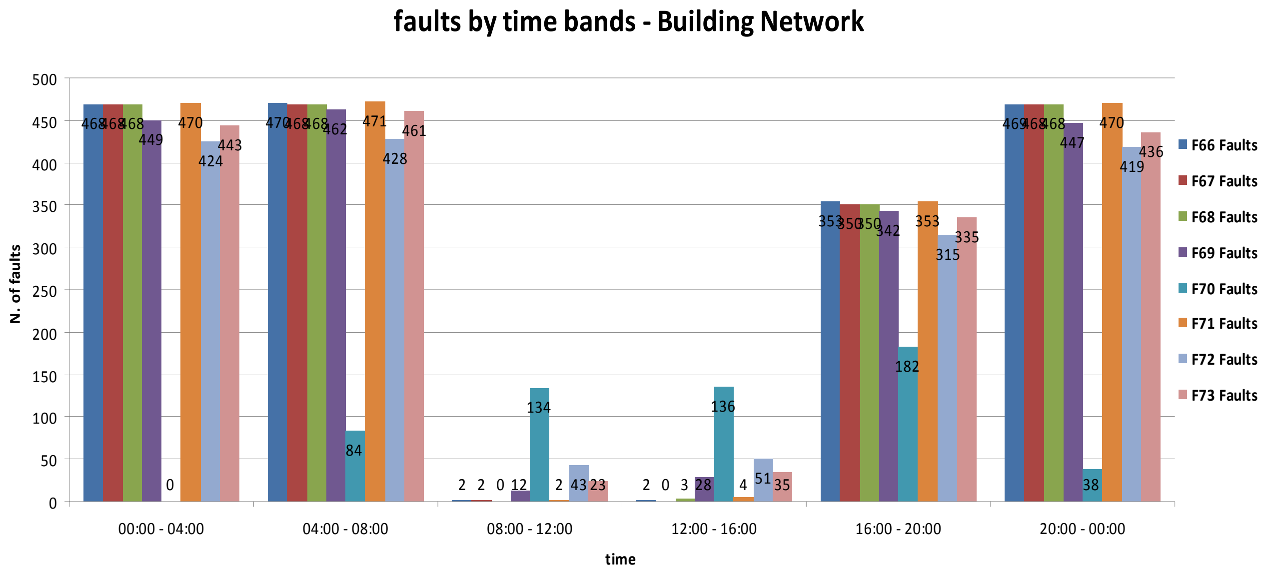
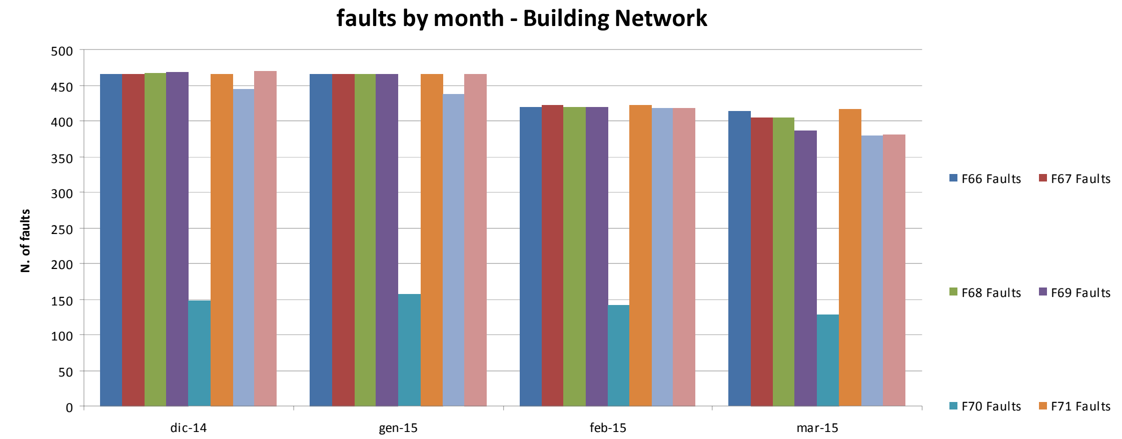



figure 4.7 : faults stats




| | dic-14 | gen-15 | feb-15 | mar-15 |
|---|---|---|---|---|
| F66 Faults | 466 | 465 | 420 | 413 |
| F67 Faults | 465 | 465 | 422 | 404 |
| F68 Faults | 467 | 465 | 420 | 405 |
| F69 Faults | 469 | 466 | 419 | 386 |
| F70 Faults | 148 | 156 | 142 | 128 |
| F71 Faults | 466 | 465 | 423 | 416 |
| F72 Faults | 445 | 438 | 418 | 379 |
| F73 Faults | 470 | 465 | 418 | 380 |

Mese

figure 4.8 : faults stats

One aspect to be highlighted of some relevance concerns the anomalies found in the building F70. By comparing the performance of the latter with respect to other buildings in the cluster, it can be noted, in any type of analysis, it is different. This is mainly due to an incorrect calibration of the sensors to the data of thermal consumption, which generates values of anomalies that are not in line with the actual behavior of the building.

### 4.2.2 Improper heat management

This indicator is aimed ato identifying the correct management of the system and is thus also dependent on the occupation of the building.

This anomaly is supported by two possible situations :

- S12 = HIGH thermal Consumption with LOW occupation
- S13 = LOW thermal Consumption with HIGH occupation

S12 is the situation when the control system provides heating when not needed (with no people inside the building), S13 is the opposite situation, when the control system does not provide heating when needed (with people inside the building).

The composition of these two provide evidence that the control system does not manage heat properly. The following table shows the fuzzy variables preprocessing used, evaluated through specific membership function. In detail:

- the percentage of employment, not as fuzzyficata already normalized;
- thermal consumption is expressed as sigmoid.

| Label | Meaning | MembershipFunction | Parameters |
|---|---|---|---|
| **P24c** | Occupation Percentage | % | / |
| **P11** | Hot thermal Consumption | $\frac{1}{1+e^{\left(-\frac{(x-c)}{t}\right)}}$ | c = 6.5<br>t = 2.5 |

table 4.9 : preprocessing fuzzy sets

Once defined the preprocessing features, there have been identified the situations linked to them :

- *HIGH thermal Consumption with LOW occupation:*

S12 = ¬P24c ∧ P11

- *LOW thermal Consumption with HIGH occupation :*

S13 = P24c ∧ ¬P11

And therefore the resulting cause as the OR of the two situations.:

C31 = S12 ∨ S13

The implementation of the rule, in the Java language, has been realized, also in this case, considering all the buildings of the Smart Village in which to apply such a cause, the F40 and the cluster (F66, F67, F68, F69, F70, F71, F72, F73).

Subsequent to this evaluation it was decided to identify, in the database the SCADA identifiers for winter thermal energy for each building studied.

For the calibration of the sigmoid function of the diagnostic rule were given the same assessment made for the tuning parameters of the previous rule, thus placing c = 6.5 and t = 2.5

The analysis of the results is based on the same principles used in the previous rule.

Starting from the building F40, (fig. 4.9 and 4.10) a substantial increase in the number of defects with high severity and those included in the working time slot 8: 00-16: 00. This situation appears to be a direct consequence of poor management of heat distribution that does not consider optimally the correlation between the heat consumption and the percentage of occupancy. In this way there are the conditions in which the supply of more or less energy does not conform to the proper number of people present, thus giving rise to situations of significant energy waste.

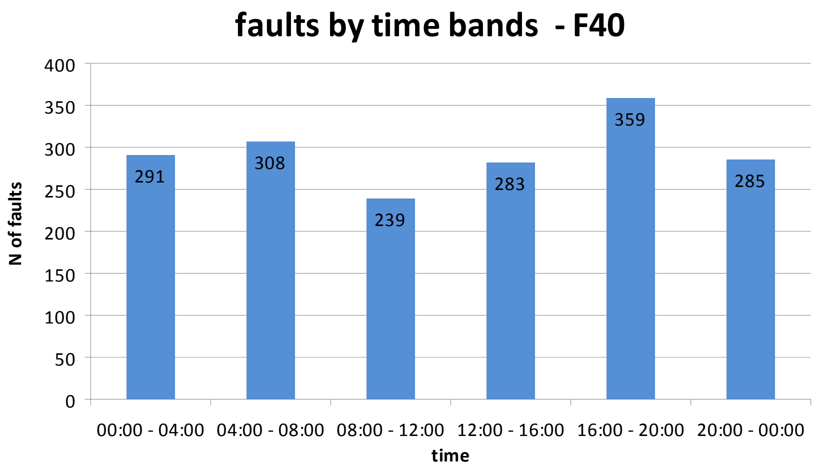



figure 4.9 : faults stats

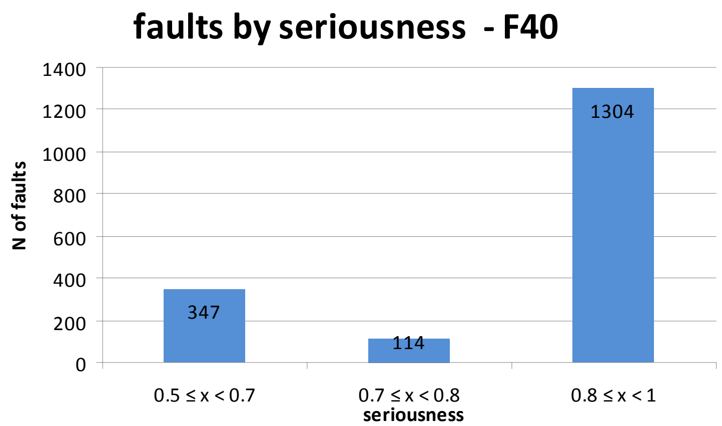



figure 4.10 : faults stats

In Fig. 4.12 it is possible to observe the breakdown of abnormalities per month. Taking account of what just explained, it can be obviously noted, also in this case, an increase in the number of malfunctions reported in the months of January, February and March, in contrast to the month of December where there is a decrease.

The study of data generated by the diagnostics of the building network deduced that:

- the sensors of the building F70, also in this case, generate incorrect data on the heat consumption. This highlights a further problem so that other structural diagnosis system in relation to the building aforesaid;
- observing the analysis of the anomalies by gravity, it presents the same situation as F40 building, ie an increase of the anomalies with index of importance between 0.8 and 1, as shown in fig. 4.11;

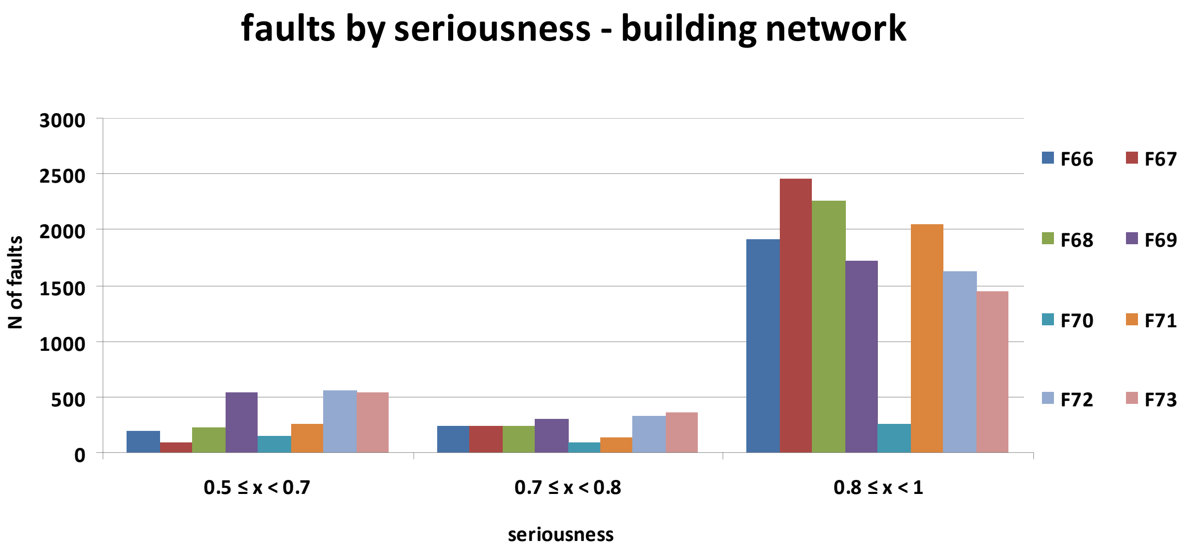



figure 4.11 : faults stats

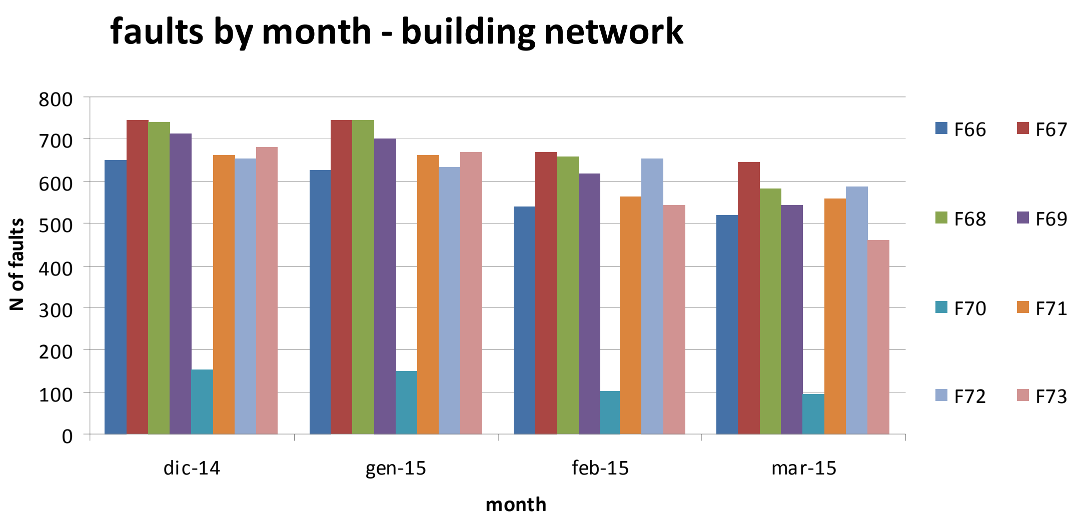



figure 4.12 : faults stats

Splitting the anomalies by hour, figure 4.13 shows a behavior of the buildings that differs mainly by time. In fact, while after the working hours there is an equivalent number of abnormalities per building, over a period of time between 8:00 and 16:00, each building has its own behavior due to the thermal consumption corresponding to the percentage of occupation.

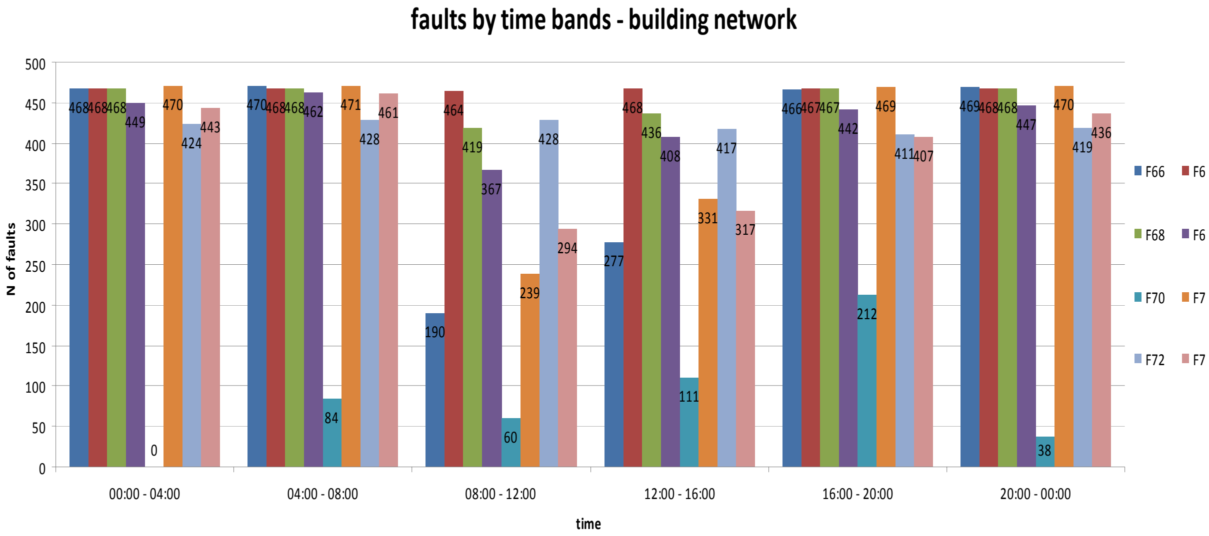



figure 4.13 : faults stats

In the monthly analysis, fig. 4.12, can be observed as the number of anomalies is higher in December and January, indicating a higher consumption of thermal energy, which is probably due to a drop in temperatures and also in consideration of a small percentage of staff attendance during the holiday period.

It is worth pointing out how the proper management of heat distribution can not be separated from the structure of the heating system. In this case, all the buildings in the cluster are connected to a single network of district heating and cooling starting from the power station and branches according to a distribution ring. From this configuration it can be assumed, in fact, that a part of the anomalies observed in buildings that are served last in the distribution network, are generated also by a loss of heat during the journey, which accordingly allows to have regular thermal consumption.

Lastly, in the following figures it is shown a comparison of the rules just described which might give rise to further indexes of higher level.

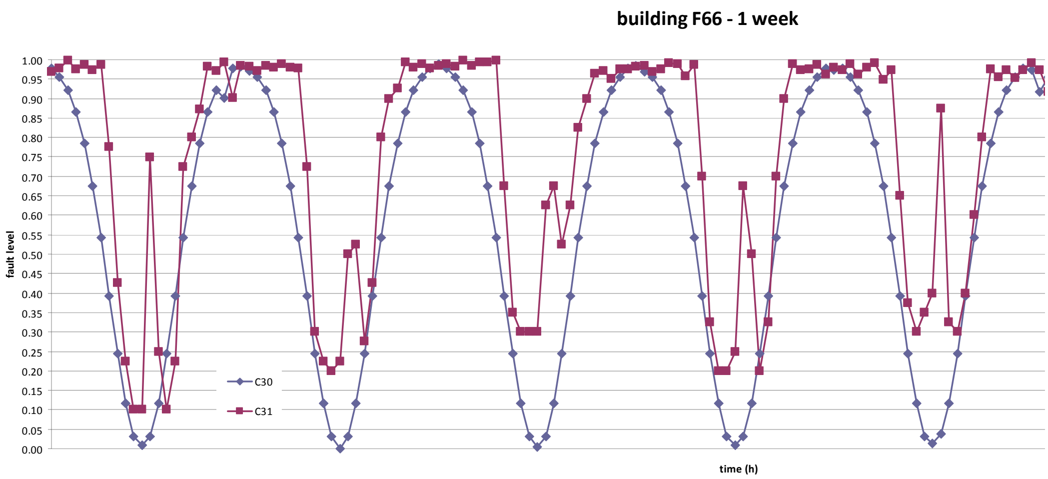



figure 4.14 : comparison of faults behaviour

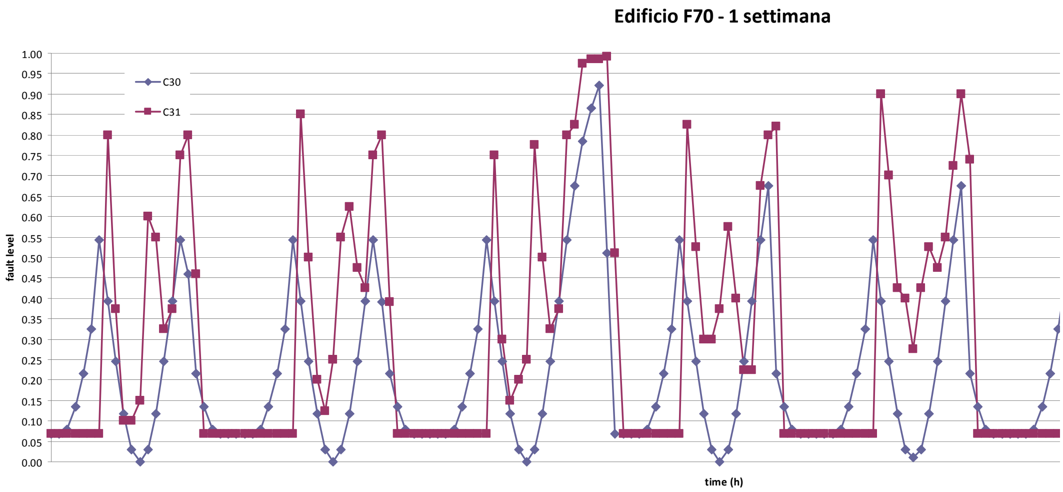



figure 4.15 : comparison of fault behaviour

### 4.2.3 Incorrect operation of the mixing valve in the boiler room

This indicator tries to identify a correct operation of the mixing valve of the fluid. To identify the anomaly there were considered the temperature difference, obtained by comparing the set-point set flow with the actual measured position, and the percentage of closure of the valve.

This anomaly is supported by two possible situations :

- S14 = the difference between the set point and the measured temperature is *little* and the valve is open
- S15 = the difference between the set point and the measured temperature is *high* and the valve is closed

The composition of these two provide evidence that the mixing valve does not work properly.

In the following table there are shown the fuzzy variables used as preprocessing, evaluated through specific membership function. In detail:

- the temperature difference is expressed by sigmoid;
- the percentage of closure of the valve, not fuzzyfied as already normalized.

| Label | Mean ing | MembershipFunction | Parameters |
|---|---|---|---|
| **P13** | Difference between the set point and the measured temperature | $\frac{1}{1+e^{\left(-\frac{(x-c)}{t}\right)}}$ | c = 2<br>t = 1.5 |
| **P14** | Valve closing percentage | % | / |

table 4.10 : preprocessing fuzzy sets

Once defined the preprocessing, there have identified the situations related to them:

The valve does not mix (based on the percentage value of opening detected) when the difference between the flow temperature and the set-point is less than a benchmark value :

$S14 = \neg P13 \wedge \neg P14 = \neg(P13 \vee P14)$

The valve mixture (based on the percentage value of opening detected) when the difference between the flow temperature and the set-point is higher than a benchmark value:

$S15 = P13 \wedge P14$

The cause is merged as the logic OR of the two situations:

$C32 = S14 \vee S15$

The calibration step is performed in order to determine the value of the benchmark in correspondence of which can be defined as an abnormal event. In the present case, it is sought to determine what would be the temperature difference between the supplying and the measured, beyond which identifies a heat consumption atypical, which will then be put in relation to the percentage of closing of the mixing valve .

The parameters chosen to define the sigmoid function are $c = 2$, to indicate that the difference threshold temperature below which it is still in a state of regular consumption, and $t = 1.5$ to represent the right degree of steepness of the curve.

For this indicator, it was not possible to carry out the experimentation because the physical system in which is inserted the mixing valve was out of order. For this reason it was not possible to make any analysis of diagnosis for energy efficiency and it has given only the theoretical definition.

### 4.2.4 Malfunction of the room thermostat in summer

That malfunction is identified when, for a given area of the building, it is detected that one or more rooms of the zone has an internal temperature higher than the set-point value. The temperature difference is obtained by comparing the set-point of the room with the actual measured temperature.

This anomaly is supported by two possible situations :

- S16 = A room of a thermal zone has an internal temperature higher than the set-point value
- S17 = Some rooms of a thermal zone have an internal temperature higher than the set-point value

S16 and S17 provide evidence that some room thermostats do not work properly because the difference between the set point and the actual indoor temperature is *too high*.

The following table shows the fuzzy preprocessing variables used, evaluated through specific membership function. In detail: the temperature difference is expressed by a Gaussian function.

| Label | Meaning | MembershipFunction | Parameters |
| --- | --- | --- | --- |
| **P15_1, P15_2... P15_n** | Difference between the set point and the actual temperature | $1 - e^{\left(\frac{-(x-m)^2}{2s^2}\right)}$ | m = 0<br>s = 1 |

table 4.11 : preprocessing fuzzy sets

The situation with regard to such preprocessing is:

- A room of a thermal zone has an internal temperature higher than the set-point value:

S16 = (P15_1 ∧ ¬P15_2 ∧ … ∧ ¬P15_n) ∨ (P15_2 ∧ ¬P15_1 ∧ … ∧ ¬P15_n)

∨ … ∨ (P15_n ∧ ¬P15_1 ∧ … ∧ ¬P15_(n-1))

- More rooms of a thermal area have an indoor temperature higher than the set-point:

S17 = (P15_1 ∨ P15_2 ∨ … ∨ P15_n)

And the resulting cause is thus

C33 = S16 · (1 – α) + S17 · α

with α = 0.7

The implementation of the rule, in Java language, has been realized considering the buildings of the Smart Village in which to apply such a cause, the building F40 and the subsequent mapping in 15 areas of the same building as shown in the figure.

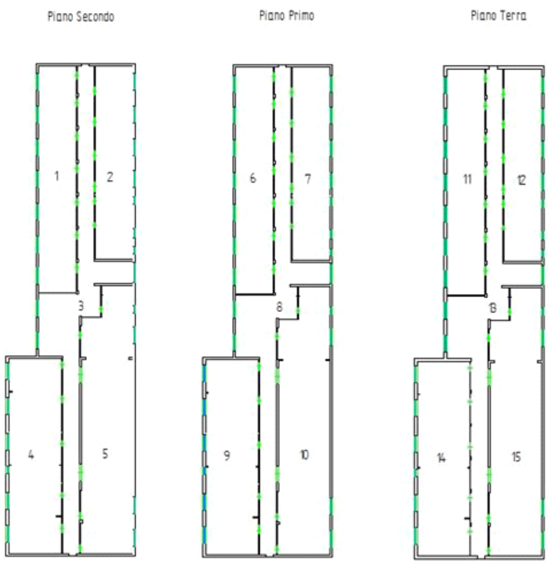



Figure 4.16 : F40 building areas

The Gaussian function of the related fuzzy set has been calibrated in order to determine which is the difference of the equivalent temperature of the room such as to indicate a malfunction of the thermostat. For this reason it was decided to set the mean m = 0, to represent the temperature difference nothing, and the standard deviation s = 1, to indicate that it is sufficient a small positive change in the measured temperature with respect to that set -point to determine a failue.

The analysis and experimentation was based not only on observation of the total number of anomalies found in the building F40, but also on the study of failures or malfunctions, according to the floors and the areas in which they occurred . In addition, the reference period used for the simulation includes the months of June and July 2015 since it is a diagnostics rule related to summer.

The following figures describe a general situation of the anomalies detected in relation malfunction of the room thermostat in the summer.

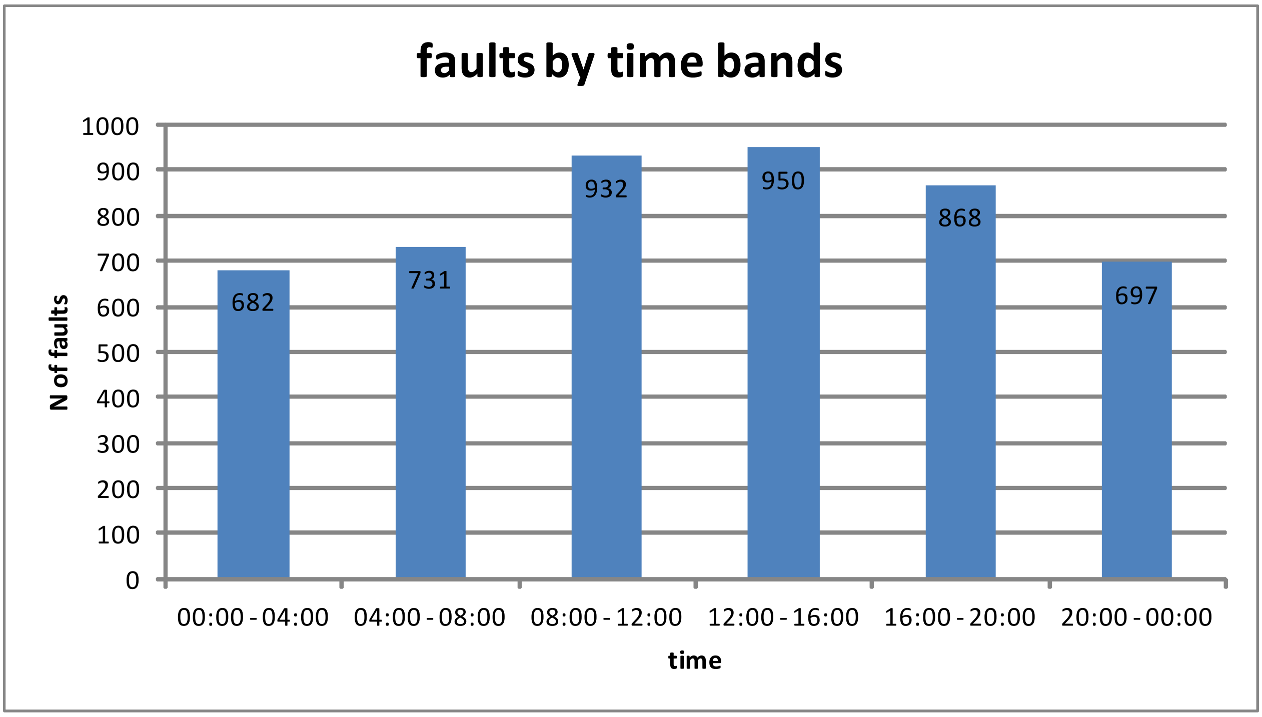



Figure 4.17 : faults stats

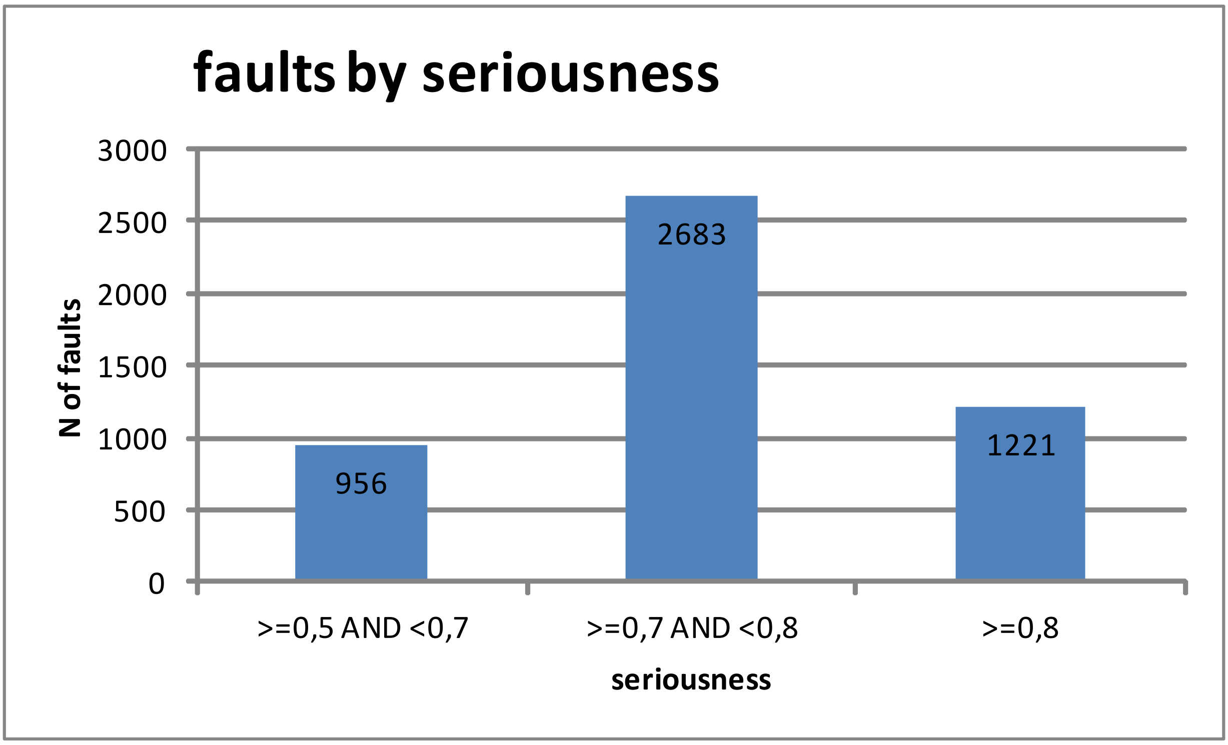



Figure 4.18 : faults stats

As regards the analysis relating to the index of seriousness, it is deduced that there are serious defects, ie there are few cases of the zones where the temperature of one or more room exceeds the preset value. This consideration, however, can certainly not make negligible the presence of more than 5000 anomalies of average seriousness, which do show a considerable malfunction of some thermostats.

Considering the analysis of the anomalies to time slots one can observe a trend which first increases and then decreases throughout the day, with significant peaks during working hours. This is a direct result of the malfunction of the thermostat, but linked also to other environmental factors such as sunlight through windows and terraces, the presence of staff, etc..

As mentioned earlier, it was decided, as a result, to perform a study on the number of anomalies detected by floor with their zones. In the following figures it is possible to see that the trend of anomalies mirrors the general dell'F40 for all floors.

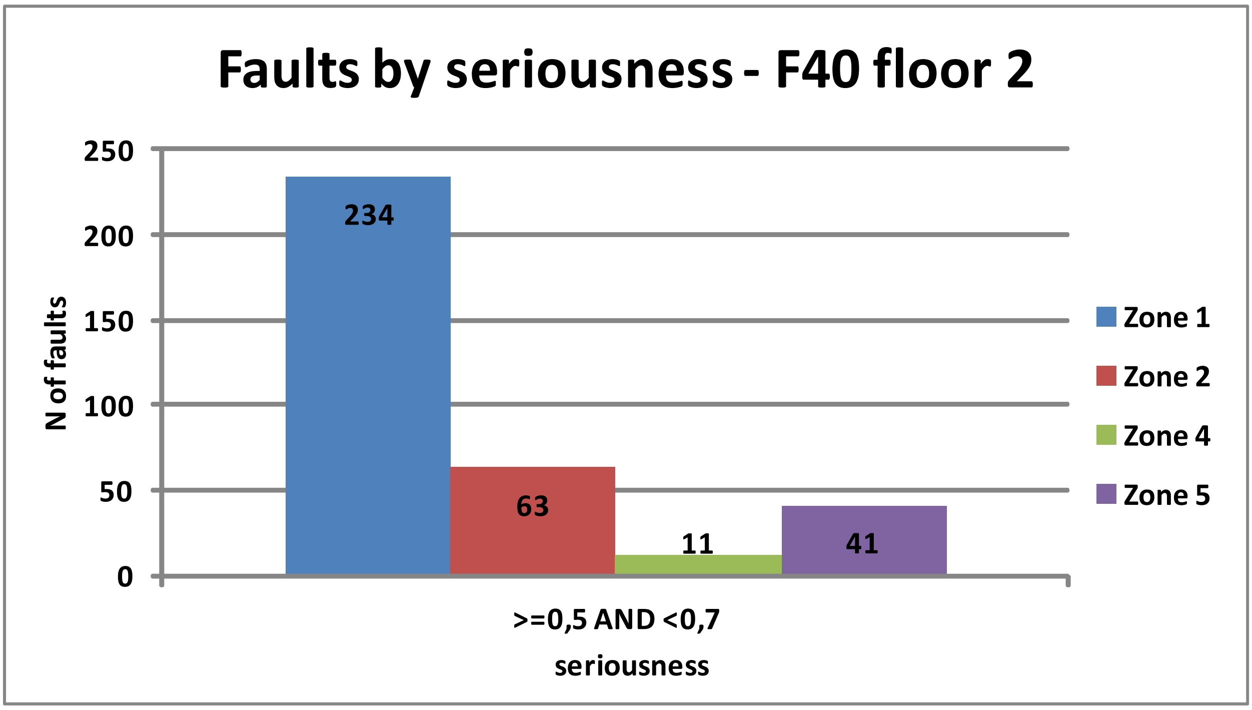



Figure 4.18 : faults stats

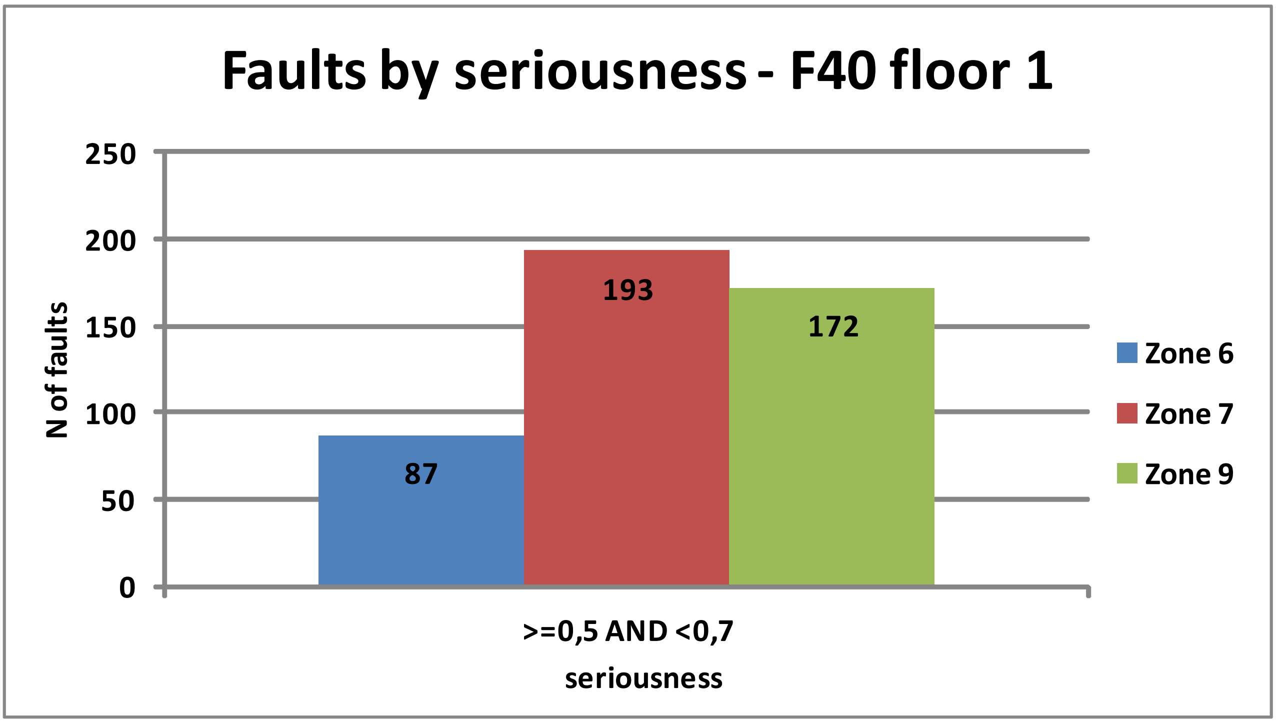



Figure 4.19 : faults stats

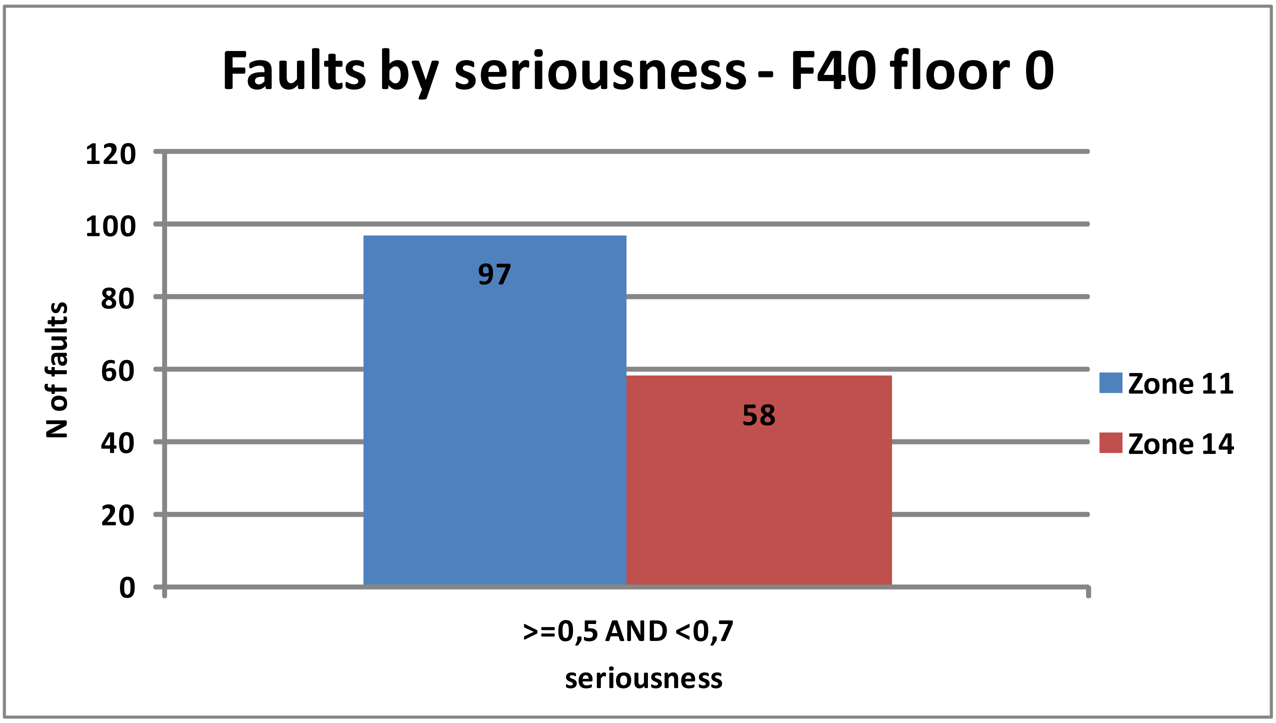



Figure 4.20 : faults stats

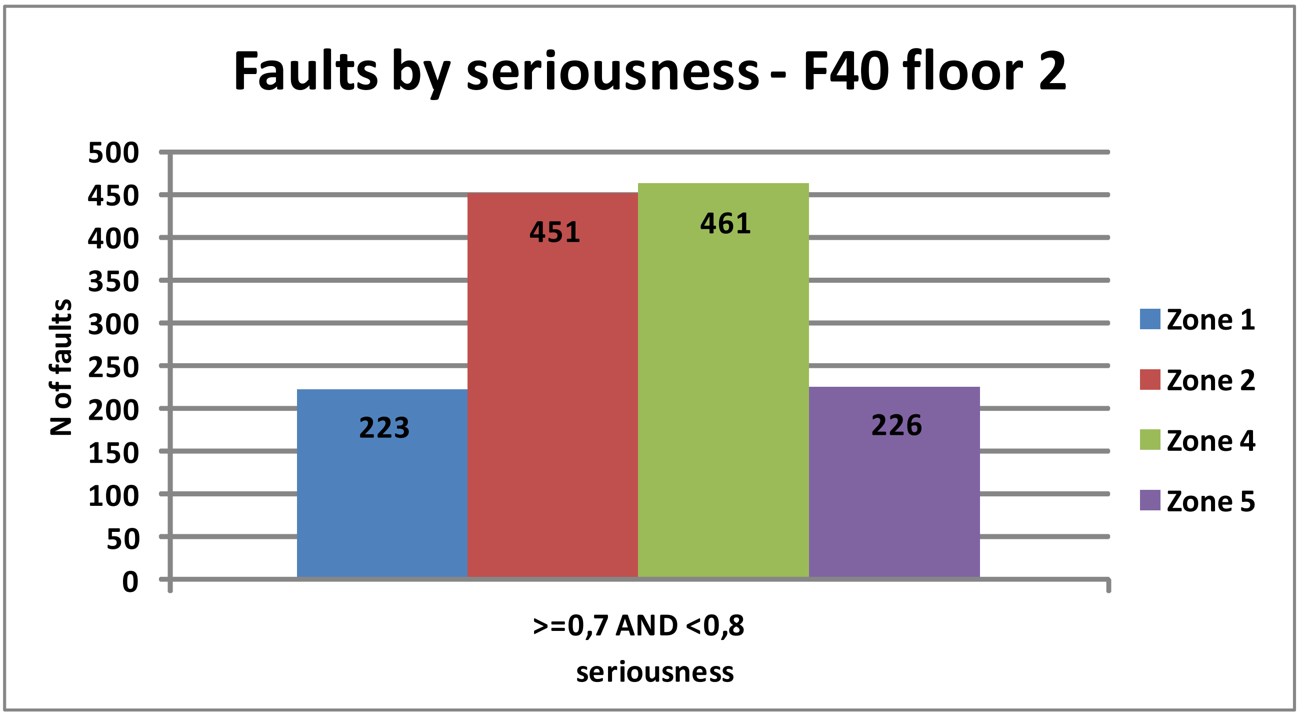



Figure 4.21 : faults stats

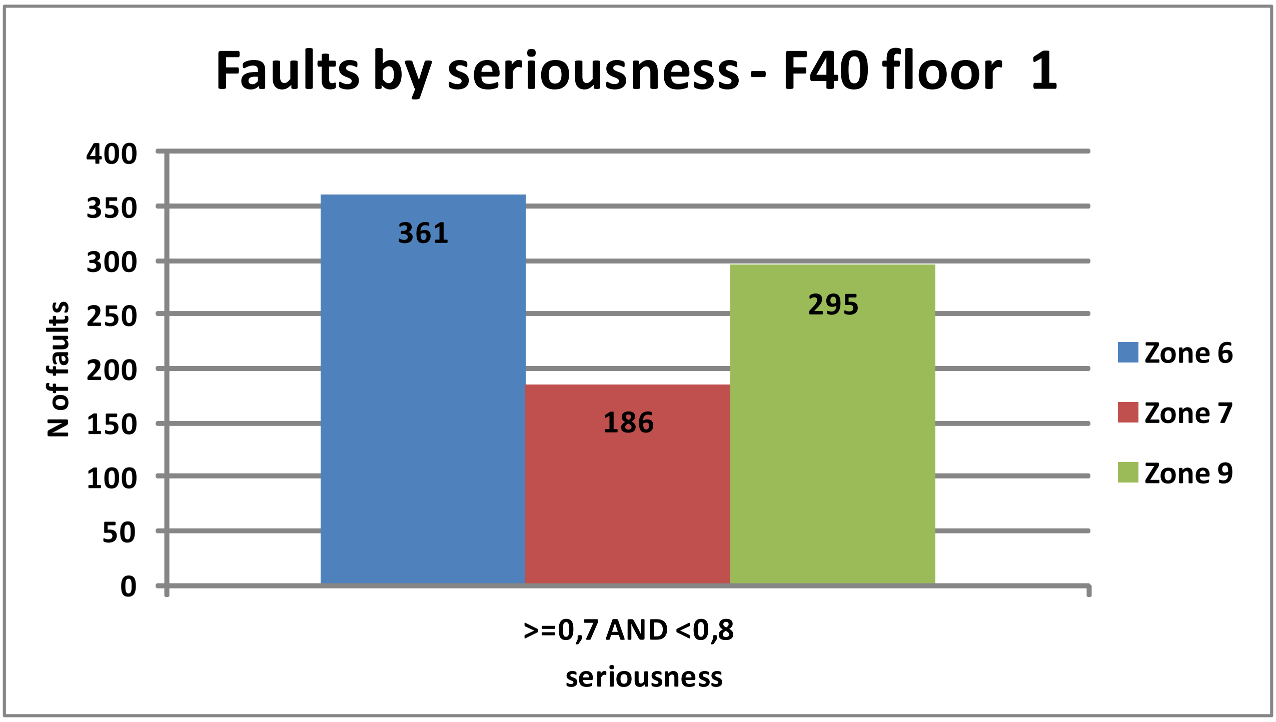



Figure 4.22 : faults stats

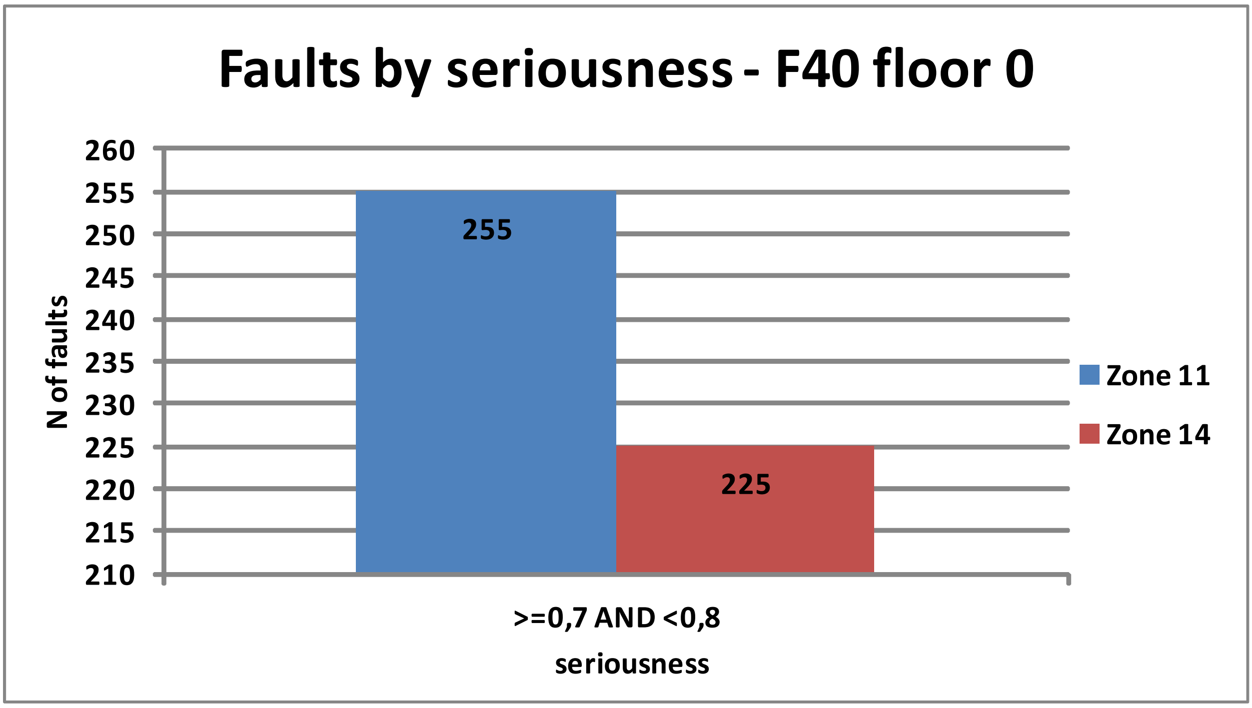



Figure 4.23 : faults stats

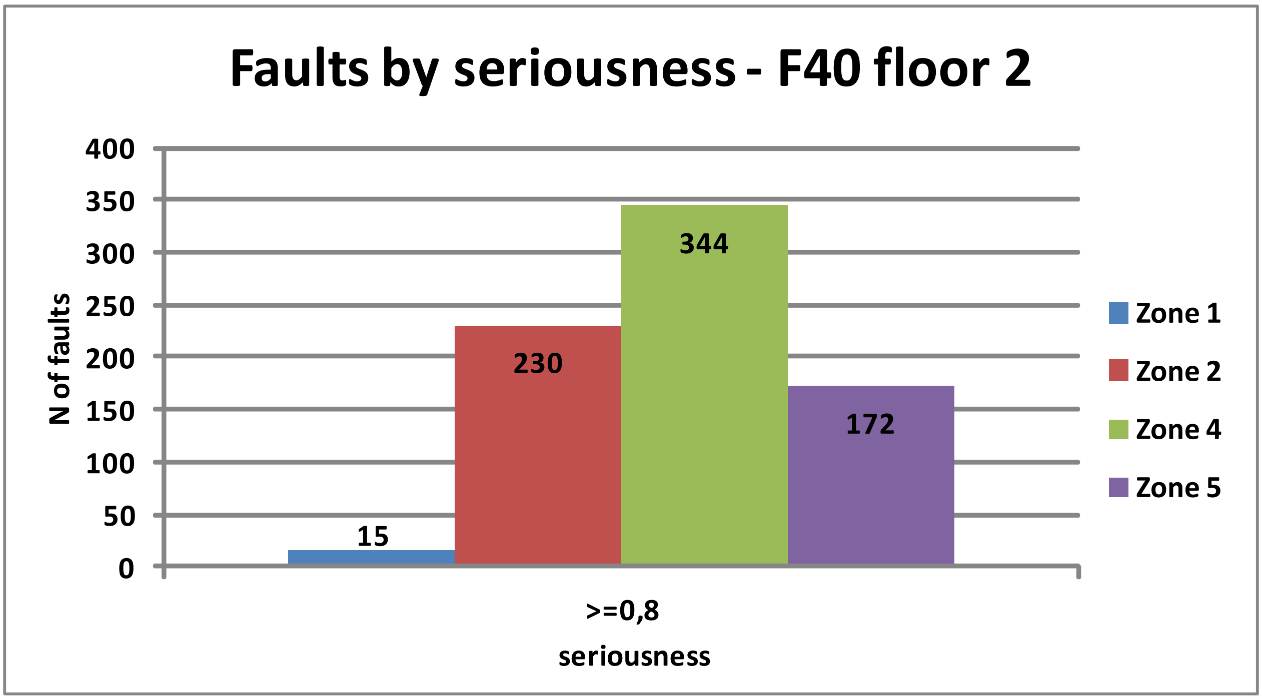



Figure 4.24 : faults stats

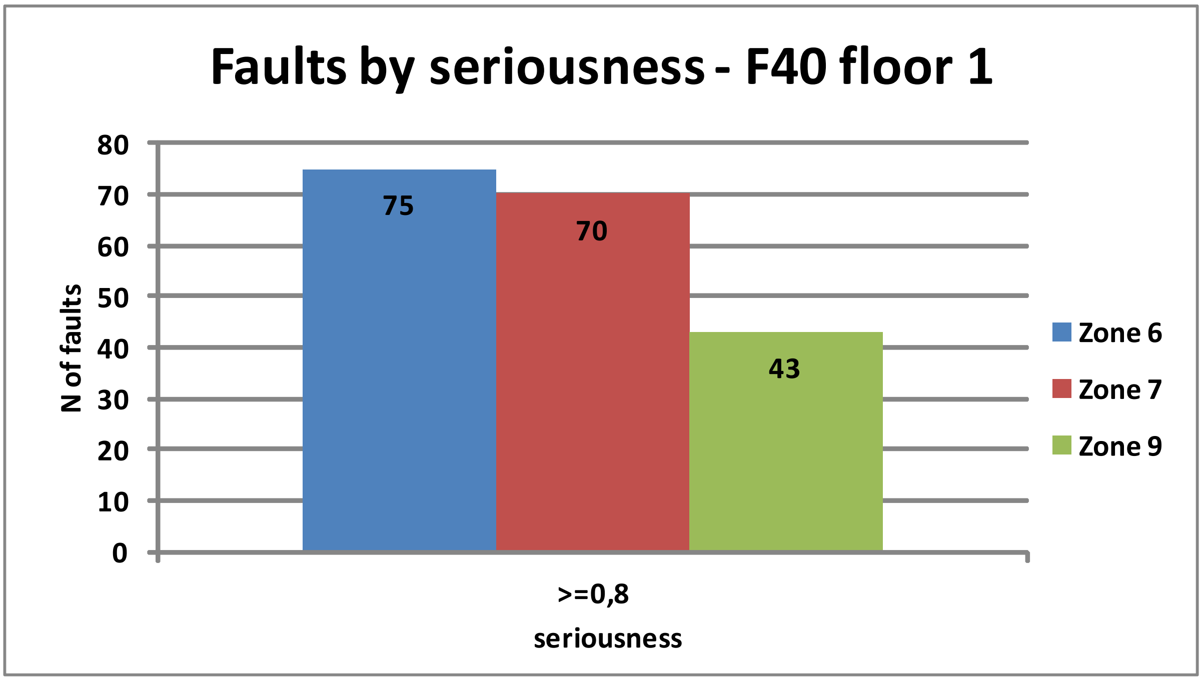



Figure 4.25 : faults stats

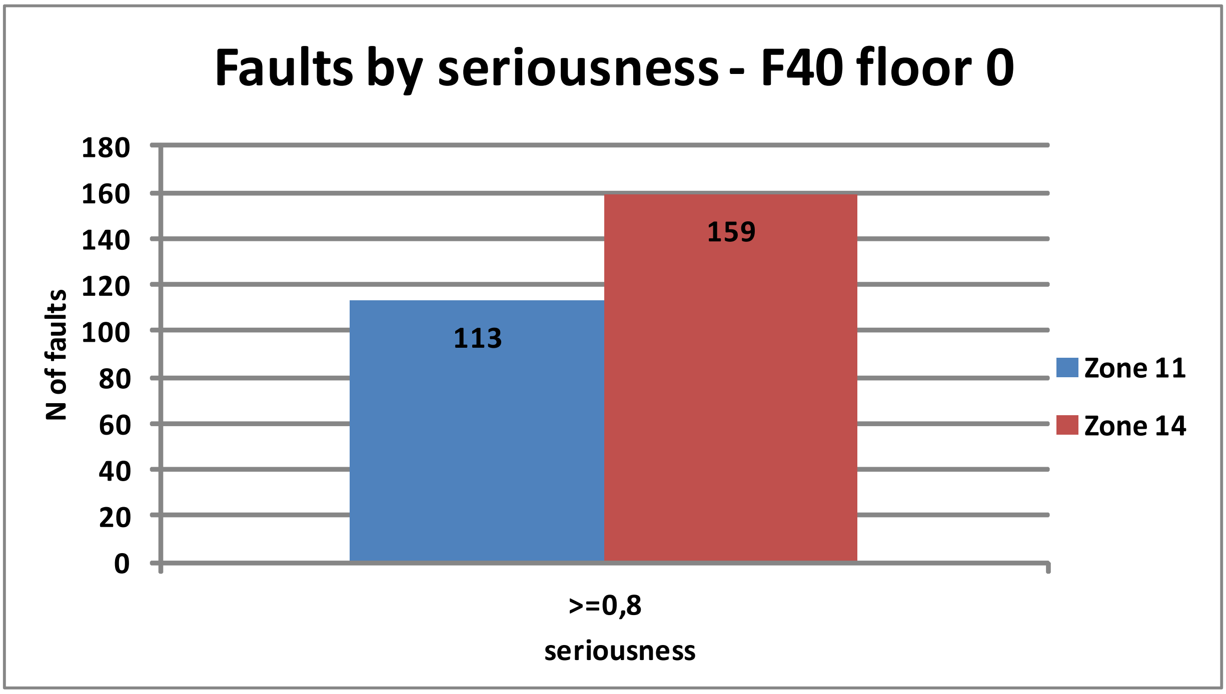



Figure 4.26 : faults stats

By analyzing the thermal behavior in reference to the time slot, we see that the floors 0 and 1 will have a generation of abnormalities equivalent and typically during working hours to all areas that are part of it. Instead, such a situation is very different on the second floor as in zones 2 and 4 do not appear any difference in the whole day, the number of faults appears to be nearly always the same and does not depend in any way the working hours.

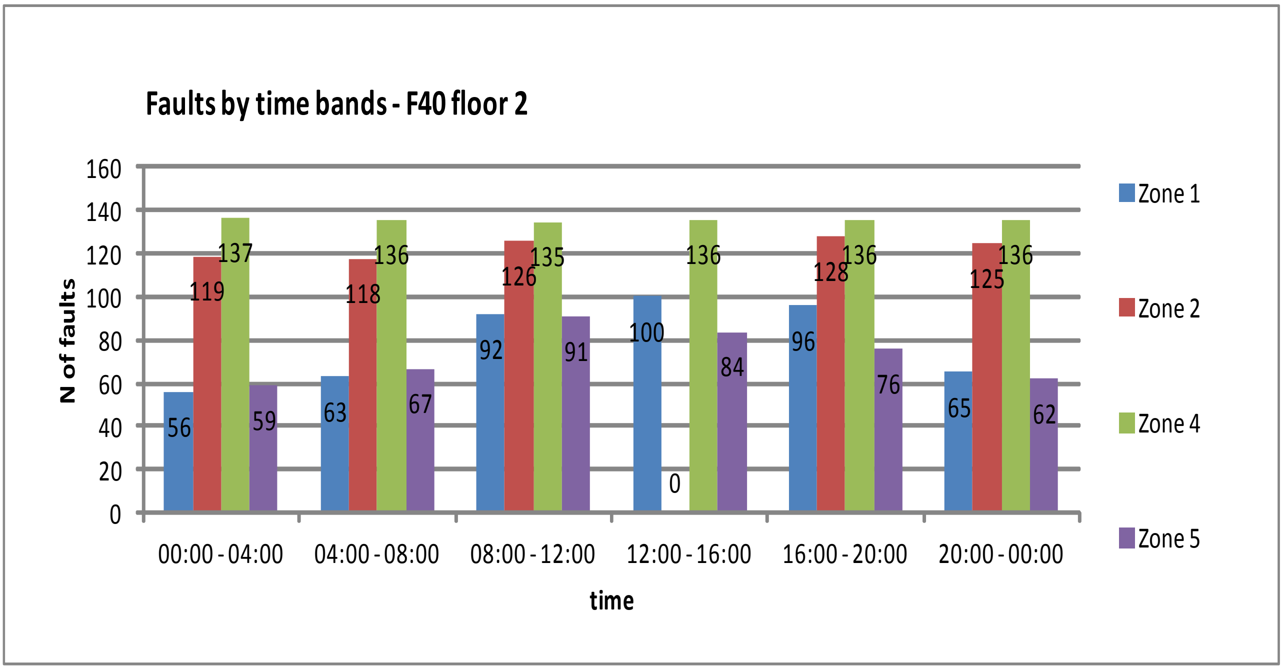



Figure 4.27 : faults stats

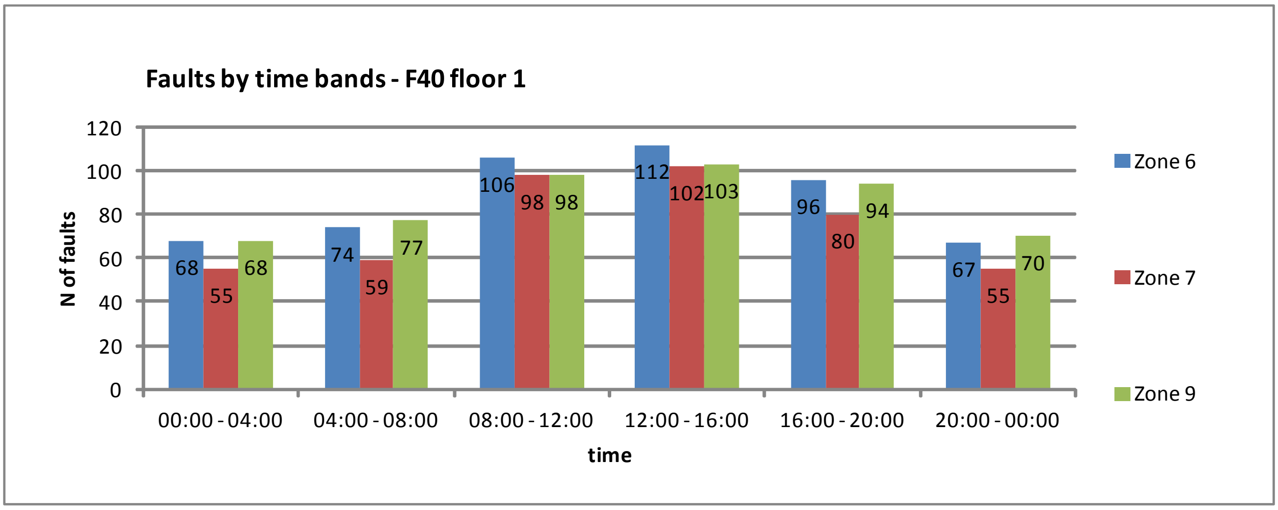



Figure 4.28 : faults stats

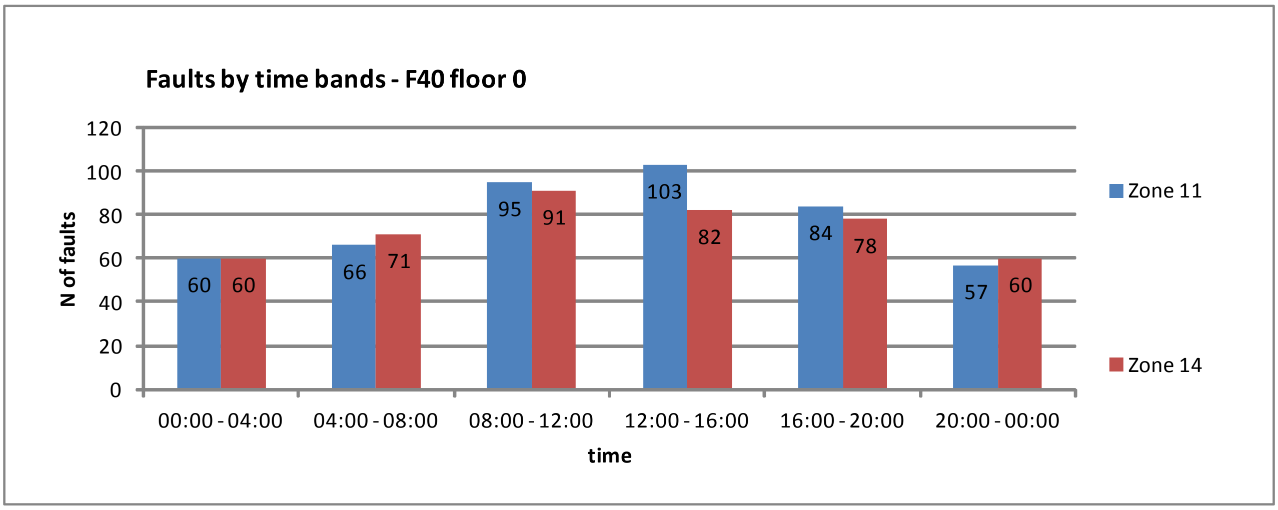



Figure 4.29 : faults stats

### 4.2.5 Defect distribution system

That failure happens if, for a given area, it is noted that in all the rooms there is a temperature higher than the set-point value. The temperature difference is obtained by comparing the set-point of the room with the actual measured temperature.

This anomaly is supported by one possible situation :

- S18 = All rooms of a thermal zone have an internal temperature higher than the set-point value

S18 provide evidence that because the difference between the set point and the actual indoor temperature is *too high* and this is unlikely that it is because all the room thermostats do not work properly, it is much more likely that there is some problem in the distribution system (ex. pipes obstructed) which prevents the fluid form reaching the area.

The table below shows the fuzzy preprocessing variables used, evaluated through specific membership function. In detail: the temperature difference is expressed by a Gaussian function.

| Label | Meaning | MembershipFunction | Parametri |
| --- | --- | --- | --- |
| **P15_1, P15_2... P15_n** | Difference between the set point and the actual temperature | $1 - e^{\left(\frac{-(x-m)^2}{2s^2}\right)}$ | m = 0<br>s = 1 |

table 4.11 : preprocessing fuzzy sets

The situation with regard to such preprocessing is:

- All the rooms in a zone have a temperature higher than the set-point value:

S18 = (P15_1 ∧ P15_2 ∧ … ∧ P15_n)

And the resulting cause is just

C34 = S18

The implementation of the rule, in Java language, has been realized considering the buildings of the Smart Village in which to apply such a cause, the building F40 and the subsequent mapping in 15 areas of the same building as for the previous diagnostics rule.

The Gaussian function of the related fuzzy set has been calibrated as for the previous diagnostics rule as well. The analysis of the data has revealed the following results.

As regards the general F40 analysis, it was found a significant increase in anomalies with gravity higher than the 0.8, that suggests a serious malfunction of the cooling system. This pattern can be found in the study released on timing, following the classic pattern noted for the previous diagnostic rule, but it has a number of atypical behaviour even higher outside working hours.

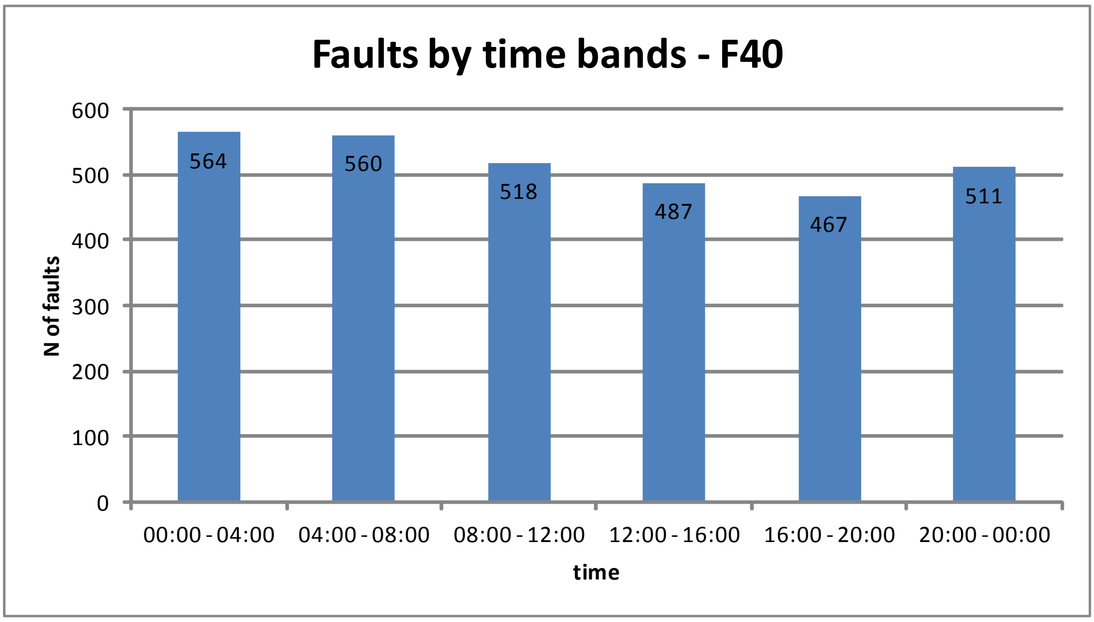



Figure 4.30 : faults stats

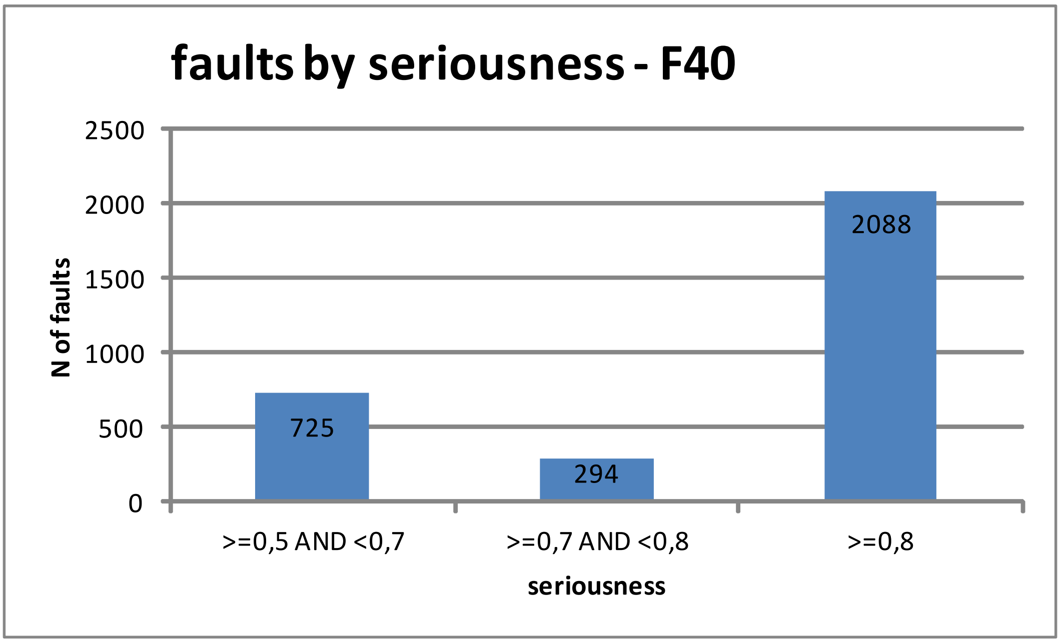



Figure 4.31 : faults stats

By analyzing in detail the anomaly detection based on the floor breakdown and related heat zones it was observed how this condition reflects the general course of the building, presenting a high number of very serious irregularities.

It is therefore possible to conclude that there is a succession of situation of malfunction of the cooling in all floors of the building, especially on the ground 0.

By examining the distribution of anomalies per time slot it is shown the floors 0 and 1 will have a similar pattern of related areas that does not take into account in any way of working time. Each time the system provides the same amount of energy, without following a precise logic. In the case of the second floor it is observed that the number of abnormalities increases and decreases in conjunction with the start and end of the workday only for zones 1, 2 and 4, while it shows a reverse behaviour only for the zone 5 which should not be.

In relation to the two last diagnostic rules it should be considered, moreover, that the temperature difference between measured and set by the system depends not only on thermal insulation but also on the installation of pipes made for cooling. In the specific case, in fact, it is necessary to observe that, as the F40 consists of three floors, it is evident that the ground floor has a real temperature closer to that of the set-point. This can be explained considering that the cold fluid, on its way to the upper floors, will have an increase, though slight, of its temperature which will generate a temperature difference of course not in line with that present in the other floors.

## *4.3 Final remarks*

In this chapter it has been proposed a methodology for the detection of thermal energy faults through indicators based on fuzzy sets. This approach has been applied to a set of building sharing the same thermal network and the results have given evidence of several poor operations in the energy management.

The final goal of this work is indeed to improve the performance of the thermal energy system in order to get energy and financial savings. The evaluation of this impact is actually not a trivial task because it depends on a large number of variables and boundary conditions and thus it requires the analysis of the data produced after some time by the diagnostic system compared to the situation before its operation. This is at present a still ongoing activity and therefore it is not possible to provide reliable results.

At this stage, only some considerations can be done.

For instance, the malfunction of the central heating timer has as consequence that, if it never gives the off command then thermal power is alwais produced and distributed in the building with a very high waste of energy. As example, in a working building which is in operation 12 hours a day, if the timer does not work (and this is not detected) then gas consumption can actually be the double of what is needed and also the electricity consumption for the pumps.

Also the incorrect operation of the mixing valve can produce a waste of thermal energy, but this can be evaluated only with data.

Other faults affect mainly the users comfort therefore the impact to evaluate is more related to users satisfaction rather than financial. This is also matter of future developments.

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# Chapter 5. Smart Building Multi-Objective Optimization

The building sector is the largest user of energy and CO2 emitter in the European Union (EU) and is responsible for about 40% of the EU's total final energy consumption and CO2 emissions. As a consequence, the cornerstone of the European energy policy has an explicit orientation to the conservation and rational use of energy in buildings as the energy performance of building directive (EPBD) 2002/91/EC and its recast (EPBD) 2010/31/EU indicate [1][2].

The EPBD's main objective is to promote the cost-effective improvement of the overall energy performance of buildings. In Europe, member states have set an energy savings target of 20% by 2020 and 27% by 2030, mainly through energy efficiency measures. A number of methodologies for optimizing real-time performance, automated fault detection and isolation were developed in IEA-Annex 25 [3]. Moreover, amongst worldwide scale organizations, the International Organization for Standardization (ISO), the European Committee for Standardization (CEN) and the International Energy Agency (IEA) have complementary provided strategic and operational directions towards the implementation of energy efficiency improvements in buildings [4]. The "conventional" measures that can be employed to improve energy performance in buildings can be classified in those that immediately relate to the building envelope i.e., the constructional elements, and those that relate to the operation of energy systems used for heating, cooling, ventilation, hot water supply, etc. [5][6]. Apart from "conventional" type measures, energy management techniques combined with innovative environmental technologies and advanced materials and systems may, if properly applied, affect drastically the process of saving energy in the building sector so as in other sectors [7-9]. A critical aspect in the design but also in the operational phase of a building, when renovation or retrofit actions are needed, is the evaluation and adjustment of the alternative measures based on a set of criteria such as energy consumption, environmental performance, investment cost, operational cost, indoor environment quality, security, social factors, etc. [5]. In some cases, the aforementioned criteria are competitive by themselves or interrelate in a non-linear way, making the problem of reaching a globally optimal solution generally infeasible; researching for such optimal solution is usually attempted via two main approaches. According to the former, an energy analysis of the building under study is carried out, and several alternative scenarios, predefined by a building expert, are developed and evaluated [10]. These specific scenarios, which may vary according to the features of the buildings, (type, use, climatic conditions,…), are pinpointed by the building experts and evaluated mainly through simulation [11-16]. The selection of the alternative scenarios, energy efficiency measures and actions is, thus, largely based on the building expert's experience. The second approach includes decision supporting techniques, such as multicriteria-based decision making methods and new approaches evolved combining simulation with notions and concepts originating from the scientific area of multi-objective optimization [17-20]. In the last area studies addressing optimization in building science mainly focus on the optimization of multi-scale systems ranging from the construction element [21], through the building envelope and HVAC systems [22-25], to building design [26][27]. In this scenario the proposed work deals with building efficient energy management through a decision support system based on Pareto front multi-objective optimization combined with simulation tools.

In this context, the goal and the main novelty of the work described in this chapter is to provide the day-ahead optimal thermal settings by keeping simultaneously into account energy consumption and occupant comfort.

## 5.1 Multi Objective Optimisation (MOOP)

Multi Objective Optimisation (MOOP) is a process aiming to optimise a set of objective functions, many applications have been carried on, due to the multi-objective nature of the majority of the problems we face everyday. The major difference between Single Objective Optimisation (SOOP) and MOOP is not, despite the evidence, just on the number of the objectives to be optimised, instead, it requires a substantially different approach. In MOOP the research space is multidimensional, depending on the objective functions number and the relationship between decision space and research space is often non-linear. Hence, it can be diffcult to map decision variables and research spaces. Furthermore, coping with a Multi Objective Problem (MOP) generally implies handling conflicting objectives, thus a trade-off between the objective is required.

There are two main approaches for coping MOOPs:

. • Preference-based approach

. • Ideal approach

The preference-based approach exploits previous knowledge of the problem, as preference order of the objectives, to weight the importance of each objective function, turning the MOP into a Single Objective Problem (SOP). This approach is strongly dependent on the weights and the impact they have on the outcome of the optimisation.

The ideal approach aims to find a set of solution and then, eventually, assign preferences. For this reason, it is crucial to find a wide range of different solutions. In fact a well distributed set of solutions in the research space give relevance to each objective function. Figure 5.1 shows an example of non uniform distribution: in this case the relevance of the first objective function is very low.

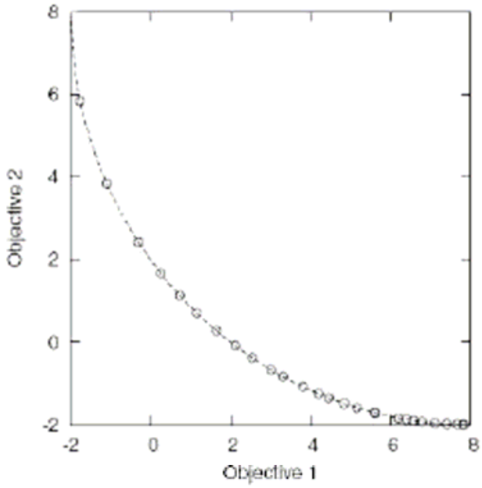



Figure 5.1 : non-uniform distribution of solutions

Equation 5.1

$$\begin{cases} Min/Max & f_m(x) & m = 1, 2, ..., M \\ subject \quad to & g_j(x) \geq 0 & j = 1, 2, ..., J \\ & h_k(x) = 0 & k = 1, 2, ..., K \\ & x_i^{(L)} \leq x_i \leq x_i^{(U)} & i = 1, 2, ..., n \end{cases}$$

where,

. • M objectives number;

. • J inequality constraints;

. • K equality constraints;

• n decision variables number;

. • $x^{(L)}$ $x^{(U)}$ upper and lower bounds of decision variables.

Hence, the research space is N-Dimensional and objectives space is M-dimensional. MOP main properties are:

. • Linearity

. • Convexity

Definition 5.1.1 (Linearity). MOP is linear if each objective and constraint is linear.

Definition 5.1.2 (Convexity). A function $f : \Re^n \rightarrow \Re$ is convex if $\forall\ x^{(1)}, x^{(2)} \in \Re^n$

$f(\lambda x^{(1)} + (1 - \lambda)x^{(2)}) \leq \lambda f(x^{(1)}) + (1 - \lambda) f(x^{(2)})$

$\forall\ 0 \leq \lambda \leq 1$

Definition 5.1.3. MOP is convex if each objective and constraint is convex.

Definition 5.1.4 (Dominance). A solution $x^{(1)}$ dominates another solution $x^{(2)}$ ($x^{(1)} \leq$

$x^{(2)}$) if, given M objectives:

1. $f_i(x^{(1)}) \ntriangleright f_i(x^{(2)})\ \forall i = 1...M$

2. $\exists\, i \mid f_i(x^{(1)}) \triangleleft f_i(x^{(2)})$ per $i = 1...M$

Definition 5.1.5 (Strict Dominance). A solution $x^{(1)}$ dominates another solution $x^{(2)}$ (x(1) < x(2)) if, given M objectives::

$$f_i(x^{(1)}) \triangleleft f_i(x^{(2)})\ \forall i \in M$$

Dominance criterion is based on following properties:

- .Asymmetry. If a solution $x^{(1)}$ does not dominate $x^{(2)}$, it is not implied that $x^{(2)}$ dominates $x^{(1)}$.
- .Not-Reflexivity. A solution cannot dominate itself.
- .Transitivity. If $x^{(1)} \leq x^{(2)}$ and $x^{(2)} \leq x^{(3)}$, hence $x^{(1)} \leq x^{(3)}$

Figure 5.2 shows an example of dominance criterion: 5 solutions and 2 objective functions are represented. Solution 2 is dominated by every other, 3 and 5 are the non dominated ones, which belong to Non-Dominated Set (NDS) defined as Pareto Front.

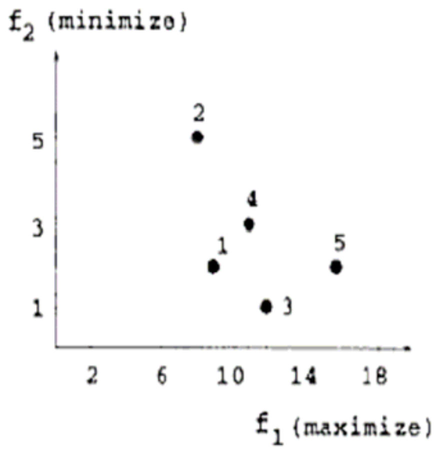


figure 5.2 : 5 solutions population

Definition 5.1.6 (Pareto Optimal Set). Given a solutions set S, optimal Pareto is the set of non-dominated solutions.

Definition 5.1.7 (Local Pareto Optimal Set). Given a set of solutions S, the solution set

P is a Pareto Local Optimum if:

$$\nexists\, y \; suchthat \; \|y - x\|_{\infty} \leq \epsilon \qquad \forall x \in \underline{P}$$

with ε > 0

Here there are some algorithms commonly used for identifying the set of nondominated solutions, hence, they are implemented in almost every MOA. The Simple Pareto Front Algorithm (Algorithm 1), is easy to implement and largely diffused, its complexity is O(M N 2).

**Algorithm 1** Simply Pareto Front Algorithm

**Require:** P {Initial Population}

1: $i \leftarrow 1 \quad j \leftarrow 1$ {Initialising indexes}
2: $P' = \{\emptyset\}$ {Initialising solutions set}
3: **for all** $j \in P(i \neq j)$ **do**
4:     **if** $P(j) \preceq P(i)$ **then**
5:         **go to** *step* 12
6:     **else if** $j \leq |P|$ **then**
7:         $j \leftarrow j + 1$
8:     **else**
9:         $P' = P' \cup \{i\}$
10:     **end if**
11: **end for**
12: $i \leftarrow i + 1$
13: **if** $i \leq |P|$ **then**
14:     **go to** *step* 3
15: **end if**
16: **return** $P'$

Kung's Algorithm is a more effcient algorithm and is based on Divide et Impera. Solutions set is divided recursively into Top and Bottom, once the set are ordered, they are merged again (Algorithm 2). Its complexity is

$$\begin{cases} O(N \log N) & M = 2, M = 3 \\ O(N(\log N)^{M-2}) & M \geq 4 \end{cases}$$

Third algorithm presented (Algorithm 3) assigns a dominance rank to each solution and is based on previous algorithms (1), (2).

**Algorithm 2** Kung's Algorithm

**Require:** $P$ {Initial Solutions Set}

$P \leftarrow PopulationSorting(P)$ {Descending order sorting according to first objective}

**Front(P)** {Recursive Function}
**if** $|P| = 1$ **then**
  **return** P
**else**
  $T = Front\left(P^{(1)} - P^{(|P|/2)}\right)$
  $B = Front\left(P^{(|P|/2+1)} - P^{(|P|)}\right)$
  $M \leftarrow T$ {Initialising Merged Set}
  **for all** $j \in B$ **do**
    **if** $P(j) \not\succeq P(i) \; \forall \, i \in T$ **then**
      $M \leftarrow M \cup \{j\}$
    **end if**
  **end for**
  **return** M
**end if**

**Algorithm 3** Non-Dominated Sorting

**Require:** $P$ {Initial Population}

$j \leftarrow 1$
**while** $P \neq \emptyset$ **do**
  $P_i \leftarrow Kung'sAlgorithm(P)$
  $P \leftarrow P \backslash P_i$
  $j \leftarrow j + 1$
**end while**
**return** $P_i \; \forall \, i = 1, ..., j$

### 5.1.1 Multiobjective Algorithms

MOA are classified into two main categories: "classic" and multiobjective. Classic ones are based on the preference approach previously described, while multiobjective ones are based on ideal approach. Firsts approach was proposed by Box in 1957 [30], and was based on the assignment of a preference to each objective, Naimes [31] proposed the a method where all the objectives but one are turned into constraints. Shaffer [32] firstly used ideal approach based algorithm called Vector Evaluated Genetic Algorithm (VEGA), Fonseca and Fleming proposed Multi Objective Genetic Algorithm (MOGA) in 1993 [33], Srinivas [34] in 1994 idealised Non-dominated Sorting Genetic Algorithm (NSGA) and successively improved by Deb [35] into Elitist Non-dominated Sorting Genetic Algorithm (NSGA-II) in 2000. Strenght Pareto Evolutionary Algorithm (SPEA) was proposed by Zitzler [36], Pareto Archived Evolutionary Strategy (PAES) by Knowles in 1999 [37]. A more detailed survay of the methods can be found in [38]. In this section, some of the well-known optimisation algorithms are presented.

In this study NSGA-II is the algorithm used, here the basic features of are reported.

NSGA-II proposed by Deb in 2000 [35], is based on levelled ranking described in Algorithm 3.

In order to maintain diversity among non-dominated solution, crowding distance is used. For each ranked level, an infinite crowding distance factor is given to extreme solutions, to the others, a value proportional to the distance to the others.

During solutions comparison, if the ranking level is the same, crowding distance is taken into account. Pseudocode of ranking level sorting, crowding distance sorting and NSGA-II are presented:

Elitism process enable to maintain best solutions of the previous generations during optimisation process, such that converging process in accelerated and the risk of decreasing the current optimal state is prevented. NSGA-II is a very effcient MOA, does not require initial parameters to be set, maintain the spreading of the Pareto Set wide.

**Algorithm 4** Ranking Level Sorting

**Require:** $P$ {Initial Population}
$j \leftarrow 1$
**while** $P \neq \emptyset$ **do**
  $P_i \leftarrow NonDominatedSorting(P)$ {Returns all non dominated individuals}
  $P \leftarrow P \backslash P_i$
  $j \leftarrow j + 1$
**end while**
$P \leftarrow P \cup P_i \; \forall\, i = 1, ..., j$
**return** P {Population ordered by rank level}

**Algorithm 5** Crowding Distance Sorting

**Require:** $P$ {Population belonging to the same rank level}
**Require:** $M$ {Cardinality of objectives}
**for** $1 \leq i \leq |P|$ **do**
  $d_i \leftarrow 0$ {Initialization of Crowding Distances}
**end for**
**for** $1 \leq m \leq M$ **do**
  AscendingOrderSort($P$,$f_m$) {Population sorted respect to $f_m$ values}
  $d_{(1,m)} \leftarrow d_{(|P|,m)} \leftarrow \infty$
  **for** $2 \leq j \leq |P| - 1$ **do**
    $d_{(j,m)} \leftarrow d_{(j,m)} + \frac{f_{(j+1,m)} - f_{(j-1,m)}}{f_m^{max} - f_m^{min}}$
  **end for**
**end for**
**return** $P$ {Population with crowding distance value assigned}

**Algorithm 6** NSGA-II

```
Require: N {PopulationSize}
P ← InitalizePopulation(N)
P ← RankingLevelSorting(P)
for all rank levels do
    P_i ← CrowdingDistanceSorting(P_i)
    P ← P ∪ P_i
end for
while notStopCondition do
    P_selected ← Selection(P) {Based on rank and crowding distance}
    P_offspring ← Crossover(P_selected)
    P_mutated ← Mutation(P_offspring)
    P ← P ∪ P_mutated {Applying Elitism}
    P ← RankingLevelSorting(P)
    for all rank levels do
        P_i ← CrowdingDistanceSorting(P_i)
        P ← P ∪ P_i
    end for
    ReplacePopulation(P, N) {Takes the best N individuals of P}
end while
return P_1 {Returns individuals belonging to the first rank}
```

## *5.2 Thermal comfort indices*

The UNI EN ISO 7730: 2006 presents methods for predicting the overall thermal sensation and degree of discomfort (thermal dissatisfaction) of people exposed to moderate thermal environments. The latter have variations contained of the fundamental quantities related to the environment (air temperature, radiant temperature, relative humidity and air velocity) and this allows the intervention, in an effective manner, the temperature control system of the organism.

The well-being thermo-hygrometric is a subjective condition that depends on a number of factors. For its assessment, Fanger has established two equations described in detail in the UNI EN ISO 7730: 2006.

The first is the Predicted Mean Vote (PMV) and is a mathematical function defined as follows:

PMV=[0,303*e^((-0,036*M) )+0,028]*{(M-W)-3,05*10^(-3)*[5733-6,99*(M-W)-R_h ]-0,42*[(M-W)-58,15]-1,7*10^(-5)*M*(5867-R_h )-0,0014*M*(34-t_a )-f_cl*h_c*(t_cl-t_a )-3,96*10^(-8)*f_cl*[(t_cl+273)^4-(t_s+273)^4 ]}

The predicted mean vote depends on:

ME = energy metabolism [W / m2];

W = effective mechanical power [W / m2];

Rh = relative humidity [%];

hc = convection coefficient between air and clothes [W / m2 K];

ta = air temperature [° C];

fcl = basic area of clothing = f (Icl);

Icl = clothing insulation [WK / m2];

tcl = average surface temperature of clothing [° C];

ts = radiant temperature [° C].

The PMV expresses the level of acceptance of a large sample of people working in the same building and who express their thermal sensation through a psychophysics scale.

| **PMV** | **Thermal evaluation** |
|---|---|
| +3 | Very hot |
| +2 | Hot |
| +1 | Warm |
| 0 | Right |
| -1 | Cool |
| -2 | Cold |
| -3 | Very cold |

Table 5.1 : Predicted Mean Vote

The PMV is experimentally related to PPD, an index that represents the percentage of workers who, in the observed conditions, is unsatisfied with the surroundings.

PPD=100-95*e^(-(0,03353*PMV^4+0,2179*PMV^2))

The figure shows the relation between PMV and PPD

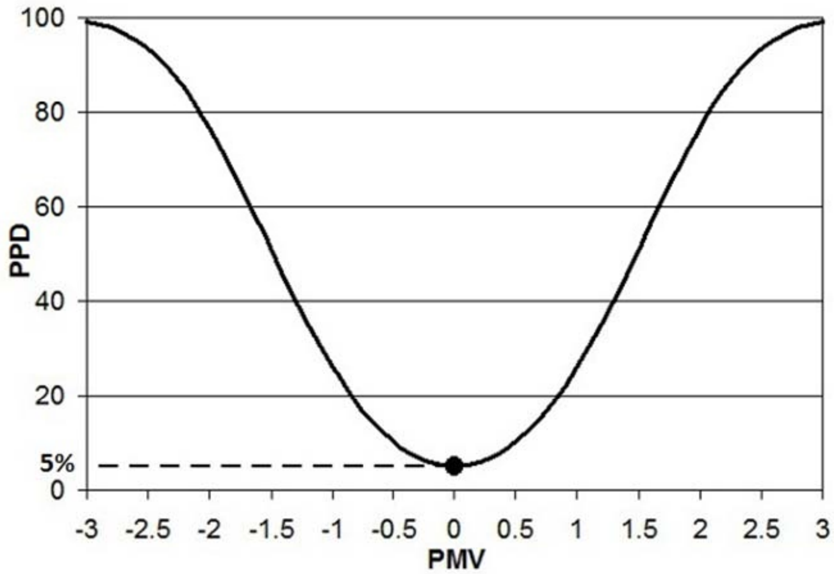



figure 5.3 : PMV – PPD relation

In abscissa there is the PMV with the scale previously described, in the ordinate there is the PPD in percentage.

Note how in conditions of PMV = 0, the PPD is equal to 5%. This means that even under optimum conditions from the point of view of thermal comfort, there is a small population of subjects who judges still unsatisfactory the microclimatic conditions of the environment. This is due to the fact that the perception of the thermal environment also depends on the different individual sensitivity which is linked to factors such as gender, age, geographical origin etc.

The UNI EN ISO 7730: 2006 establishes the acceptance range of PMV between -0.5 and +0.5, therefore it states that in a situation of well-being, the PPD does not exceed 10%.

## 5.3 Mathematical formulation of the problem

At this stage is therefore possible to provide the mathematical formulation of the problem that is being tackled in this work.

So, by eq.1 in par. 5.1, we have that the actual optimization problem can be stated as

$$
\begin{cases}
\min E(\overline{S_r}, S_w) \\
\max PPD \\
subject \\
to \\
E(\overline{S_r}, S_w) > 0 \\
s_r^{(L)} \le s_r^i \le s_r^{(U)}, i = 1,2,...,n \\
s_w^{(L)} \le S_w \le s_w^{(U)}
\end{cases}
\qquad \text{Equation 5.2}
$$

where,

$E(\overline{S_r}, S_w)$ is the global building energy consumption

PPD is the one presented in the previous paragraph

$\overline{S_r} = \{s_r^1, s_r^2, ..., s_r^n\}$ is the vector of room/zone temperture set points

n is the building's rooms/zones number

$S_w$ is the set point temperature of the supply water

$s_r^{(L)}$, $s_r^{(U)}$ are upper and lower bounds of the room/zone temperture set points

$s_w^{(L)}$, $s_w^{(U)}$ are upper and lower bounds of the supply water temperture set point

Therefore this is a non linear (since the objectives are non linear) two-objectives problem.

## *5.4 The F40 Building*

A real office building located at ENEA (Casaccia Research Centre, Rome, Italy) was considered as a case study. The building was built between 1970 and 1972 and it is composed of three floors and a heating plant in the basement. There are 41 offices of different size with a floor area ranging from 14 to 36 m2, 2 EDP rooms each of about 20 m2, 4 Laboratories, 1 Control Room and 2 Meeting Rooms. Each office room has from 1 up to 2 occupants. Each room and laboratory is equipped with fan-coils with on-off fan speed controlled by a room thermostat with hysteresis. The heating plant consists of a traditional natural gas boiler. The building is equipped with an advanced monitoring system aimed at collecting data about both external and internal ambient conditions, electrical and thermal energy consumption. In order to simulate the variables of interest, a MATLAB Simulink simulator based on HAMBASE model was developed. In particular, the building was divided into 15 different zones according to different thermal behavior depending to solar radiation exposure. Therefore a zone consists of a group of rooms with about the same indoor ambient conditions and the same climate control policy. As a consequence of this assumption, thermostat behavior in the same zone was assumed equal.

figure 5.4 : F40 building

| Final Use | Number | Area | Occupants |
|---|---|---|---|
| Office | 41 | $15m^2$ | $[1, 2]$ |
| Laboratories | 4 | $32m^2$ | $[0, 1]$ |
| EDP | 2 | $20m^2$ | $[3, 4]$ |
| Meeting Room | 1 | $25m^2$ | max 12 |
| Confrence Room | 1 | $81, 2m^2$ | max 50 |
| WC | 9 | $15m^2$ | – |

The final model of F40 building consisted of 15 thermally homogeneous zones

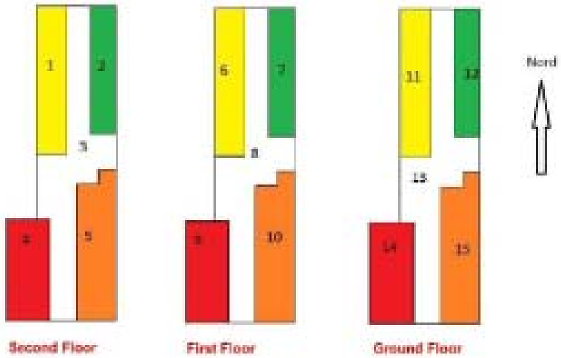
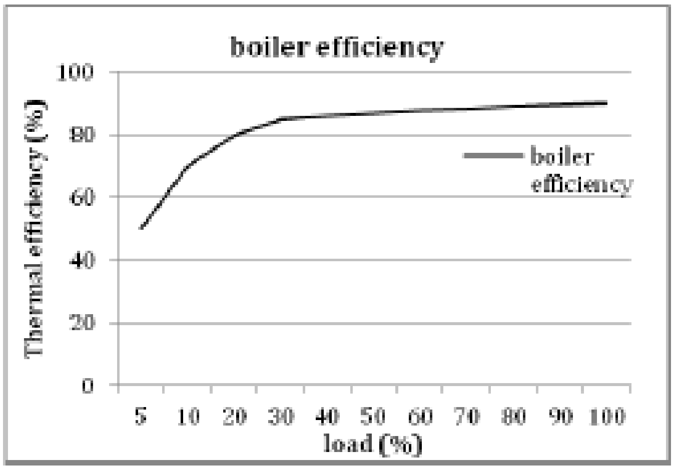


figure 5.4b : F40 building zones

Three of them (white zone in figure) correspond to corridors and are not provided with heating system. For each zone, the thermal model output includes radiant temperature, air temperature and relative humidity. From those variables, the PPD can be computed using PMV model. Among those taken from the building model, there are four variables, that were set to their typical values - metabolism (70 [Wm−2]), external work (0 [Wm−2]), clothing (1 [−]), and air velocity (0.1 [ms−1]).

The gas consumption, mgas, was calculated according to eq.1, as the thermal energy provided to the building (distribution system losses included), Eth_building, divided by the boiler efficiency, ηth_boiler, which is a function of its thermal load; in each time step of simulation, thermal load is calculated as the ratio between the actual thermal power provided by the boiler and its nominal thermal power.

$$m_{gas} = \frac{E_{th\_building}}{\eta_{th\_boiler}}$$




The thermal power of the entire Casaccia R.C. consists of three boilers of 7MW each fueled by methane from which branches off the district heating network, which uses as the carrier fluid superheated water at 120 ° C, pressurized at 400 kPa so as to avoid the boiling, which in turn feeds the under-fired thermal power service groups of buildings. The water reaches a heat exchanger tube bundle with a rated power of 430000kcal / h (516 kW) placed in the boiler in the F40 building. The hot fluid which serves the fan coil circuit is obtained by heat exchange in said heat exchanger. The nominal flow rate of fluid that feeds the circuit of fan coil is 11.5 m3 / h.

A refrigeration unit with a rated output of 180000 frig / h (209 kW), connected to a cooling tower outside the building F40, has the task of generating cold heat transfer fluid for the summer season. The fluid reaches the environments where the fan coils are installed thanks to the thrust of an electric pump (actually three but in a redundant configuration) characterized by a maximum flow rate Q of 11.5 m3 / h and by a manometric head H of 17 m. It can easily be traced back to power knowing the specific weight of water at that temperature and pressure (P = γQH with γ = specific weight).

A three-way valve the water mixes at different temperatures (flow and return), so that it reaches the temperature corresponding to the one set by the Set-Point (typically 65 ° C for the winter season). Two energy meters, placed one on the delivery circuit and the other on the return circuit of the fan coil, have the task to maintain energy balance for the calculation of the thermal energy consumption [Wh].

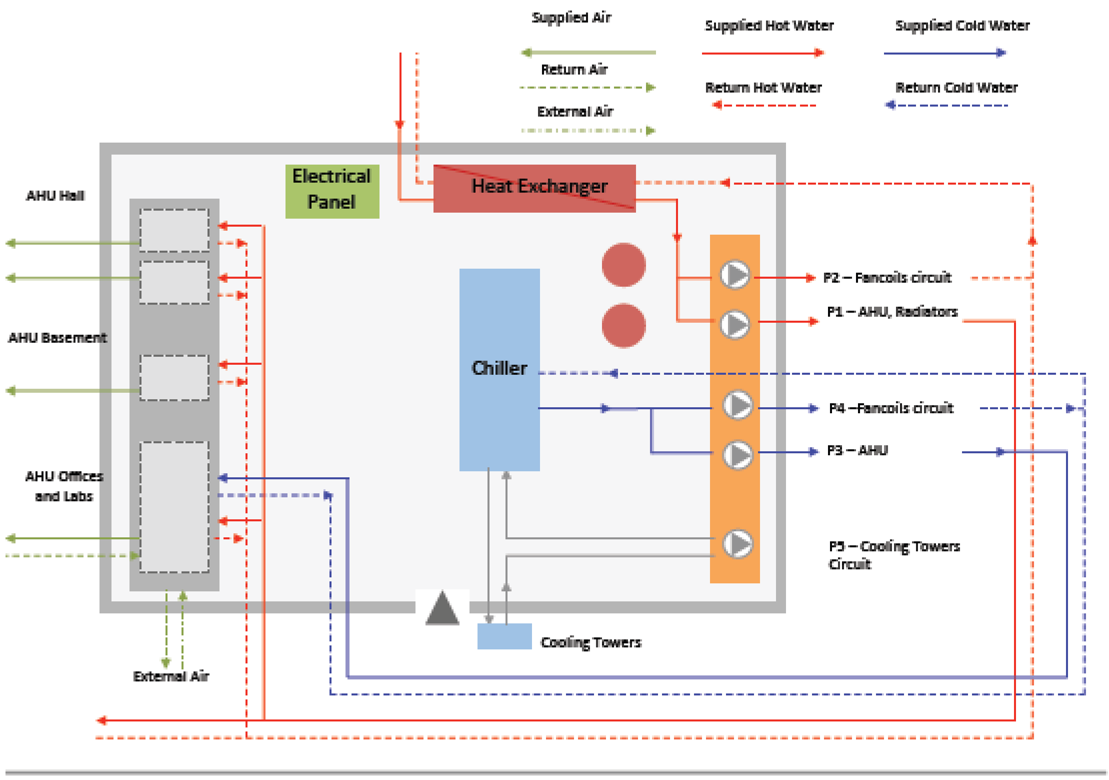



figure 5.5 : thermal circuit layout

Fan-coils were modelled with the ε-NTU method which allows to calculate the heat provided to the zones and the outlet water temperatures once known zone air temperatures, fan-coil inlet water flows and fan speed. The simulator is used to generate data from which the occupant comfort can be evaluated the main inputs being the indoor temperature set points and external meteorological data.

### 5.4.1 the simulator set-up

Thus, the simulator parameters are :

Input

1. Set point zone thermostat: value provided by optimization algorithm;
2. Set point water supply: value provided by the optimization algorithm;
3. Speed of the fans of the fan coil: value that can be set to 1 or 2 depending on the needs;
4. Weather Outside: read from a file from the weather station installed in the ENEA Research Center;

5. Presence: value that identifies the areas actually in employment (active zones) in the building;
6. Occupancy: value that identifies the number of people represented by the individual active zones.

Output

1. Gas consumption in $m^3$ and TOE;
2. Electricity consumption stemming from the fans of the fan coil units of kWh and TOE;
3. Consumption heat for single zone and total in kWh;
4. Temperature profile within individual zones;
5. Performance of radiant temperature within individual zones;
6. Relative humidity inside the individual areas;
7. Hourly PPD in individual areas;

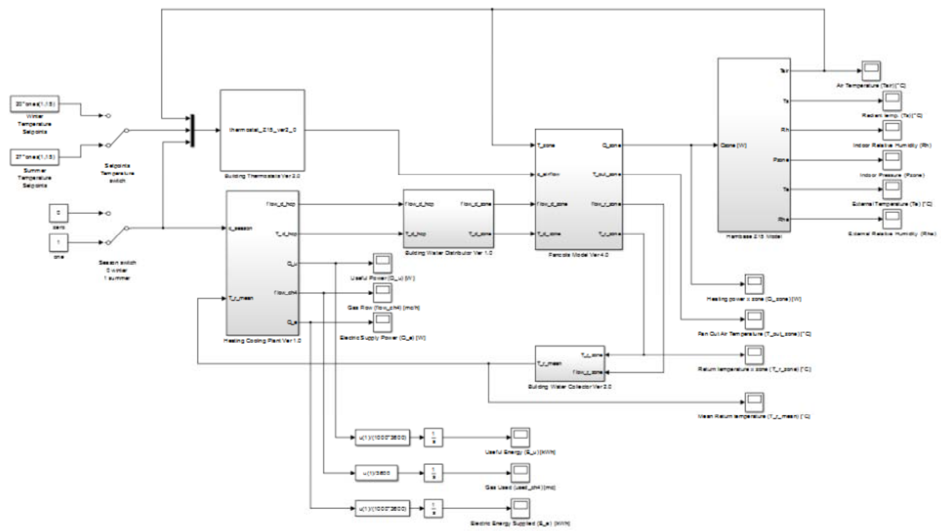


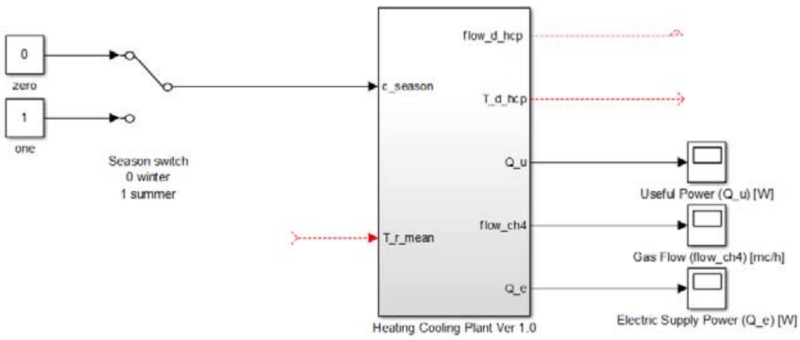

Figure 5.6 : matlab/simulink simulator layout

the model is made of the following sub-systems :

- Thermal Plant
- Fancoil
- HAMbase
- Return collectors
- Distribution
- Thermostat
- Energy counters

The thermal plant block includes both the heat (boilers) and the cool generators (chillers) with a switch function. The boiler model has been implemented by inserting inside the code thermal efficiency values as a function of the heat generator load, that is to say the percentage ratio between the instantaneous power value of the boiler (in this case refers to the value for each step of calculation that is, every 30 seconds) and the nominal one.

As for the heat generator also for the chiller it was modeled a variable efficiency (for each time step of the calculation, 30 seconds). Compared to the heat generator, however, the energy performance of the refrigerator unit is a function of the load percentage of the plant and also of the conditions of external environmental parameters, mainly the temperature.




The fancoil system has been modeled according to the following equation in order to calculate the heat provided

$$Q_{zone} = P_{f_c}(i) = \varepsilon n_{fc} \dot{m}_{air} Cp_{air} (T_d - T_{zone}(i))$$

where

-$P_{f\_c}$ (i)= thermal power at time i in the current zome [W]

-$n_{fc}$ = fancoil number in the zone

- $\dot{m}_{air}$ = Massic air flow rate [kg/s]

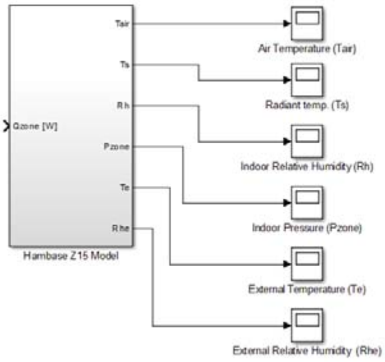
-$Cp_{air}$ = Calorific value at constant air pressure [J/kg˚K]

-$T_d$ = supply water temperature [˚C]

-$T_{zone}$ = zone temperature [˚C]

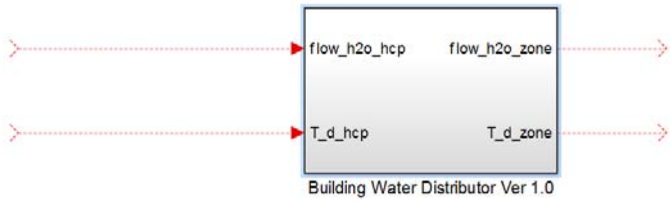
moreover, there are also calculated the radiant and the outcoming temperature.

The HAMBase subsystem receives as input the heating power supplied from fancoil units in each assigned area and performs the compilation of the operations of calculation of thermo-hygrometric exchange supplying at the output the needed thermal parameters : air temperature, humidity value relative, internal pressure, external temperature and relative humidity outside.

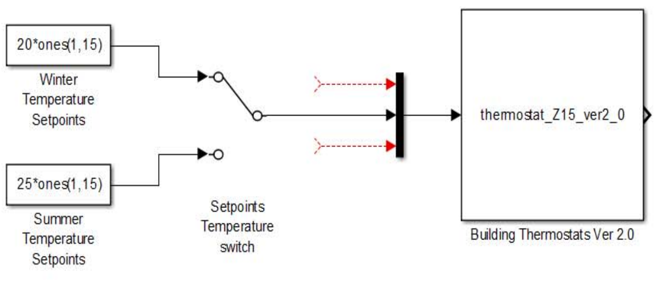



In the return collector subsystem the fluid returning from the system terminals flows into a manifold where all the thermal contribution of the flows of the T_r_zone temperature are added and as output from the collector we'll have a main flow to a T_r_mean outlet temperature. The subsystem has a vector input channel with dimension equal to the number of collectors and an output one-dimensional channel with the temperature of the resultant main stream.

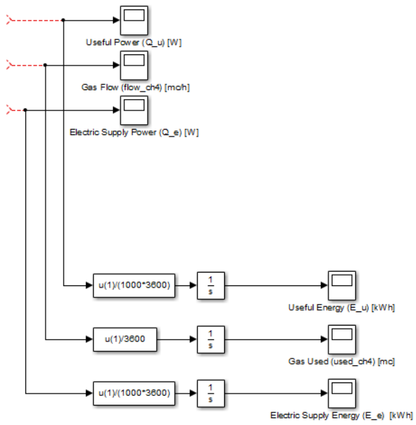
The distribution block assigns the flow of hot / cold water supplied from the boiler room to the fan present in the building zones. In this modeling there were not taken into account the thermal losses along the network.



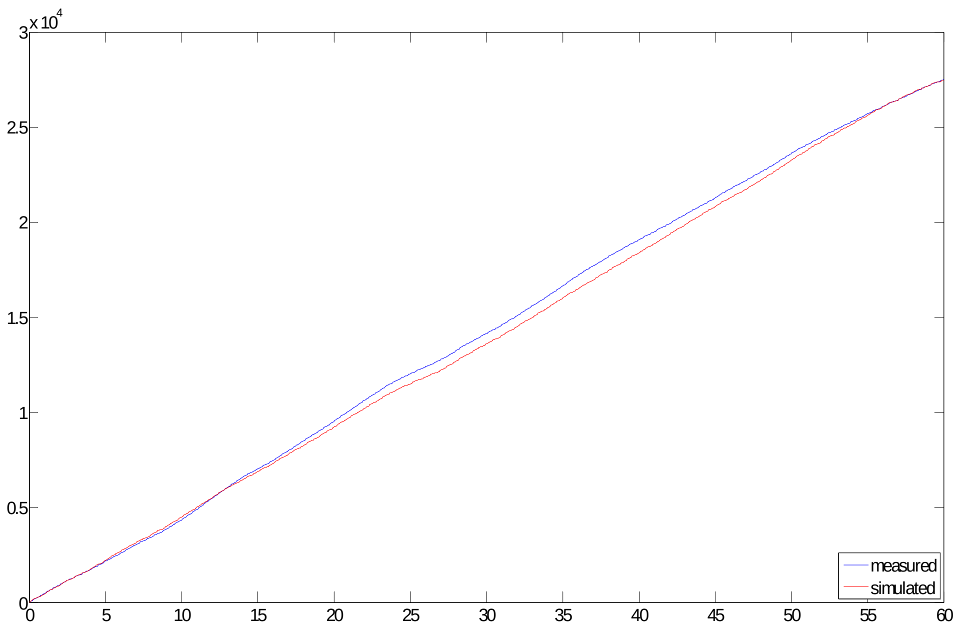

The thermostat subsytem executes the control for each climate zone in which a fan has been installed. If the ambient temperature rises above the limit set in the set up, in winter switches off the fan of the fan coil while in summer the reverse process occurs if the temperature falls below a threshold value. It therefore has two upper and lower limit values of the temperature setting for both summer and winter. With these two operations it changes the value of the thermal power exchanged by convection between the heat exchanger and the ambient air.



The energy counters are nothing more that three integrating blocks applied to three output channels of the thermal plant. They integrate in the range of simulation time the thermal power provided by the power plant, the methane flow rate consumed and the electrical power consumed by providing for these three parameters of values in kWh and m3. These will then be revised to define primary energy performance indicators (TOE).




The simulator has been finely tuned with real experimental data of the building and in the following graph we can see the global behavior of the simulator which achieves very good performances on terms of accuracy.



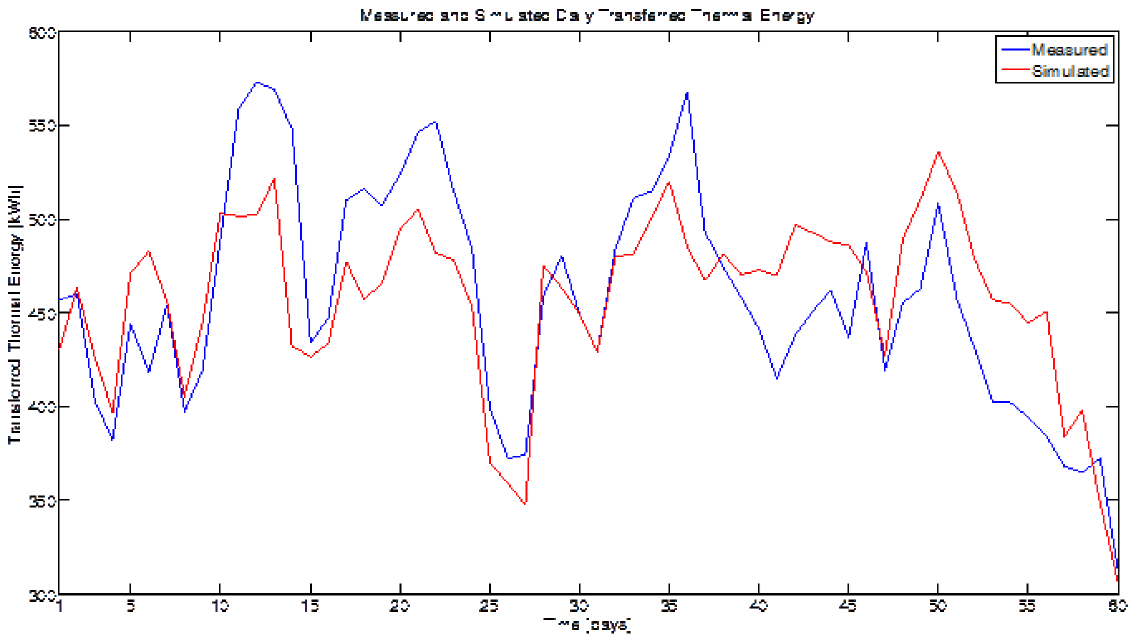



figure 5.7 : simulated vs real behaviour

| | |
|---|---|
| Mean Absolute Percentage Error (dayly) | 7.06 % |
| Absolute error max | 741.51 kWh |
| Absolute error avg | 327.14 kWh |
| Max relative error | 28.5 % |
| Max relative error (no initial transient) | 4.6 % |
| Avg relative error (no initial transient) | **2.6 %** |

table 5.2 : simulation accuracy

### 5.4.2 Experimentation : winter season

Firstly, let's define the objective functions that the algorithm must optimize. These are two objective functions (consequently M will be equal to 2):

1. daily energy requirements of the building F40 for heating during the winter. This objective function is expressed in TOE and is the sum of the heat consumed by the heating plant and electricity consumed by the fans of the fan coil.

2. Predicted Percentage Dissatisfied (PPD) or the percentage of staff occupying the building and F40, in the observed conditions, is not satisfied with the surroundings. This value is obtained by averaging the PPD separate area during the work.

The constraint of the problem is the following:

$$\mathbf{PPD_{constraint}} = \max(PPD < \mathbf{10\%})$$

Namely, the optimization, at each iteration, tries to reach a value of PPD, which is maximum but always below the threshold of 10% imposed by legislation.

As regards the range of the problem, the decision variables input to the simulator take on discrete values within the following ranges:

- Set point Flow [50: 1: 80];
- Set point thermostat [19: 0.1: 23].

The entire search space is therefore made up of 1271 combinations.

Considering that for each possible pair of set point values in input to the simulator it takes a certain time before returning the outputs needed to optimize, it is appropriate to choose the parameters N, G and R in such a way that the entire optimization process not too onerous from the computational point of view, and at the same time to return a number of points sufficient to the construction of the Pareto front.

From tests carried out, a good compromise is had for:

N = initial population = 30;

G = number of generations = 4;

R = number of runs of the algorithm = 3;

The total number of calls made by the algorithm in the simulator is calculated as:

$$N*(G+1)*R = 30 * (4+1) * 3 = 450$$

It has to be noted that, since each optimization process foresees an initial population, in the computation of total calls, you must always add 1 to the number of generations desired.

Each optimization thus provides 450 executions simulator. The time taken to perform the entire optimization for a single day is about 100 minutes.

For 1271 combinations it is required a 12 bits encoding. Each individual will be identified by its chromosome (a binary string of 12 bits).

As it regards the genetic operators :

pc = probability of crossover = 0.8;

pm = mutation probability = 1/1271;

The winter season to be simulated runs from December 21 to March 20. The optimization strategy involves:

1. The identification of the optimal Pareto front for every single day. At each point of the front it is associated with a pair of set point values (thermostat and flow) and a value of (PPD mediated in the sun hours (8-19) only for the active zones that is, those actually heated);

2. The choice of one among the points of the front great. This choice is dictated by the need to comply with the UNI EN ISO 7730 on the microclimate in the workplace moderate. It is expected that the percentage of dissatisfied never exceeds 10% of the staff in the building. This is why every day is chosen the optimum point that present a PPD (excellent) such that:

$$\mathbf{PPD_{constraint}} = \max(PPD < \mathbf{10\%})$$

This is because, by maximizing the PPD (always remaining below the threshold established by law), it minimizes the energy consumption.

Once you choose the optimum point for a day we proceed to the optimization of the following day. The latter will have as initial conditions the final terms of the previous day.

3. The definition of a good seasonal profile, obtained by adding the consumption of individual days and mediating each PPD.

4. The comparison of the seasonal optimized profile with the not optimized profile in order to assess both the global energy saving and the PPD trend. The not optimized profile is the one with which the F40 building is heated normally, thus keeping the thermostat set points and flow constant for the entire winter season.

The choice of these temperatures was carried out by verifying what are the typical temperatures of use of the system and the fan-coils employed:

Baseline 1:

Thermostat set point = 21 ° C;

Set point flow = 60 ° C.

Baseline 2:

Thermostat set point = 21 ° C;

Set point flow = 65 ° C.

Baseline 3:

Thermostat set point = 21 ° C;

Set point flow = 70 ° C.

Before showing the results of the optimization, it is important to be aware of what the fuel consumption and the respective values of PPD of a not optimized strategy.

Baseline 1

A first simulation was performed with the set point flow and thermostat constant for the whole season :

Thermostat set point = 21 ° C;

Set point flow = 60 ° C.

In figure 5.8 and 5.9 there are shown respectively the trend of daily consumption (sum of thermal and electrical consumption of the fan coil) expressed in TOE and the PPD daily expressed as a percentage. The total seasonal (sum of heat and electricity to power the fans of the fan coil) for this strategy was equal to 11.9651 TOE and the corresponding PPD average seasonal amounts to 6.66%.

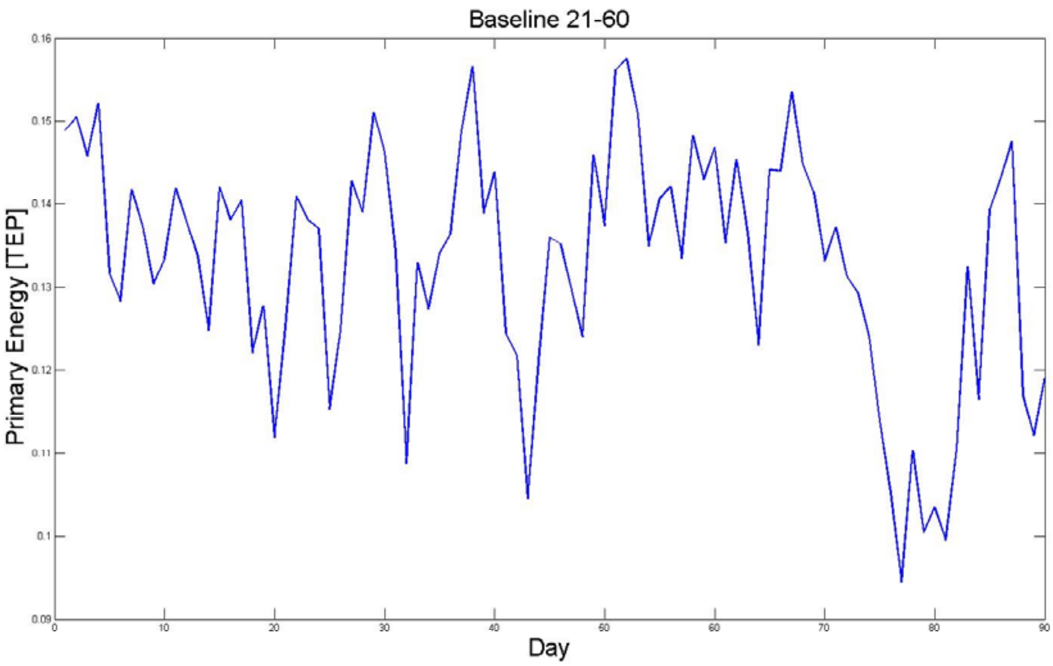



figure 5.8 : primary energy seasonal trend

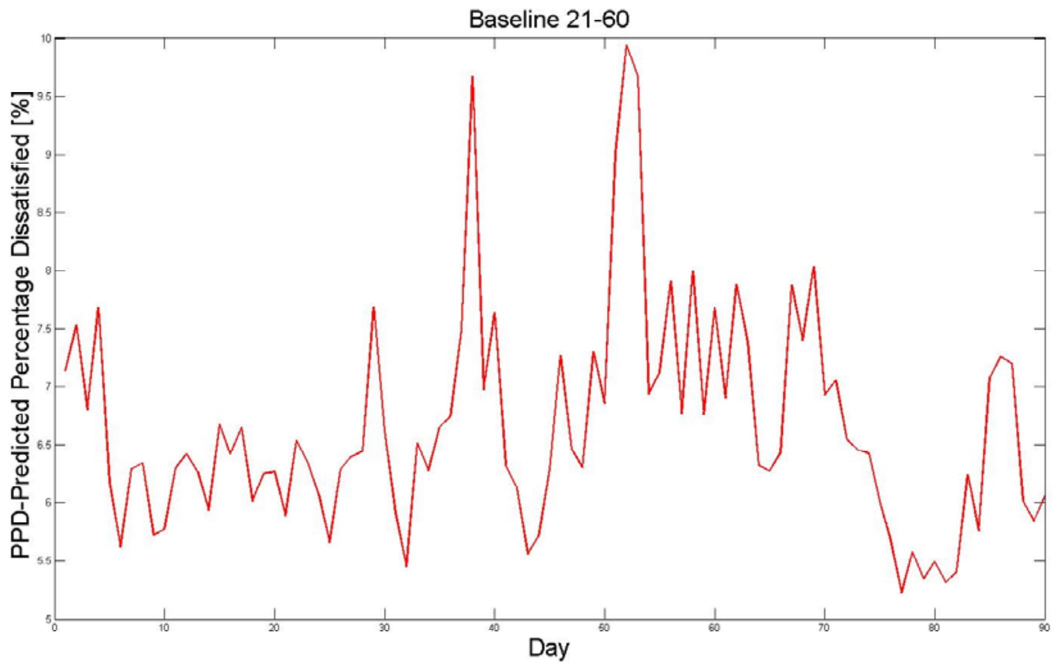



figure 5.9 : PPD seasonal trend

Baseline 2

A second simulation, which corresponds to the real scenario applied in the building, was performed with the set point flow and thermostat constant for the whole season :

Thermostat set point = 21 ° C;

Set point flow = 65 ° C.

In Figure 5.10 and 5.11 there are shown respectively the trend of daily consumption (sum of thermal and electrical consumption of the fan coil) expressed in TOE and the PPD daily expressed as a percentage. The total seasonal (sum of heat and electricity to power the fans of the fan coil) for this strategy was equal to 12.0168 TOE and the corresponding PPD average seasonal amounts to 6.44%

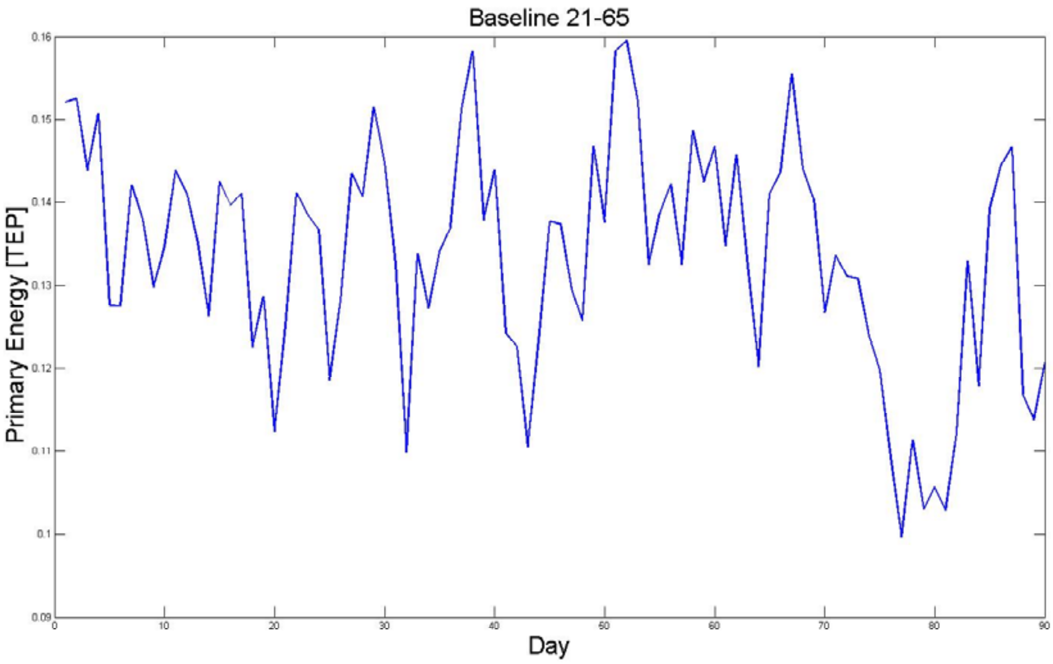



figure 5.10 : primary energy seasonal trend

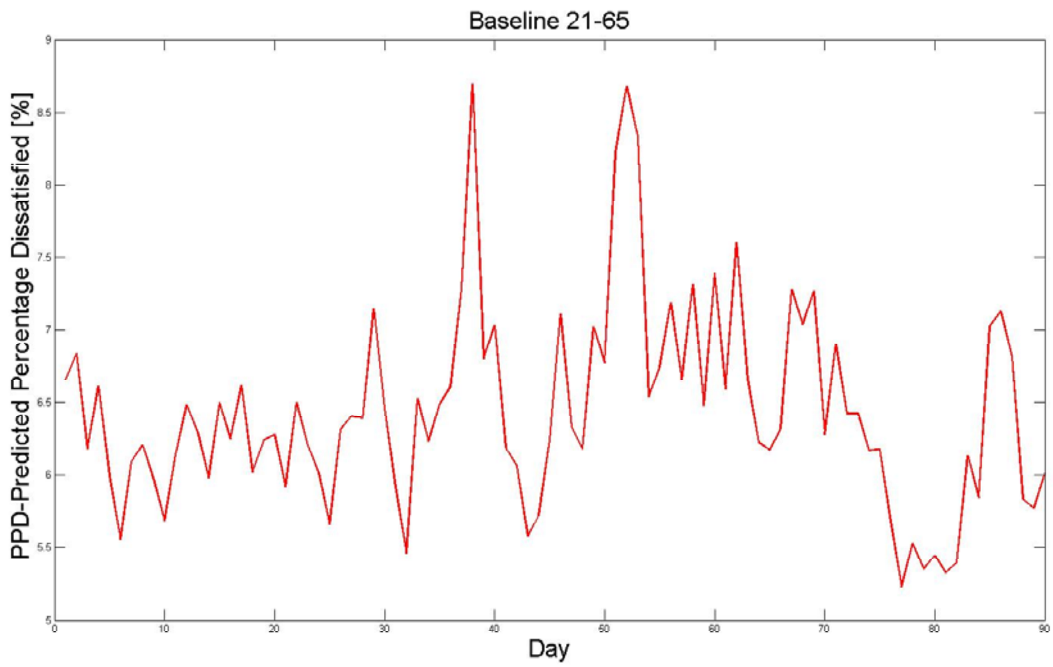



figure 5.11 : PPD seasonal trend

Baseline 3

A third simulation was performed with the set point flow and thermostat constant for the whole season :

Thermostat set point = 21 ° C;

Set point flow = 70 ° C.

In Figure 5.12 and 5.13 there are shown respectively the trend of daily consumption (sum of thermal and electrical consumption of the fan coil) expressed in TOE and the PPD daily expressed as a percentage. The total seasonal (sum of heat and electricity to power the fans of the fan coil) for this strategy was equal to 12.1489 TOE and the corresponding PPD average seasonal amounts to 6.36%

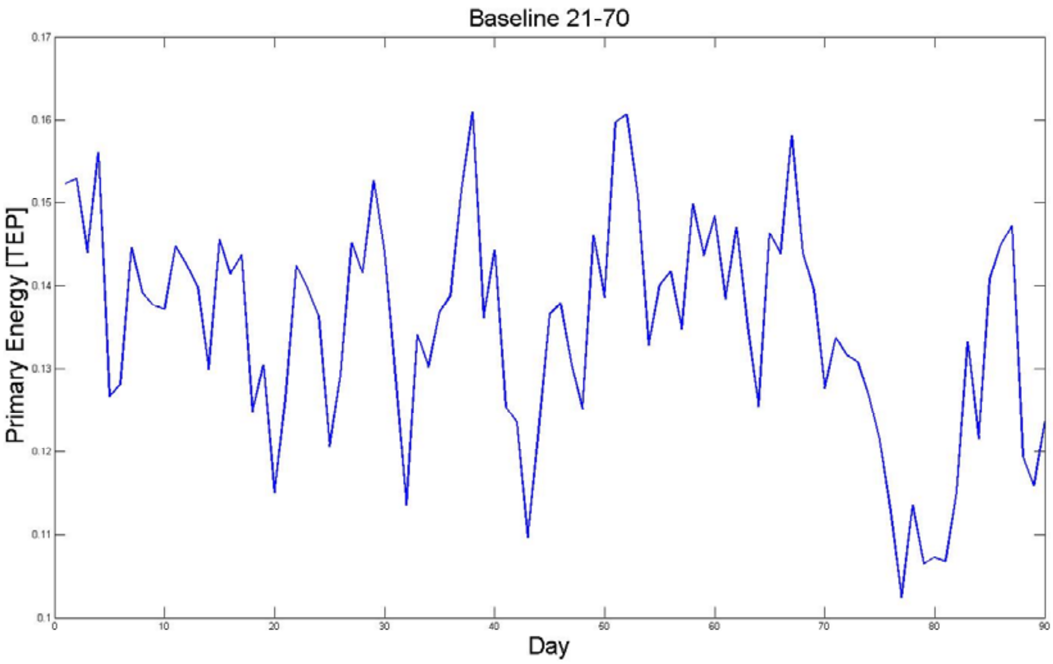



figure 5.12 : primary energy seasonal trend

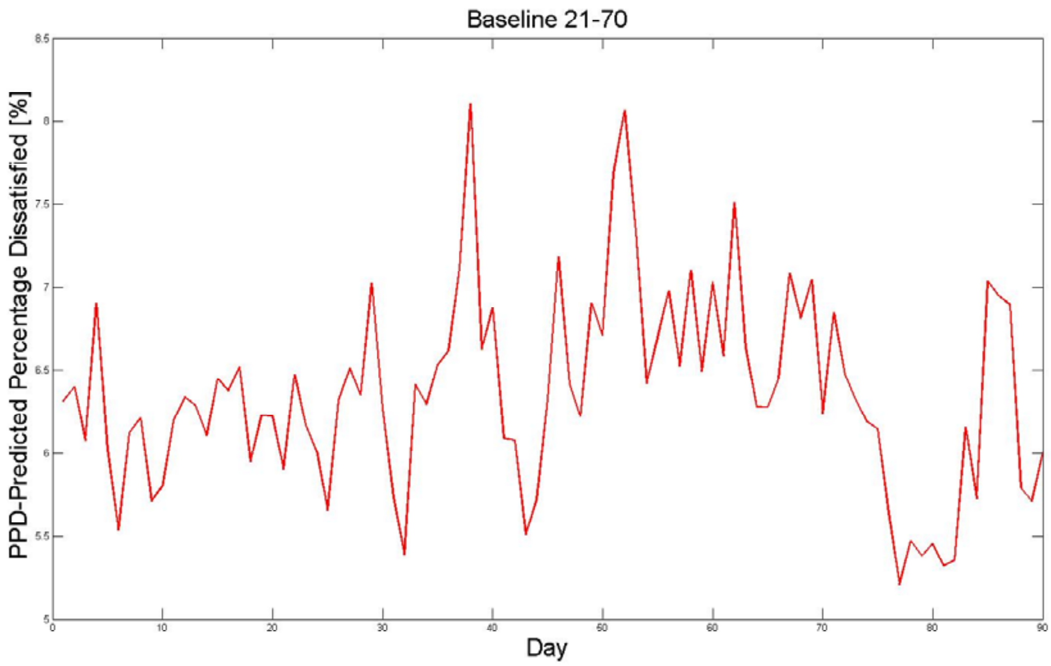



figure 5.13 : PPD seasonal trend

Multi-objective optimization

First of all it has been carried out an exaustive serch in order to realize the potentail savings as benchmark. This has been carried out on gas consumption without considering the electrical loads due to fancoils.

The control variables have been discretized as follows:

TSP : from 17 to 22.5 with step 0.5

SWT = from 30 to 80 with step 1

Giving rise to 12x51=612 total possible combinations of the control variables.

As first experimentation we explored the entire search space simulating the whole winter season in order to perform some preliminary analysis and to get some reference for the effectiveness of the optimization algorithm. In fig. 5.13 it is reported the graphical result of this experimentation (which took 12 days of computation). In the graph each of the 612 points corresponds to a different combination of the control variables giving as result some PPD and energy consumption.

The first analysis is to understand if the current real building settings are at least within the theoretical set of optimal solutions (Pareto front) and the answer was negative. Indeed, the combination TSP=21°C , SWT=65°C was not on the Pareto front having PPD=6.1% and a seasonal consumption of 8419 m3. The optimal solution with the same comfort level (PPD=6.1%) is provided by shifting on the left up to the border (indicated by the red arrow) where there is the optimal solution with TSP=21.5 and SWT=52 which has a consumption of 7821 $m^3$, thus saving about 5% of thermal energy without affecting the current comfort level.

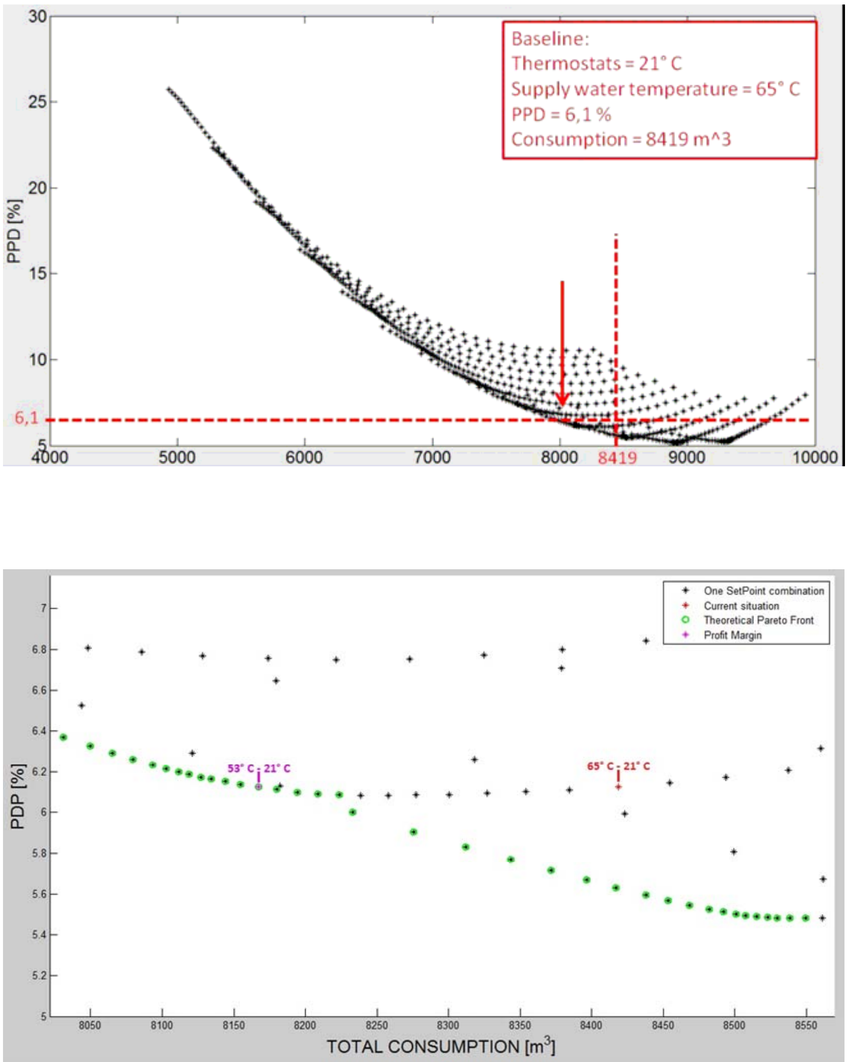



Figure 5.14 : seasonal potential saving

The next step is to apply the optimization algorithm to the seasonal scenario. Below there are the settings for the NSGA-II that we found out after tuning pre-processing. It is important to point out that for this experimentation we employed only ¼ of all the possible combination with a remarkable saving of computational time.

POPULATION 10

SELECTION TOURNAMENT

CROSSOVER SINGOLE POINT RATE=0,8

MUTATION UNIFORM RATE=1/612

FITNESS EVALUATIONS 150 (1/4 OF THE TOTAL)

Then it has been applied a strategy that, as already mentioned, has provided the daily variation of the set-point of the thermostats and supply water in order to reduce the consumption of primary energy and, at the same time, appropriately controlling the comfort .

In this scenario it has been considered the primary energy consumption as sum of gas and electrical loads.

The season includes simulated day period from December 21 to March 20 for a total of 90 days.

There were obtained 90 different Pareto fronts, one for each day.

For obvious reasons they are shown only four (one for each month) in Figures 5.15, 5.16,  5.17, 5.18.

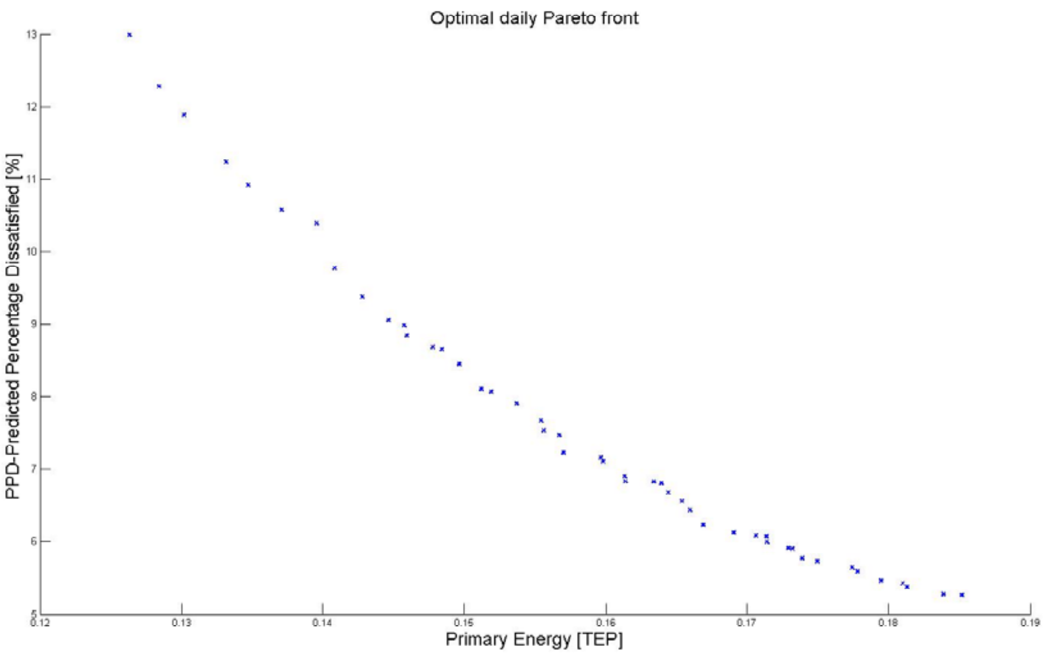



Figure 5.15 : example of 1 day of December Pareto front

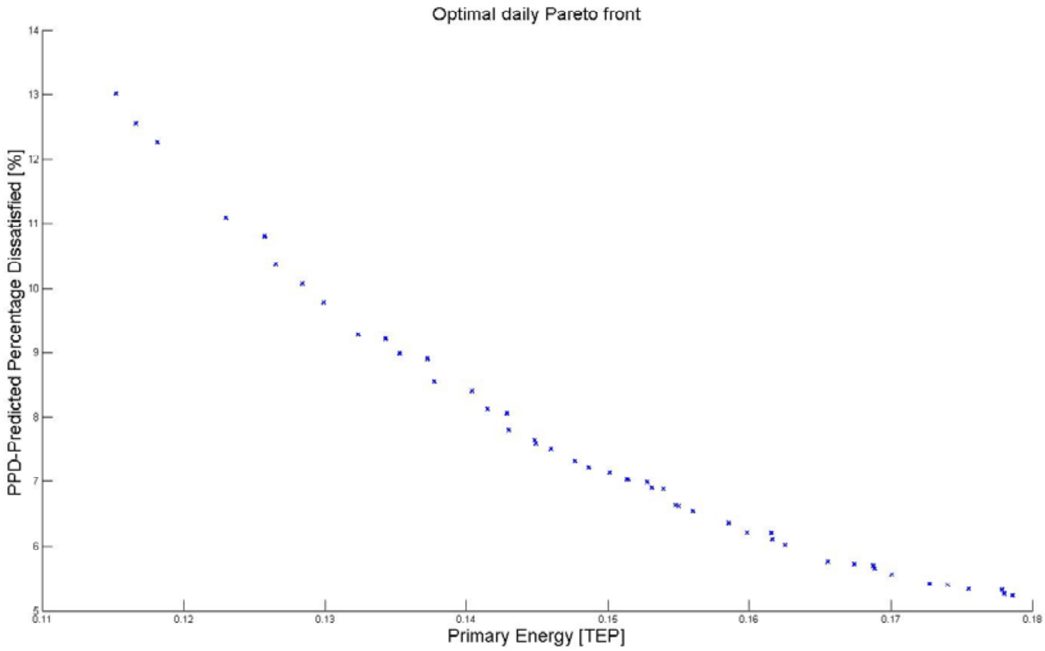



figure 5.16 : example of 1 day of January Pareto front

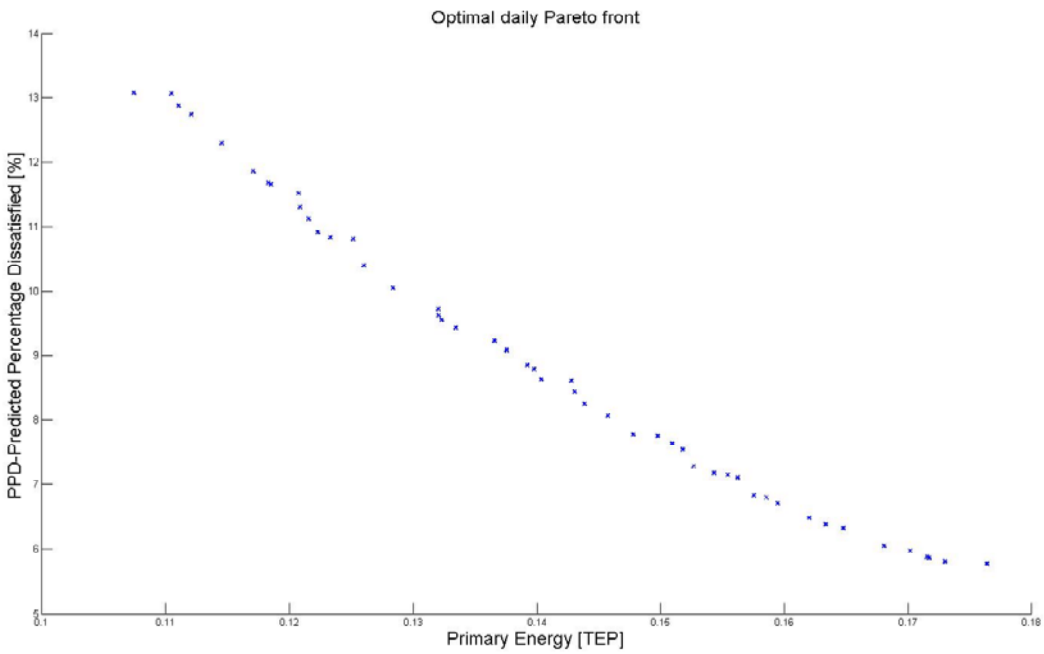



figure 5.17 : example of 1 day of February Pareto front

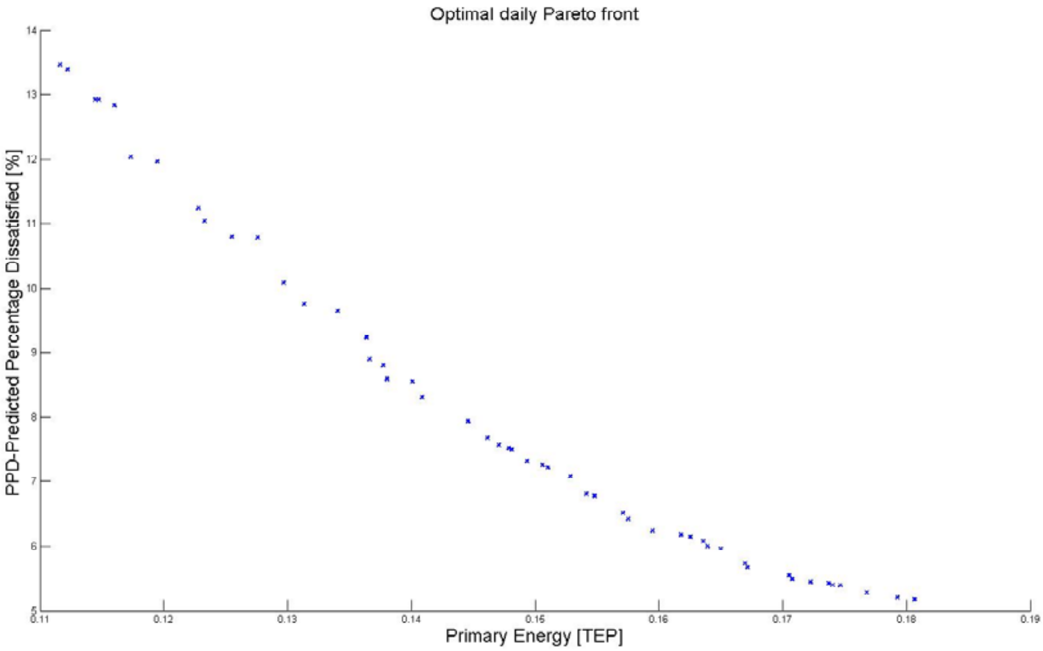



figure 5.18: example of 1 day of March Pareto front

Let's consider now a single front among the 90 obtained, for example, the front of the day of January. Since each solution of the Pareto Front is optimal the chosen solution was the one by considering the UNI EN ISO 7730 on the microclimate for the workplace of moderate type. It is expected that the predicted percentage of dissatisfied (PPD - Predicted Percentage Dissatisfied) is not higher than 10%. At this point, in order to reduce as far as possible the consumption of primary energy, it is chosen a point of the face which ensures the lowest consumption, while maintaining the PPD to below 10% (Fig. 5.19).

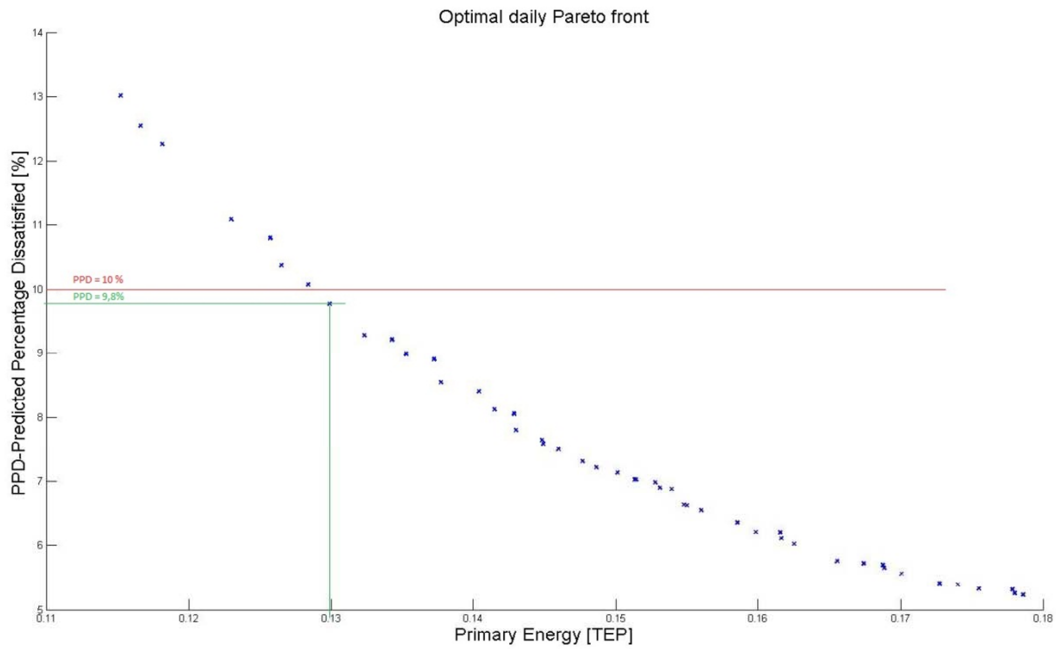



figure 5.19 : choice of the solution of the Pareto front

The point in question corresponds to a daily consumption of primary energy of 0.13 TOE and a PPD daily average of 9.8%. This operation was repeated for all 90 fronts. It is possible at this point to show the trend of consumption and of the PPD, relative to the season optimized, respectively in Figure 5.20 and 5.21.

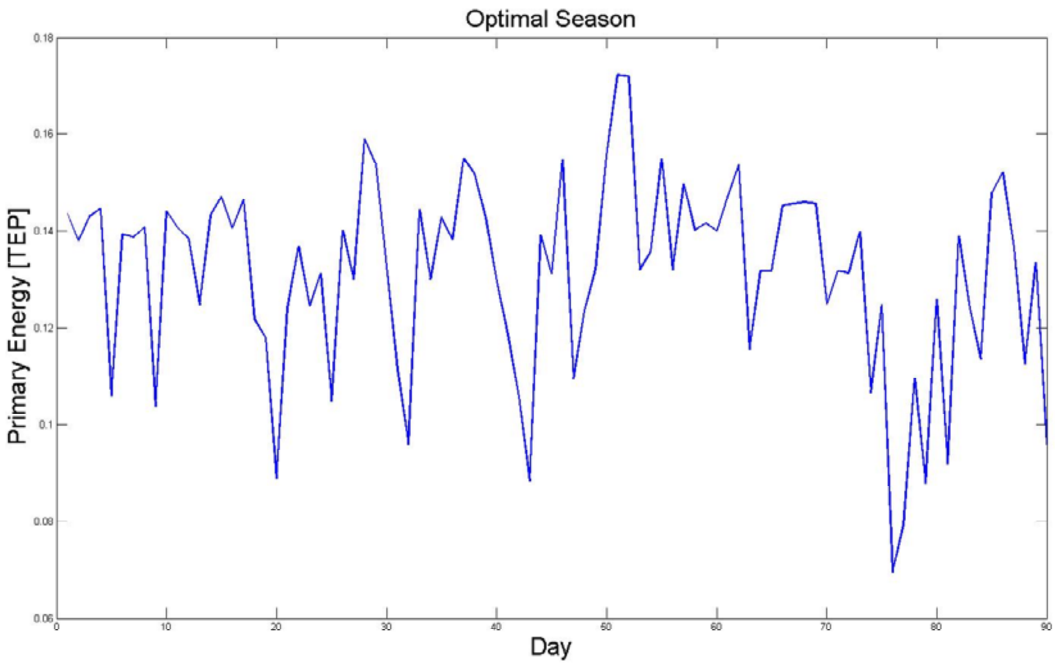



figure 5.20 : optimal primary energy seasonal trend

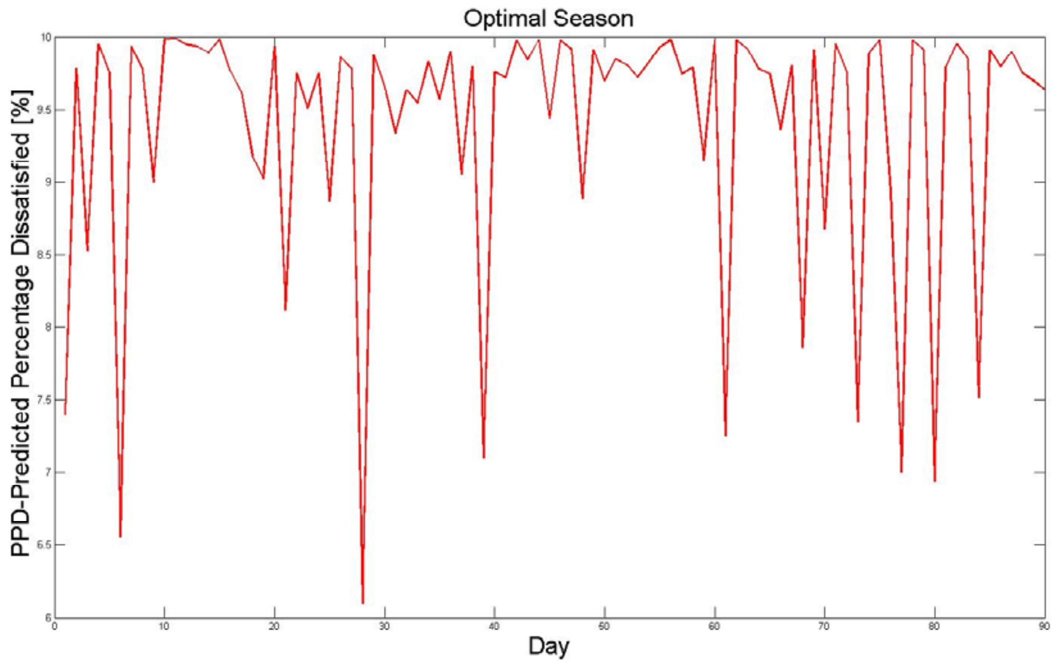



figure 5.21 : optimal PPD seasonal trend

The PPD average seasonal corresponding amounts to 9.4%. Figure 5.21 and 5.22 compare the consumption-related Baseline (21-60), with the consumption of the optimized season and the corresponding PPDs.

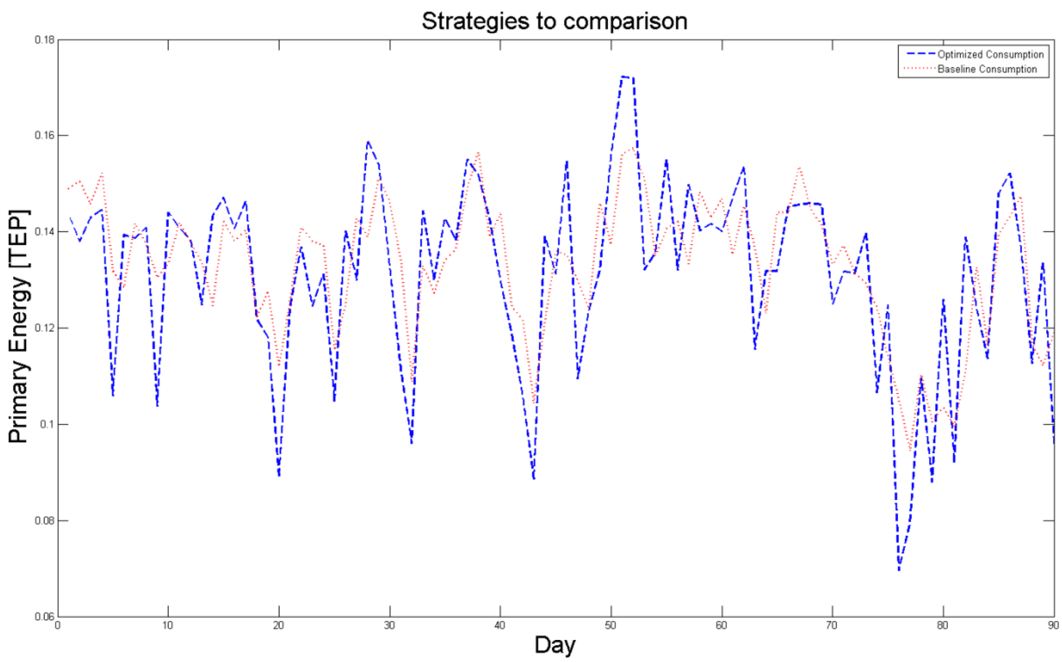



Figure 5.22 : comparison of primary energy seasonal trends (baseline 21-60)

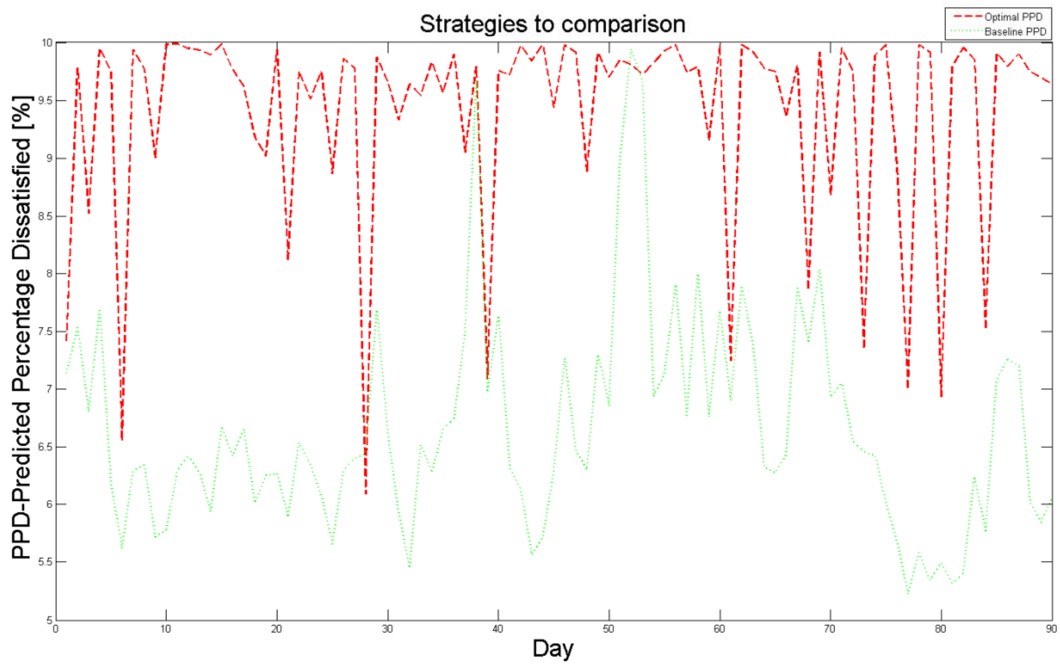



figure 5.23 : comparison of PPD seasonal trends (baseline 21-60)

In the following figures it is reported the comparison with the other baselines (21-65 , 21-70)

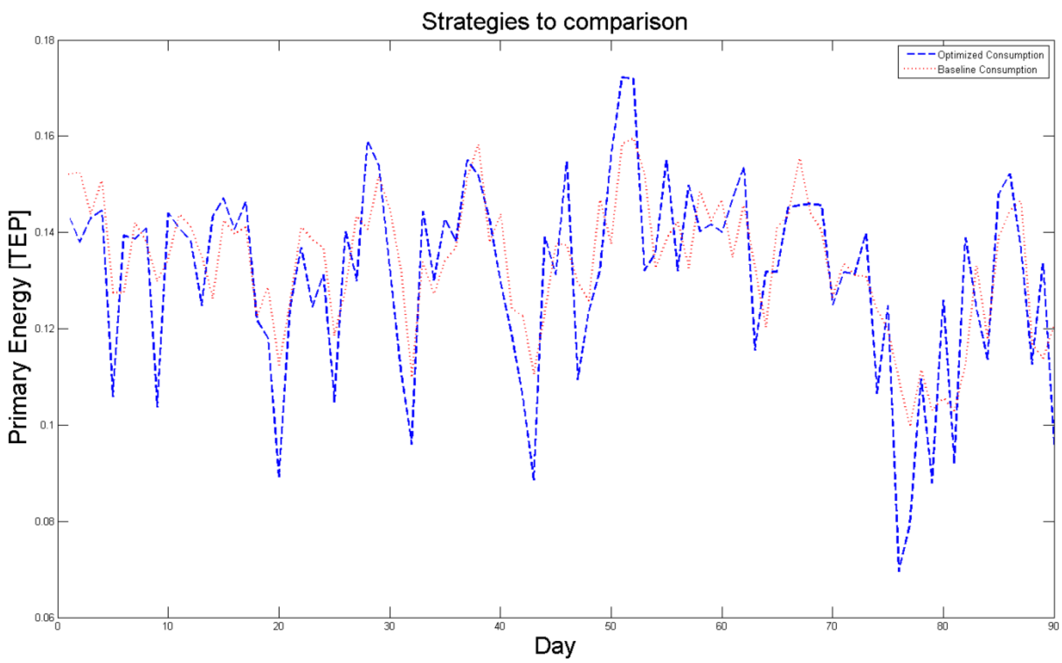



figure 5.24: comparison of primary energy seasonal trends (baseline 21-65)

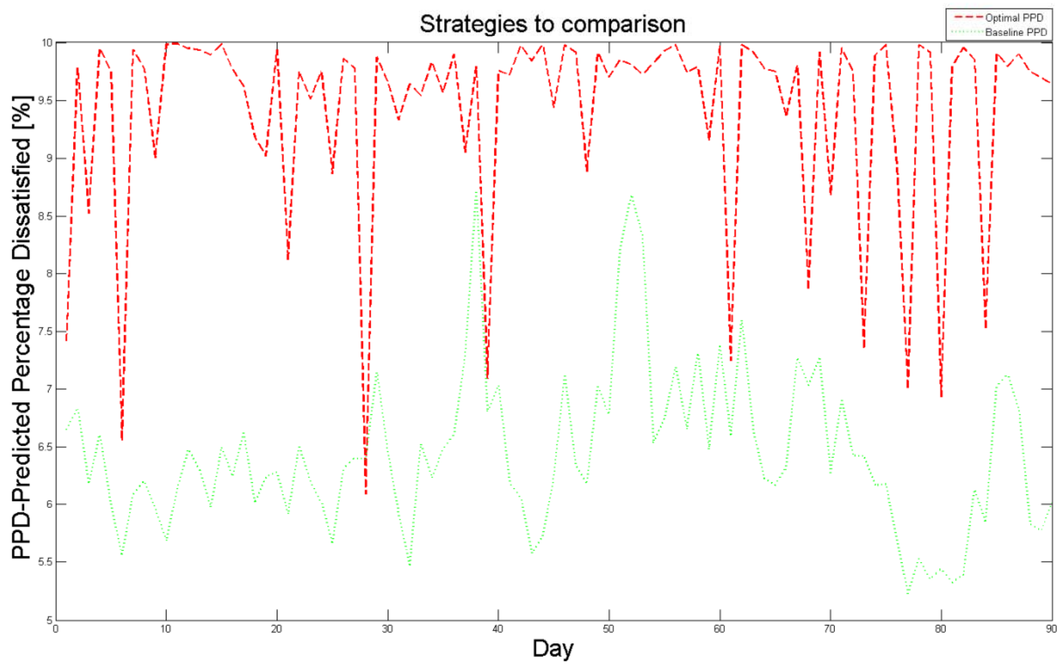



figure 5.25: comparison of PPD seasonal trends (baseline 21-65)

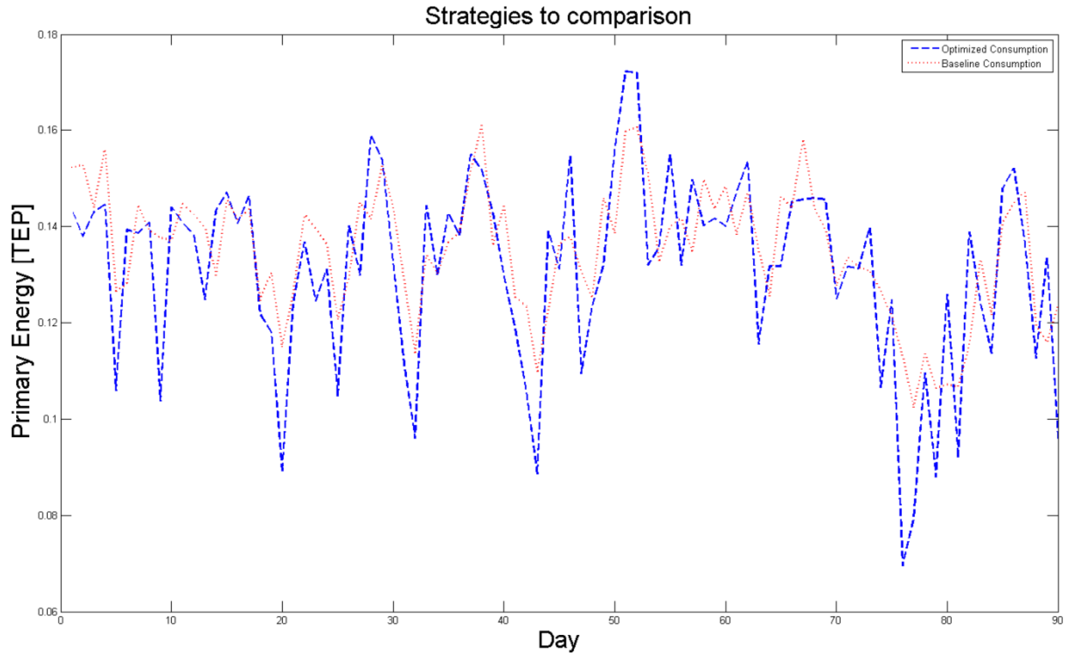



figure 5.26 : comparison of primary energy seasonal trends (baseline 21-70)

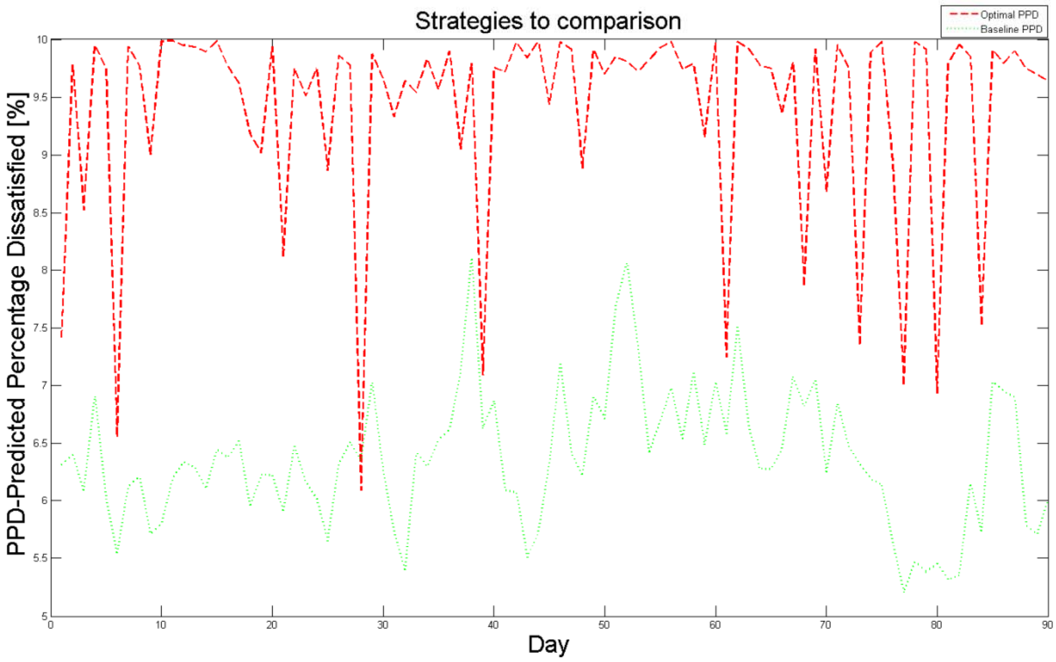



figure 5.27: comparison of PPD seasonal trends (baseline 21-70)

In Table 5.3 it is possible to see the fuel consumption and the values of PPD average for the various strategies used

| | Avg seasonal PPD [%] | seasonal primary energy [TOE] |
|---|---|---|
| **Baseline (21-60)** | 6,66 | 11,965 |
| **Vaseline (21-65) - REAL** | 6,44 | 12,017 |
| **Baseline (21-70)** | 6,36 | 12,149 |
| **Optimum** | 9,4 | 11,671 |

**Table 5.3 : comparison of the results**

In Table 5.4 it is shown the percentage of the energy savings of the optimal strategy with respect to the different baselines over the entire winter season

| Baseline (21-60) | Baseline (21-65) | Baseline (21-70) |
|---|---|---|
| 2,5% | 2,9% | 4% |

**Tabella 5.4: energy savings**

### 5.4.3 Experimentation : summer season

As for the winter season, before proceeding with the optimization, it was performed an exhaustive search for the summer. In order to assess the power consumption resulting from the refrigeration unit, used to cool the building F40, and the corresponding percentages of discomfort expressed by the PPD (Predicted Percentage Dissatisfied), it has been simulated the period from 12 June to 31 July, for a total of 50 days. The month of August was not taken into consideration because in those days the Casaccia Center is closed for two weeks and most of the staff take their holidays in August. The exhaustive research carried out, will be used to quantify the energy savings and evaluate the differences in comfort between the baseline and optimized strategy.

The Baselines provided the variation of the water supply and thermostat set points in the following ranges:

Set point supply water= 8° C – 15° C by 1° C step;

Set point thermostat = 21° C – 24° C by 1° C step;

Each supply water-thermostat combination constitutes a baseline to be taken as a reference for future optimization strategies. One baseline provides the cooling of the building with the thermostat and supply water set point fixed for the entire season, therefore with no dynamic control. The latter will be implemented in the future during the optimization phase.
In the following table there are the total seasonal consumption and average PPD relating to all the possible combinations of the control variables in the ranges and steps previously defined.

| Simulation period: June 12 – July 31 | Supply water temperature [°C] | Set point thermostat [°C] | Total Consumption [kWh] | Mean PPD [%] |
|---|---|---|---|---|
| 50 days | 8 | 21 | 16.460 | 6,55 |
| 50 days | 8 | 22 | 14.601 | 8,36 |
| 50 days | 8 | 23 | 13.022 | 11,25 |
| 50 days | 8 | 24 | 9.864 | 13,94 |
| 50 days | 9 | 21 | 15.598 | 6,7 |
| 50 days | 9 | 22 | 14.051 | 8,5 |
| 50 days | 9 | 23 | 12.840 | 11,4 |
| 50 days | 9 | 24 | 9.639 | 14,1 |
| 50 days | 10 | 21 | 14.953 | 6,9 |
| 50 days | 10 | 22 | 13.423 | 8,7 |
| 50 days | 10 | 23 | 12.322 | 11,5 |
| 50 days | 10 | 24 | 9.515 | 14,2 |
| **50 days** | **11** | **21** | **14.198** | **7,1** |
| 50 days | 11 | 22 | 12.898 | 8,9 |
| 50 days | 11 | 23 | 11.322 | 11,5 |
| 50 days | 11 | 24 | 9.236 | 14,4 |
| 50 days | 12 | 21 | 13.436 | 7,4 |
| 50 days | 12 | 22 | 12.202 | 9,1 |

| | | | | |
|---|---|---|---|---|
| 50 days | 12 | 23 | 10.909 | 11,8 |
| 50 days | 12 | 24 | 8.922 | 14,9 |
| 50 days | 13 | 21 | 12.625 | 7,68 |
| 50 days | 13 | 22 | 11.572 | 9,44 |
| 50 days | 13 | 23 | 10.315 | 12 |
| 50 days | 13 | 24 | 8.895 | 15,1 |
| 50 days | 14 | 21 | 11.797 | 8,1 |
| 50 days | 14 | 22 | 10.836 | 9,74 |
| 50 days | 14 | 23 | 9.730 | 12,3 |
| 50 days | 14 | 24 | 8.260 | 15,2 |
| 50 days | 15 | 21 | 10.942 | 8,56 |
| 50 days | 15 | 22 | 10.057 | 10,13 |
| 50 days | 15 | 23 | 8.856 | 12,4 |
| 50 days | 15 | 24 | 7.037 | 15,8 |

Based on the results of the above table Pareto fronts baselines can be defined. In the follwing figure there are two Pareto fronts, each of which has a set point temperature of the thermostat constant. In particular, the red front identifies a set point temperature of the thermostat of 21 °C, the blue one represents a set point temperature of the thermostat of 22 °C and the black one 24°C. It may be noted that as the temperature of the supply water decreases, the consumption of the refrigerator unit grows as the value of the PPD decreases. This is permissible since being in the summer period, the water temperature tends to rise very quickly (in agreement with the weather conditions outside the building). In addition, the decrease of the supply water temperature, it will provide a higher cooling with a resulting decrease in the percentage of dissatisfied.
From the first figure it can be seen that the thermostat higher than 22°C provide a PPD too high, therefore the second figure provide a detailed comparison of the two legal fronts.

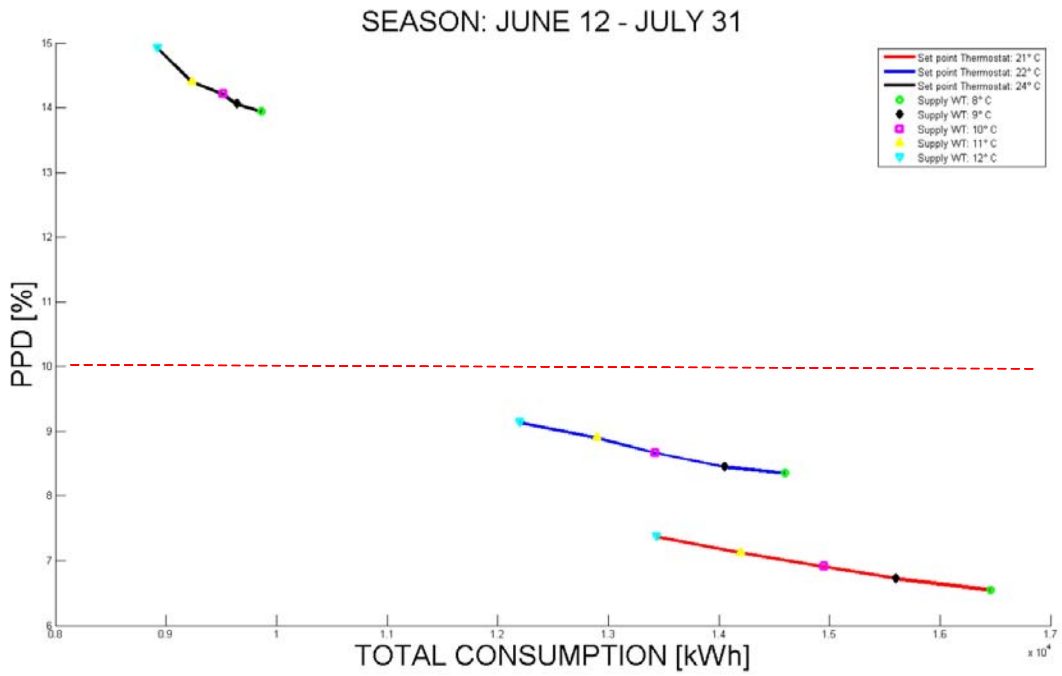



figure 5.28: summer optimization

In the real case the F40 building is cooled with a 11 ° C supply water temperature and a thermostat temperature of 21 ° C which corresponds to a consumption of 14,198 kWh and a 7.1% PPD.
The UNI EN ISO 7730: 2006 on the microclimate in moderate workplace provides that the PPD does not exceed 10% of total employees. Therefore, it is possible to reduce the consumption of electricity for the cooling of the building compared to an increase in the percentage of dissatisfied, consistent with the limit imposed by legislation:

$$PPD \leq 10\%$$

The figure 5.29 shows the comparison of the two fronts and the corresponding potential saving in energy vs PPD with closest point whose PPD is lower than 10%.

The following table summarizes the result

| | Supply water temperature [°C] | Set point thermostat [°C] | Total Consumption [kWh] | Mean PPD [%] | Energy saving [%] |
|---|---|---|---|---|---|
| Real case | 11 | 21 | 14.198 | 7,1 | - |
| Interesting case | 14 | 22 | 10.836 | 9,74 | 23,6 |

table 5.5: summer optimization

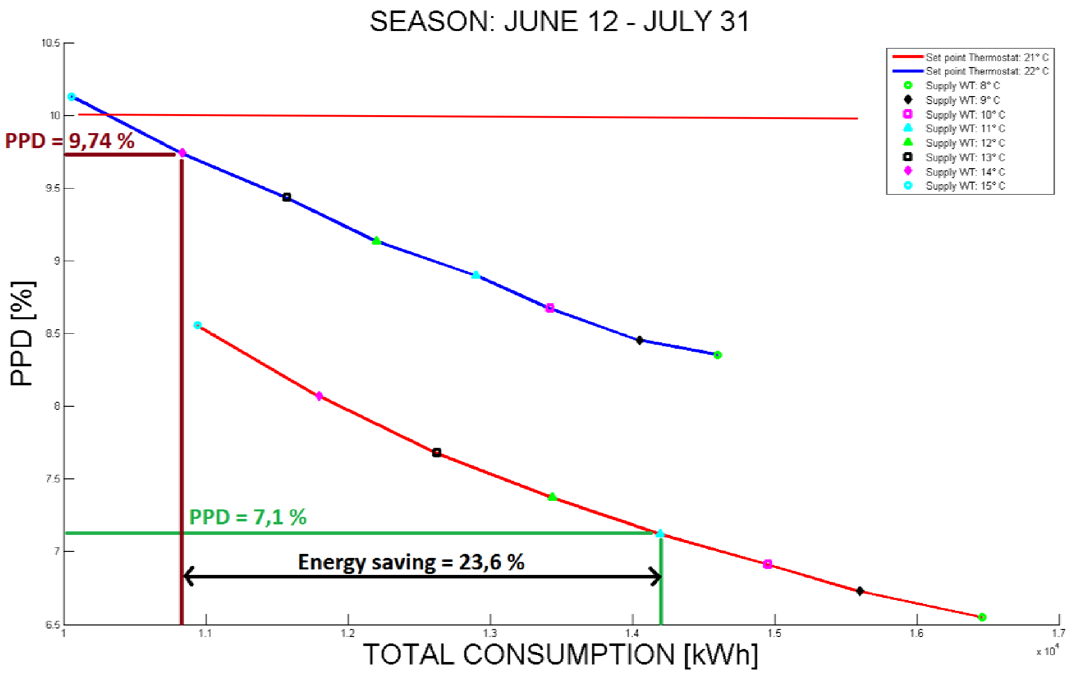



figure 5.29: summer optimization and seasonal potential saving

In the following table there are reported the main results of this experimentation.

| | Winter | | Summer | |
|---|---|---|---|---|
| | Energy (TOE) | PPD | Energy (TOE) | PPD |
| Baseline | 12.017 | 6.4 | 2.66 | 7.1 |
| Optimal | 11.671 | 9.4 | 2.03 | 9.7 |
| Difference % | -3 | +3 | -23 | +2.6 |

table 5.6: summer optimization saving summary

From this comparison it is clear the difference of potential energy saving between winter and summer in the considered case (office building in Rome). In particular, it is possible to point out the highest potential energy saving is in the summer season which is in line with similar studies carried out in the southern Europe climatic area.

## 5.5 Ferrarese Palace

In this experimentation there have been studied heat consumption, used for heating in winter, for the building that houses the Division of Building Heritage, located in the town of Bari in Piazza del Ferrarese.

figure 5.30: Ferrarese Palace

This is an historic building of the nineteenth century (1840), located in the southern part of Old Bari, overlooking the old harbor. It consists of a ground floor and a first floor characterized by a plant fairly regular rectangular. The facade of the first floor consists of impressive arches while the first floor can be distinguished with large windows and balcony railings in smaller windows with masonry parapet. The ground floor houses mainly the daily market fish and it is constituted by local rather wide and tall. Especially in the north develop the local fishmongers with cold rooms and ample storage; the central rather large open space to the west of the square of the Ferrarese is used for the daily fish market. Finally the south-west is the main entrance to the municipal offices in the south-east and the technical room where there is a diesel boiler and the relative distribution and regulation systems security (burner, pumps, thermostats, expansion vessel) that feeds the plant heating. The first floor is divided into several rooms, about 30, used as offices, archives and toilet. The environments are similar to each other both in size and conditions thermohygrometric. There are also three long, narrow corridors (also for the presence of furniture). Unlike the ground floor, the premises have a smaller volume also for the presence of ceilings. There are also large single glazed windows, no curtains, and casings dated circumstances indicate that heat loss to the outside is not negligible. The building has energy certification with energy performance index for winter heating EPi of 20 kWh / $m^3$ / year, which gives energy class E.

The building is heated by means of cast iron radiators of different sizes. The number of elements varies depending on the size of the room in which they are installed. The heat exchange with the environment takes place by radiation and natural convection. The heat consumption is dependent on the temperature of the water flow coming from the heating and reaches the radiators, the temperatures at which thermostatic valves on each radiator are set.

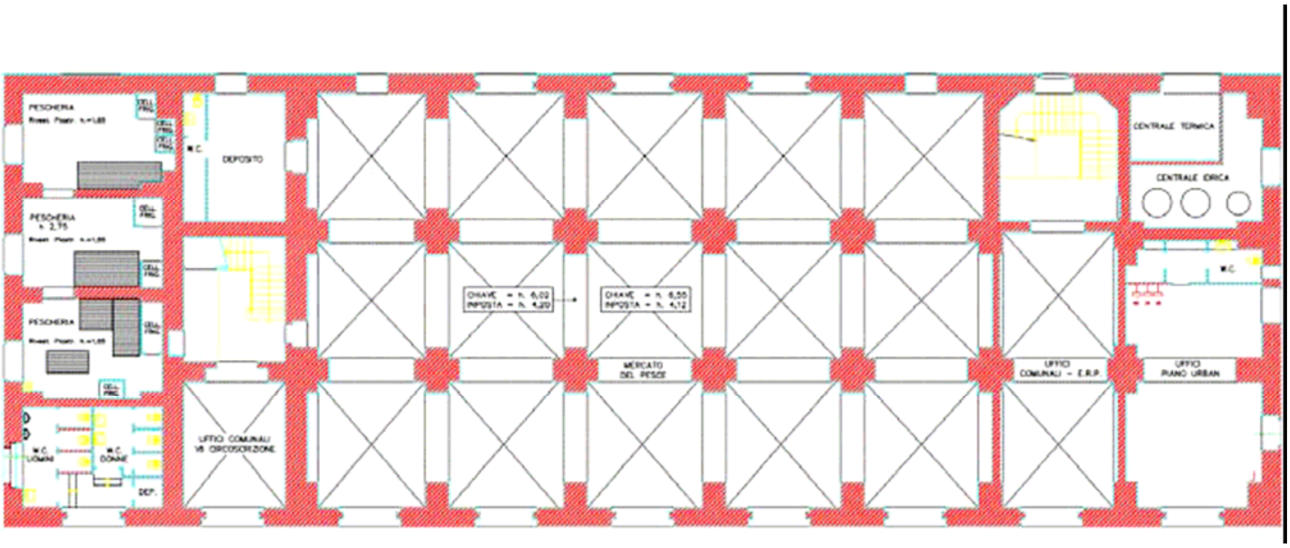


figure 5.31 : ground floor

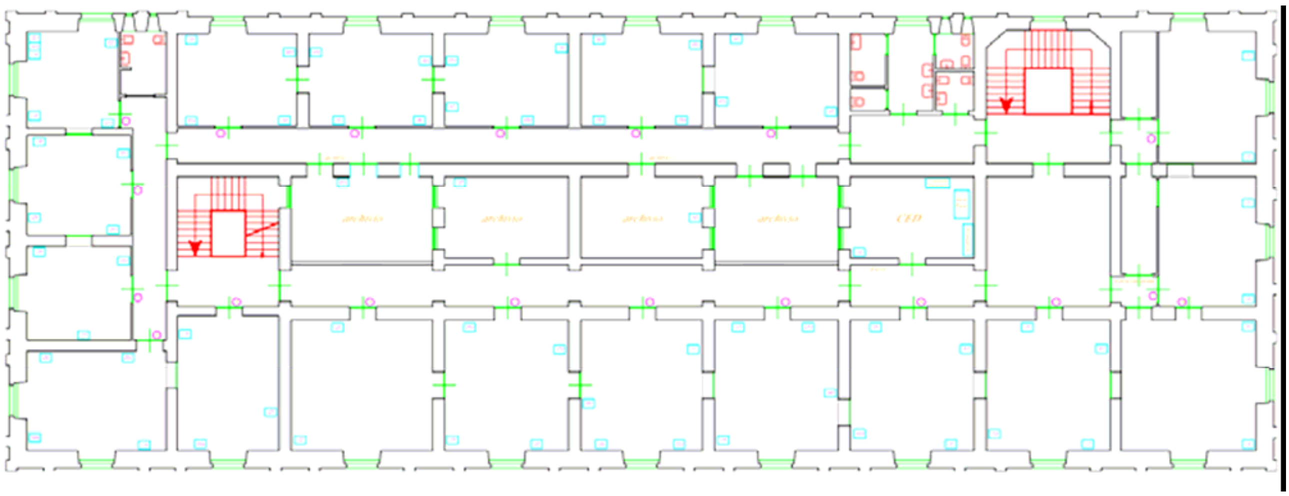


figure 5.32 : 1st floor

It is also assessed the percentage of dissatisfied occupying the building thanks to the PPD (Predicted Percentage of Dissatisfied) present in the existing rule UNI EN ISO 7730.

The objective is to minimize the heat consumption of the building, by controlling in an appropriate way the comfort of the occupants. The baseline is represented by the set point temperatures, thermostatic valves and flow, with which it is currently heated the building.

The methodology involved for this experimentation is very similar of the one used for the F40 experimentation. Firstly, the use of a simulator MATLAB / Simulink able to predict, based on the external conditions (temperature, humidity, wind speed, etc ...), on employment of the individual zones in the building, on the set point settings of supply water and thermostatic valves in individual rooms, the behavior of the building in terms of consumption and temperature and humidity conditions.

The simulator, after being suitably interfaced with the MATLAB software, is used to formulate the optimum strategy.

Currently there is no control on the temperature set point of thermostatic valves and flow, they are kept constant for the entire season. In this way, in addition to not optimize consumption, there is no control over the PPD.

A first approach to the problem is supposed to carry out the following points:

- Based on the set point settings of the real building, it is estimated, thanks to a special simulator, the consumption over the entire winter season (90 days);
- The starting baseline, that of the real case, is obtained by setting the temperature of the thermostatic valves at 21 ° C and the outlet temperature of the water at 60 ° C for the entire season;
- The simulator, taken in the different values of the input set point, returns as output the seasonal consumption and average seasonal PPD that will be used to construct the Pareto fronts;
- The outputs are analyzed to identify the optimal strategy.

The building is modeled using software HAMbase. It allows to analyze and simulate the behavior of a building using the model of the indoor temperature, the indoor air humidity and the consumption of energy required for heating and cooling of a building multizone. The acronym stands for is Heat Air and Moisture balance that shows the three main parameters of the degree of thermal comfort of a building. The program was developed by researchers at the University of Eindhoven, is open source but works in programming environment Matlab / Simulink.

The main parameters to be set HAMbase are:

- Meteorological data;
- Geographical location (latitude, longitude, height above sea level);
- Number of zones that comprise the building and their constituent characteristics;
- Constructional features of components inside the building;
- Phenomena shading;
- Detailed Description of the surfaces which constitute each zone;
- Presence of windows;
- Furniture;

The parameters provided as input required by the simulator are:

- Power [W];
- Steam [kg / s];
- Ventilation rate [g / s];

As regards the parameters supplied as output from the system :

- Temperature [C];
- Relative humidity [%];

Simulator details : electrical modelling

the first floor of the building consists of 19 offices (each occupied by two people), from archives, a data processing center, a photocopier, three corridors and toilets. Each office has a minimum provision of electrical utilities, as reported below.

6 ceiling lighting

Personal computer 2

Conditioner 1 split

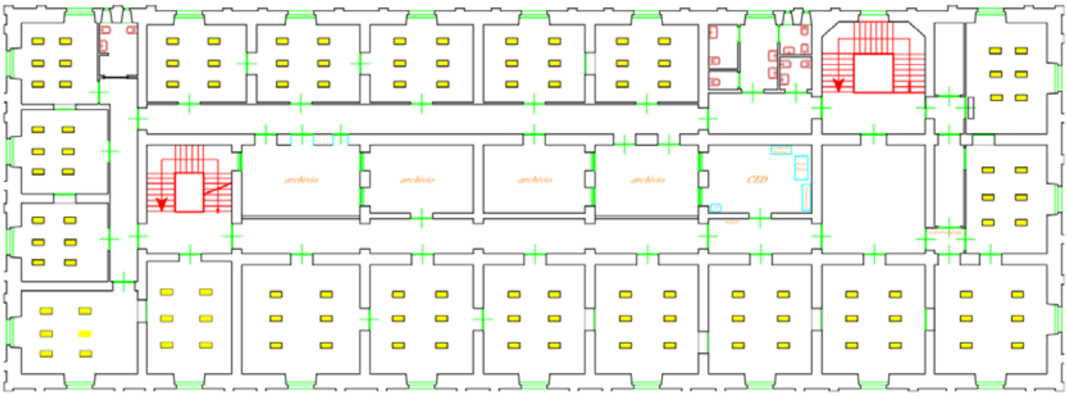


Figure 5.33: office lights layout

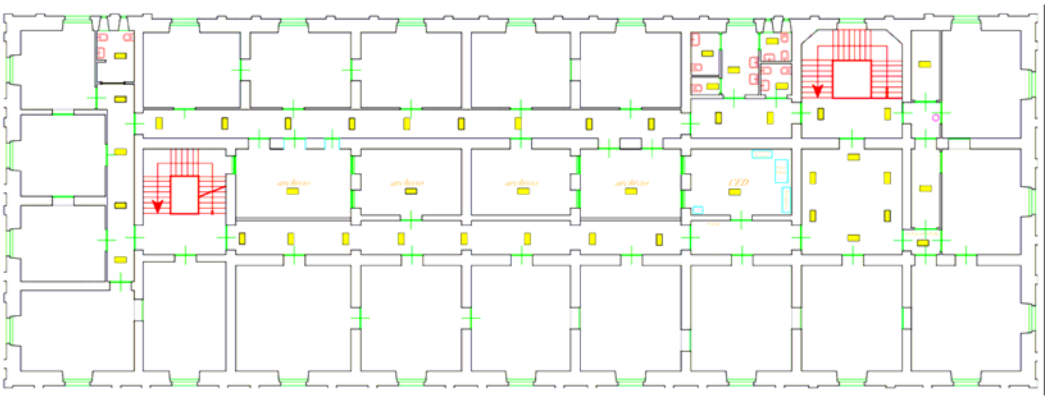


Figure 5.34 : other lights layout

## 5.5.1 the simulator set-up

Some considerations relevant to phase modeling / simulation of the building

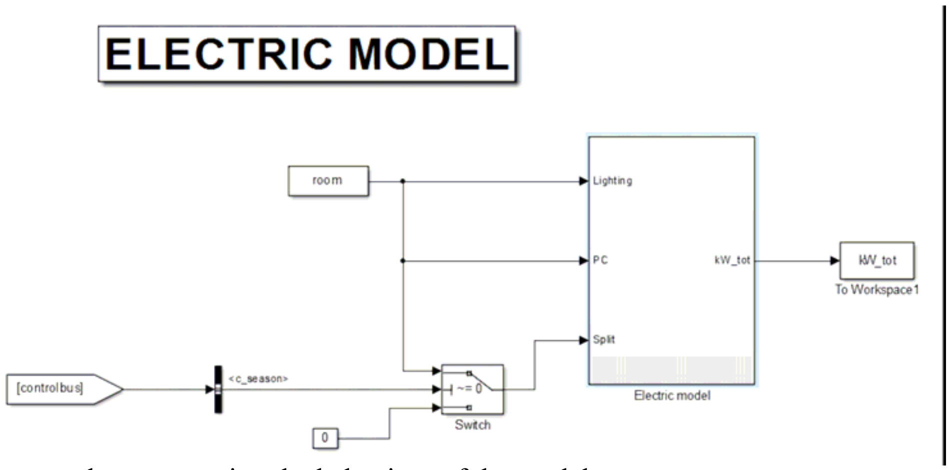
- The consumption of lighting are a function not so much the number of presences in the building as the number of active environments, or those rooms in which there is at least one occupant: very probably in fact the office lights are switched on when a person enters the room. Then a room consisting of 2 persons will have the same consumption of a room with only one person given that the number of ceiling lights is the same for each office;
- the power of the lighting of a single active substance is given by the power of the ceiling (72 W) multiplied by the number of the same in each room (n ° 6) and is equal to 432 W;
- the power socket represented by stock, bathrooms and corridors (ie the power which would be used if all the lamps in bathrooms and corridors were lit together) is equal to 2.66 kW;
- the power socket represented by stairs and services (ie the power which would be used if all the lights in stairways and services were lit together) is equal to 0:58 kW;

- consumption of the line PCs are instead more closely related to the number of people present, since in this case may vary from one office to another as it is not said that it is turned on both locations simultaneously at all hours;
- consumption of air conditioners in the summer instead depend on the number of rooms else.

The objective of the electrical model is twofold: on one hand it has to simulate / reconstruct the absorption of the equipment building, on the other hand it should support the development of strategies to reduce electricity consumption. The simulations were carried out in the programming environment Matlab / Simulink. The model reconstructs the pattern of absorption electrical, over a period of 15 days in the winter season (mid-January), regarding the use of lights and PC and trends, always on 15 days during the summer season (first half of July), considering absorption of air conditioners. It is considered a business hours Monday through Friday.

The model takes as input only the number of active rooms of the building (Via a profile of attendance time loaded into input from the workspace of Matlab) and is controlled by Block switch according to the following logic: you get in the output value of 0 if the number of rooms is active

void for that particular hour (please note that the data is collected every hour), or multiply (Via the block gain) the number of active rooms for a value of 0.432 kW to obtain the power consumption of each office due to lighting and for a value of 0.180 kW to get power consumption of each office had to PCs. Via a switch Summer / winter you can take into account of the electric input for the operation of each split for cooling air only in the summer season. Finally, it added a block that adds the power socket on the corridors, bathrooms, archives and scales equal to 3.24 kW if they were switched on simultaneously.




Here there are shown graphs representing the behaviour of the model.

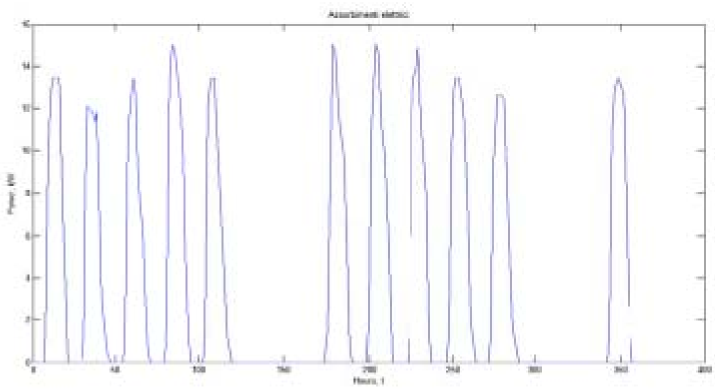


Figure 5.35 : winter electrical loads simulation

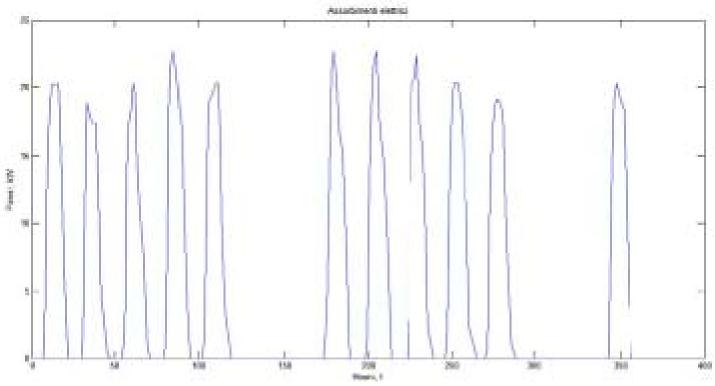


Figure 5.36 : summer electrical loads simulation

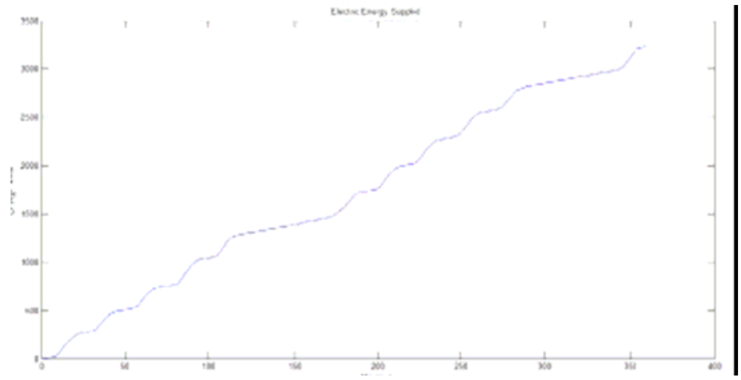


Figure 5.36b : summer electrical consumption

Thermal modelling

First of all the building has been divided into 35 different zones (4 on the ground floor and 3 on the 1st floor) which are the object of the simulation.

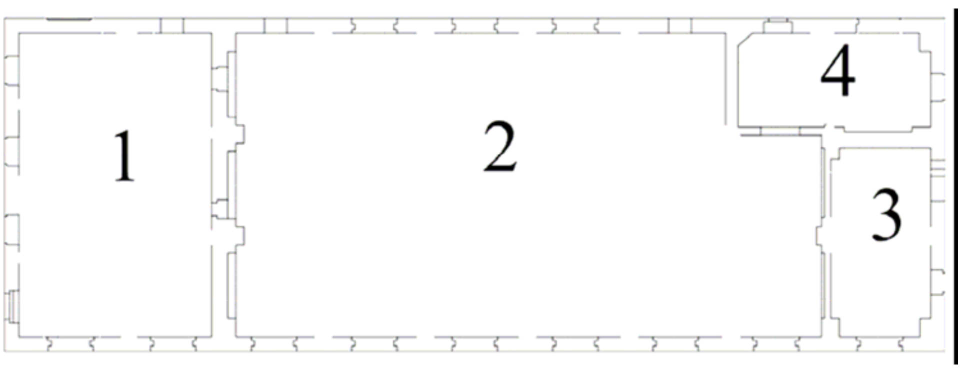



figure 5.37 : ground floor zones

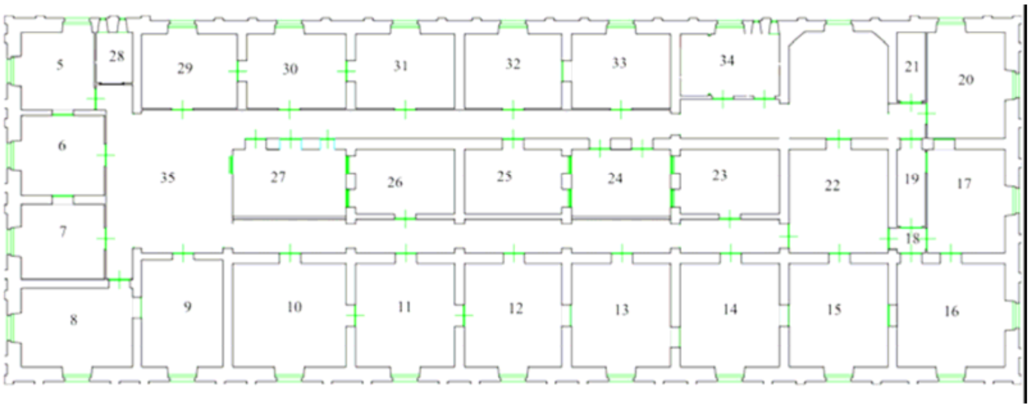



figure 5.38 : 1st floor zones

Figure 5.39 shows the Simulink simulator building layout: especially it is possible to see the main subsystems: Building, Central thermal control unit (which manages input / output and future management logic), block power consumption, and display block results (Scopes). The following figures show the details of the subsystems.

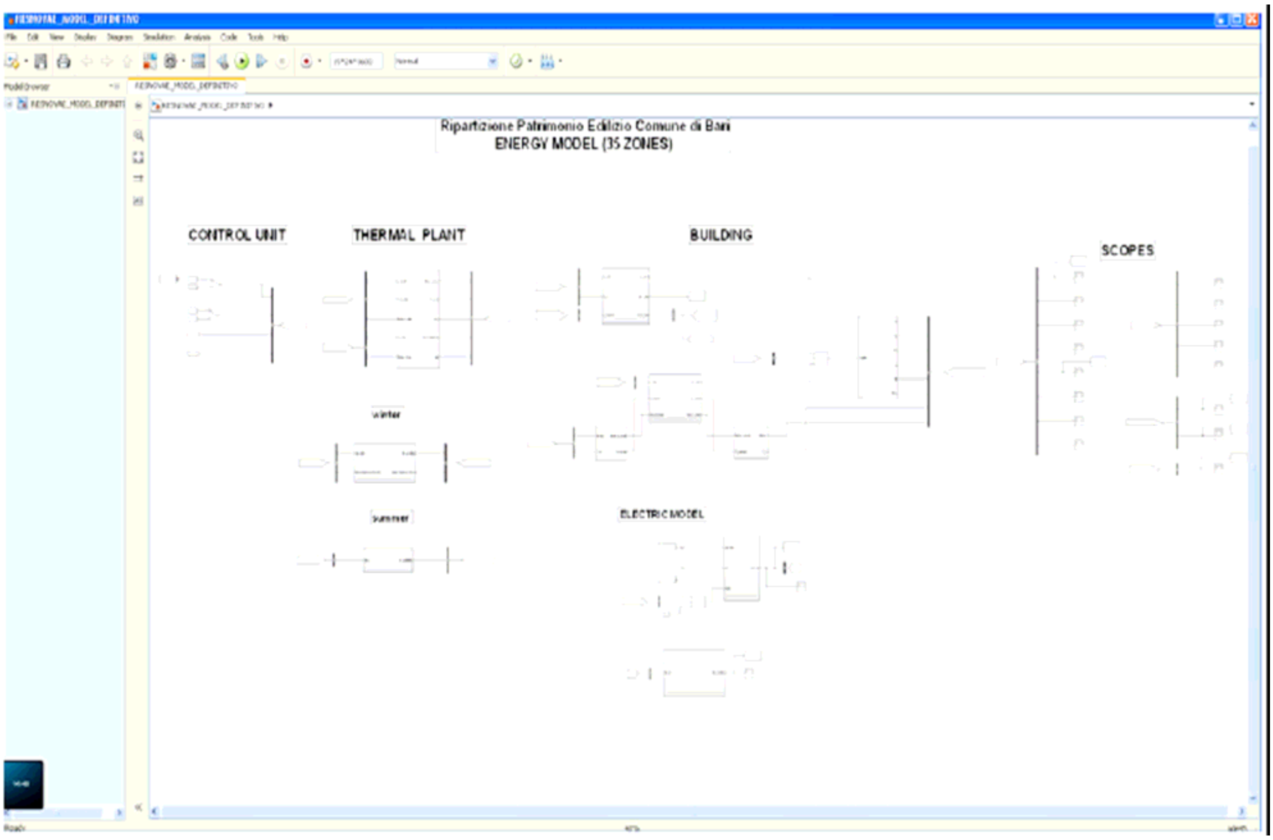



Figure 5.39 : thermal simulation layout

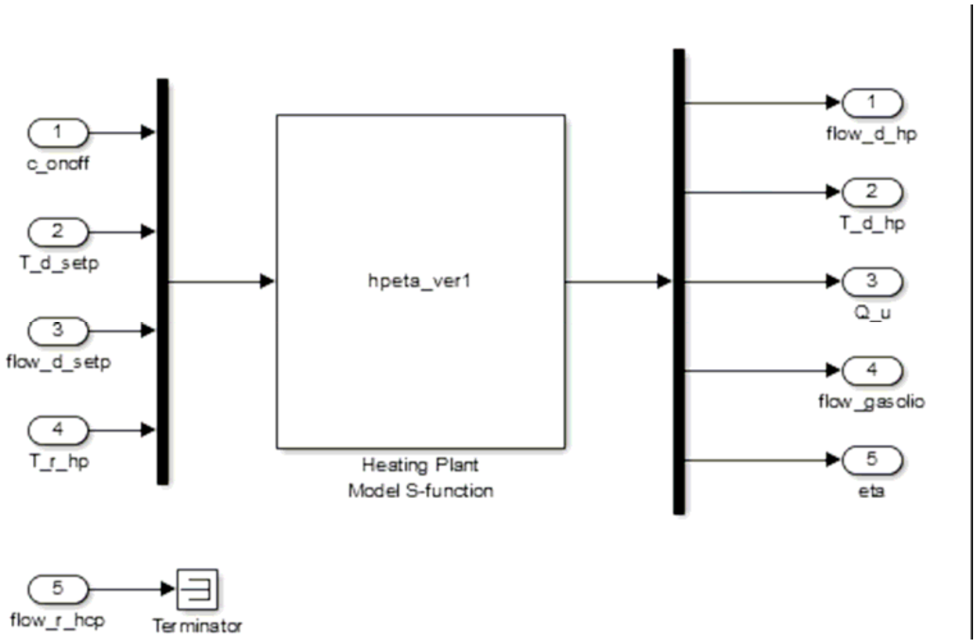



figure 5.40 : thermal subsystem layout

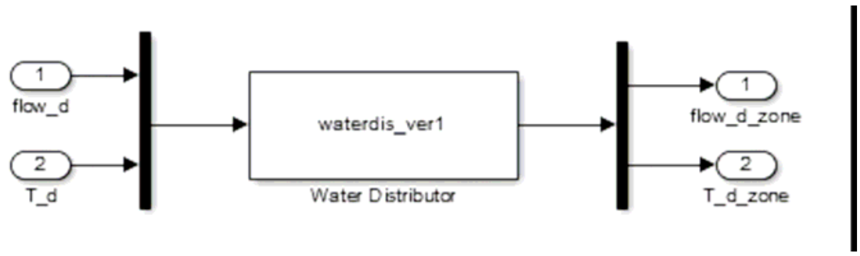



figure 5.41 : distribution subsystem layout

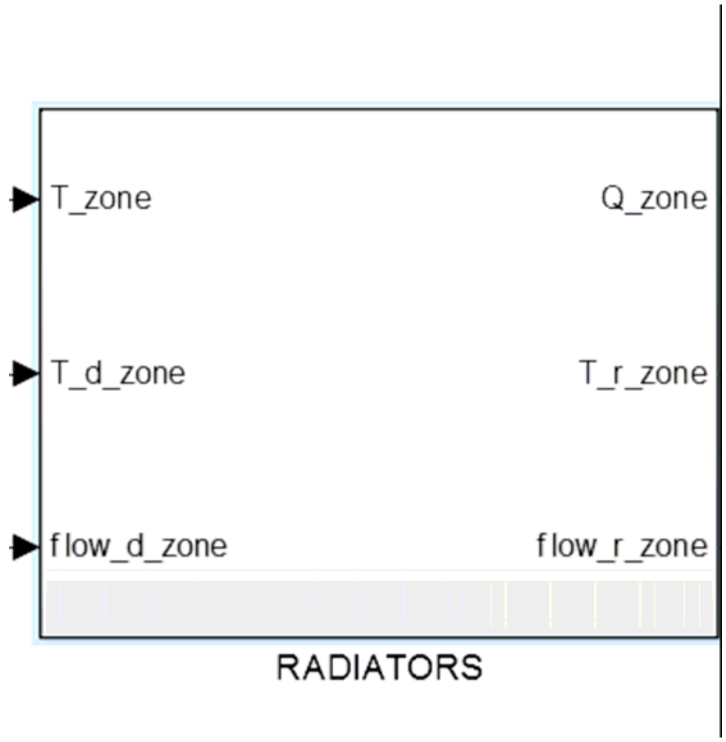



figure 5.42: radiator subsystem layout

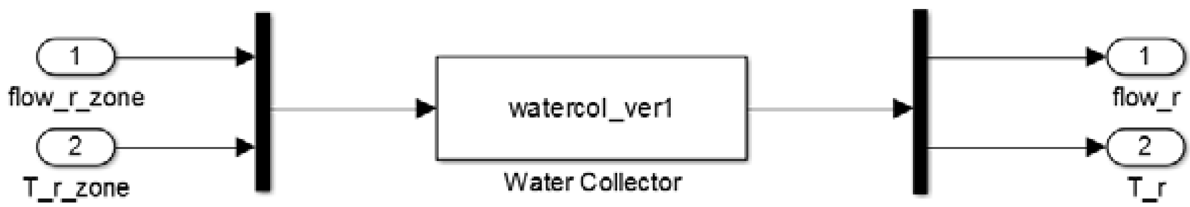



figure 5.43: water collector subsystem layout

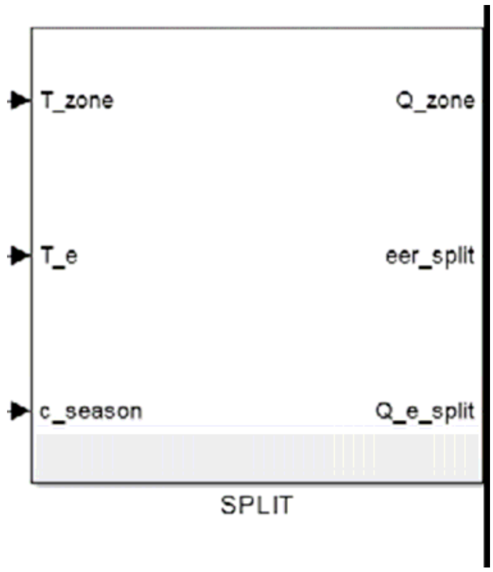



figure 5.44 : conditioning subsystem layout

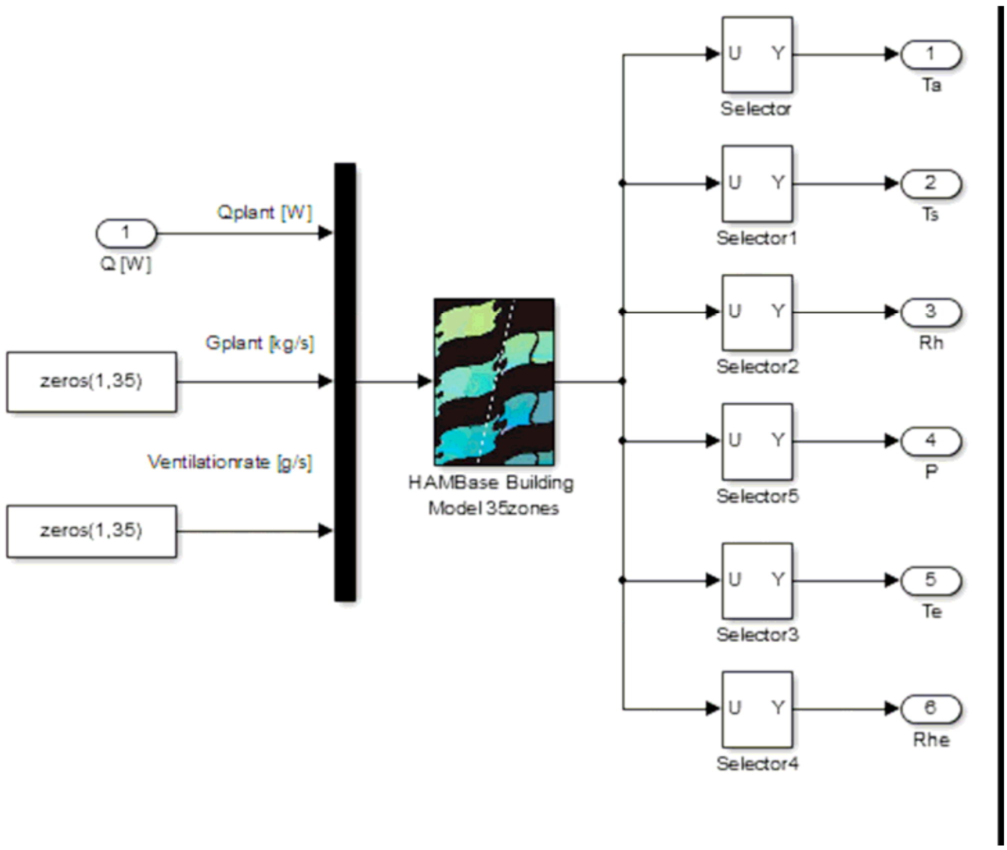



figure 5.45 : HAMBase subsystem layout

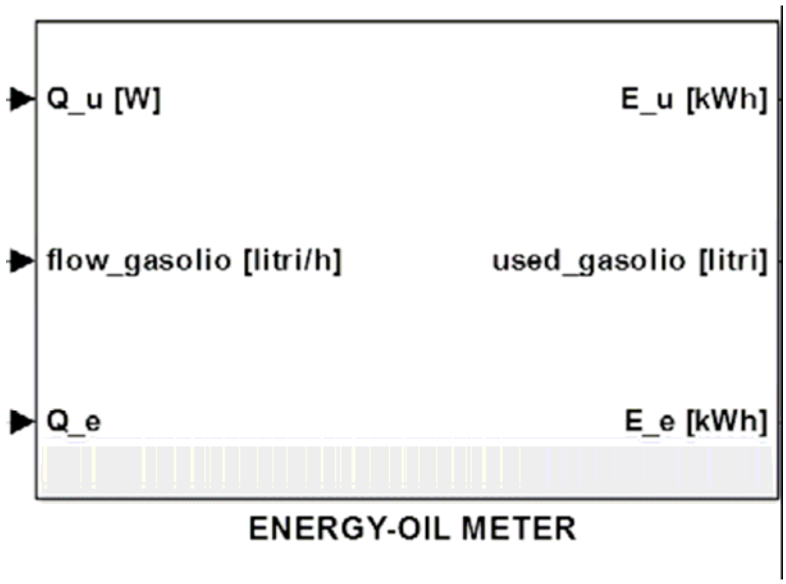



figure 5.46 : metering subsystem layout

### 5.5.2 Experimentation

In this paragraph we report, the simulation results obtained with the model described in the previous paragraph . Preliminarily considerations are reported regarding the data processing and the simulation speed. Then we will focus on analyzing trends obtained for the thermodynamic variable of interest. The purpose of this paragraph is to highlight the potential of simulator developed.

Validation and accurancy analisys, as carried out for the F40 building, was not possible because of lack of real data.

Firstly, it has to be clarified how the data processing takes place within the software HAMbase. The program solves the differential equations to compute the thermodynamic variables, therefore this condition strongly affects computational speed if you choose a simulation period very long or by increasing the characterization of the building complicating the geometry or by entering many microclimate areas.

Ultimately the processing time of the data will be a function of the following conditions:

- Time frame that you want to simulate (day, week, month, season, year);
- level of detail of the building.

As described previously the calculation process within HAMbase considers three general input conditions which are:

- Weather;
- Geometry, orientation and characteristics of the building;
- HVAC systems (Heating, Cooling) contained in s-function.

The simulations were performed for the model of the building in 35 climatic zones for the town of Bari. Simulations are:

- Modes free-running winter: this mode simulates the behavior the building without thermal plants on. It will present the trends of temperature inside the premises without heating;
- Modes free-running summer: this mode simulates the behavior of the building without conditioning systems switched on. It will present the trends of temperature inside the premises without heating;
- Modes free-running winter: this mode simulates the behavior the building with thermal plants on. In addition to the data of internal temperature, maintained with the thermostat, it will also show data of submissiveness radiator and consumption of the plant Thermal.
- Modes free-running summer: this mode simulates the behavior of the building with split on.

The model simulated the building was divided into 35 micro-climatic zones, including 4 on the ground floor and 31 to first floor. The simulated periods were 7 to 21 January for the winter and the first fifteen days of July for summer. It is shown below for both seasons charts inside temperature obtained in any path (ie not connected with the thermal plants).

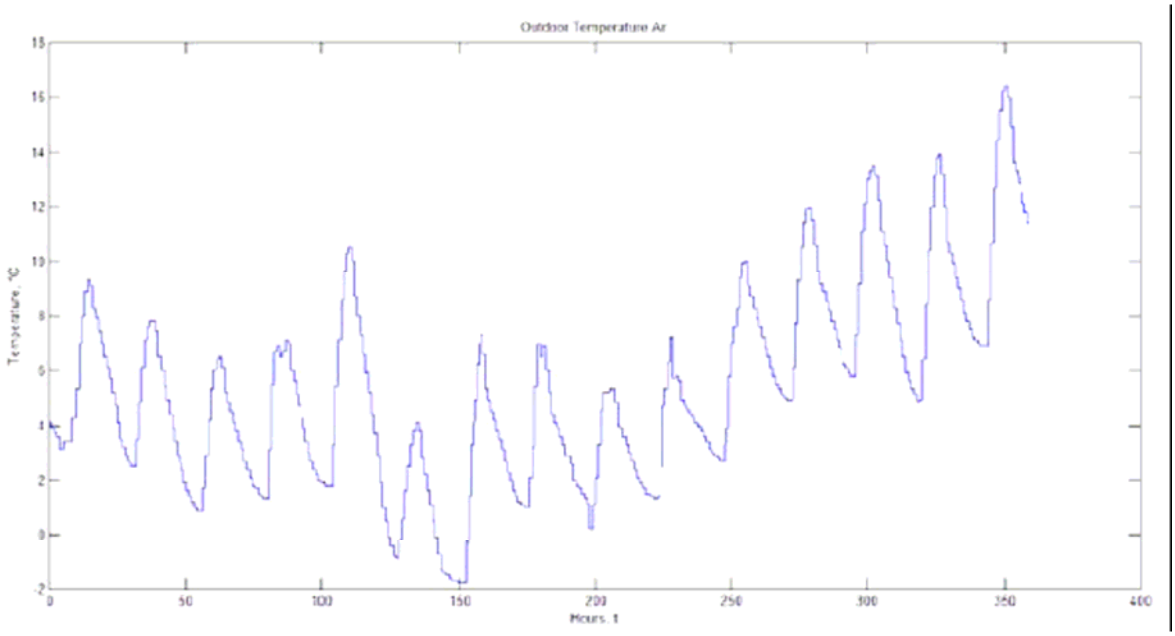



figure 5.46 : winter outdoor temperature

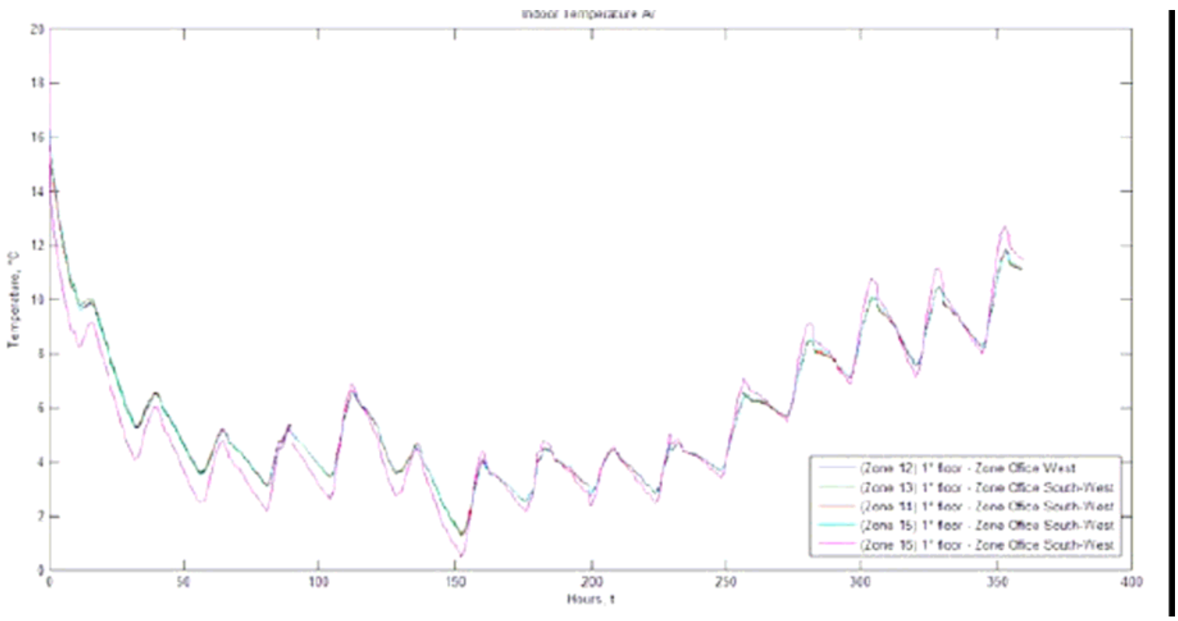



Figure 5.47 : free running winter, indoor temperature example

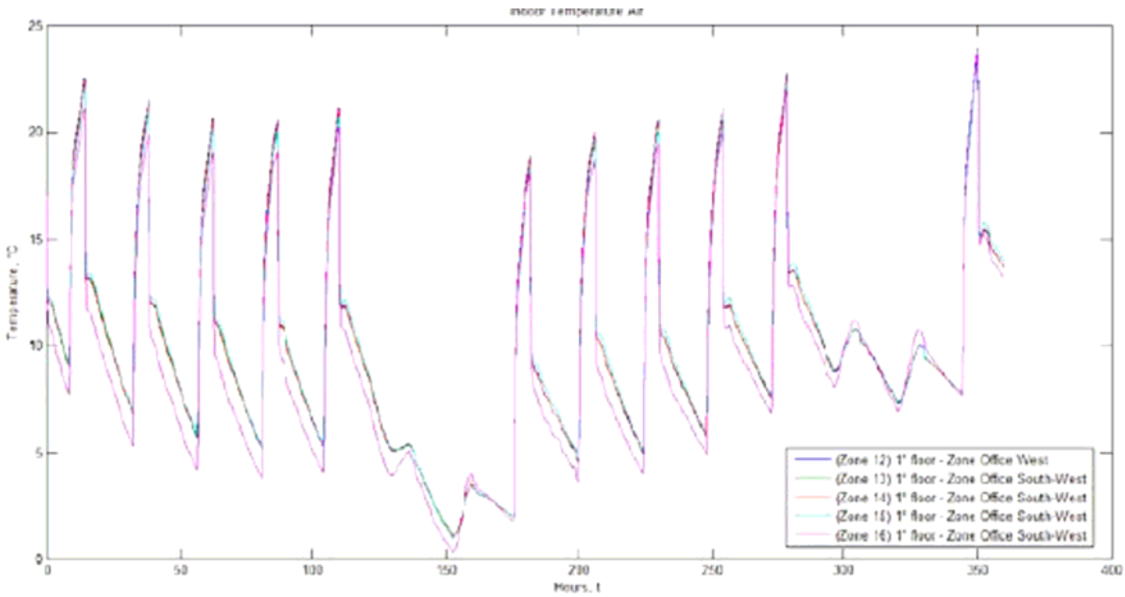



figure 5.48 : winter, indoor temperature example

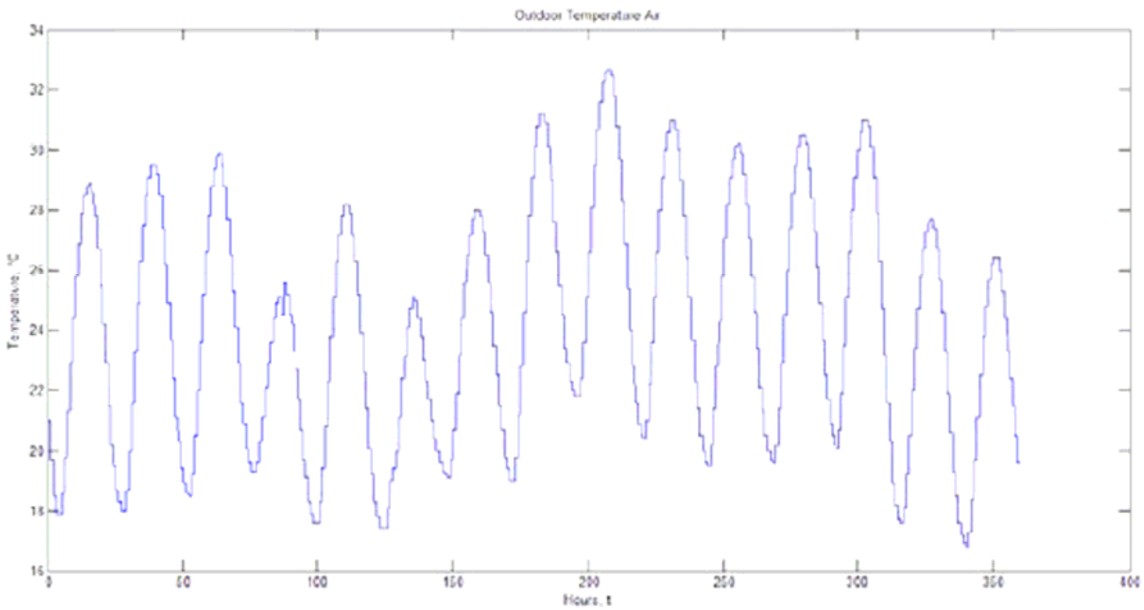



figure 5.49 : summer outdoor temperature

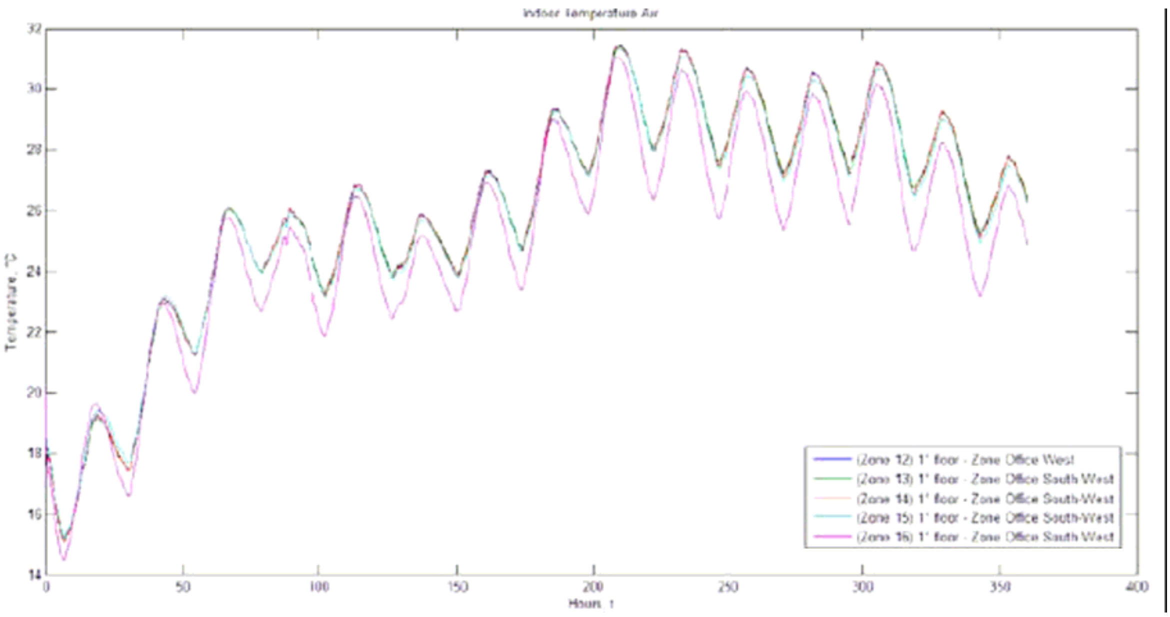



figure 5.50 : free running summer, indoor temperature example

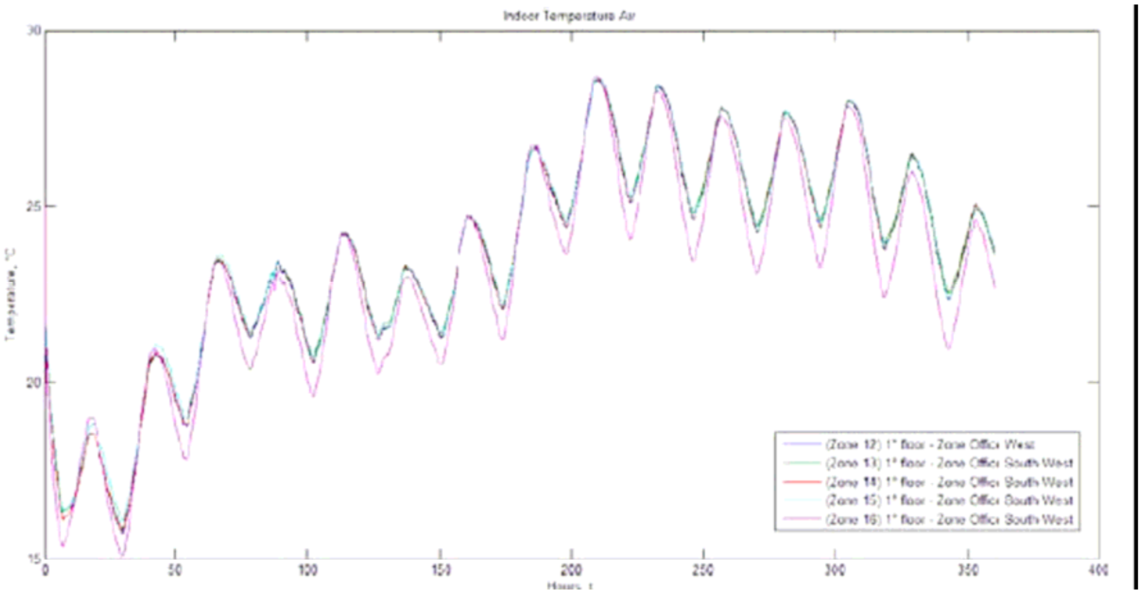



figure 5.51: summer, indoor temperature example

lastly, in the last graph it is shown the thermal energy consuption for the winter season.

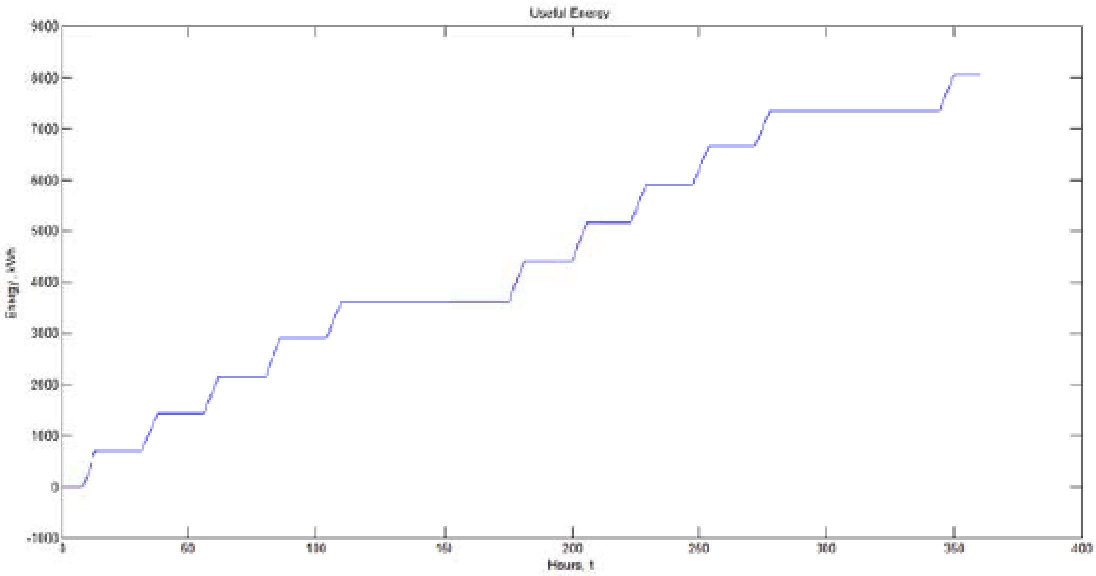



figure 5.52 : thermal energy consumption

This paragraph has presented the activities of the development of a simulator of energy consumption (electrical and thermal) of the municipal building of the Division of Building Heritage of the city of Bari. The activity was carried out in collaboration with the Department of Engineering Industrial and Mathematical Sciences of the Polytechnic University of Marche as part of the RES NOVAE project concerning the city of Bari. The simulator developed has been designed in such a way as to be used in a flexible manner to the definition of policies of active demand management in an optical of reducing consumption and maintaining occupant comfort.

The simulation results show a good operation of the simulator. However, the next phase will be the validation of the model on the basis of real data from the sensors installed in the building object of the present research.

Optimization results

The winter season that was simulated runs from December 21 to March 20. The optimization strategy involves :

1. The identification of optimal seasonal Pareto fronts. Each single front is constructed with points that have a flow temperature of the water constant (in a range of from 40 ° C to 80 ° C in step 5). Every single point of the front represents a different temperature of the thermostatic valve (in a range of from 18 ° C to 22 ° C to 0.5 ° C step). They will then have 9 different fronts (one for each inlet temperature) each of which consists in turn of 9 different points (one for each temperature of the thermostatic valve). As already mentioned, at every point of the front is associated a value of seasonal consumption and a value of PPD (averaged over the whole season in the sun hours (8-19) only for the active zones actually heated);

2. The choice of one among the points of the front. This choice is dictated by the need to comply with the UNI EN ISO 7730 on the microclimate in the workplace moderate. It is expected that the percentage of dissatisfied never exceeds 10% of the staff in the building. For this reason, we will choose a good point that present a PPD that:

$$PPD_{optimal} = \max(PPD < 10)$$

This is because, by maximizing the PPD (always remaining below the threshold established by law), it minimizes the consumption of energy;

3. The comparison of the profile with excellent seasonal profile not optimized, obtained based on the data of the simulations, in order to assess both the global energy saving is the trend of the PPD. The profile is optimized which is heated normally the building in Piazza del Ferrarese:

Set point thermostatic valves = 21 ° C;

Set point flow = 60 ° C.

The following shows the 9 Pareto fronts mentioned previously, in order to observe the differences that exist in terms of consumption and PPD. Each point corresponds to a specific pair of values of temperature (thermostatic valves and water supply) and identifies, in the abscissa and ordinate, respectively, the total consumption and the PPD seasonal average.

It can be seen, with increasing water flow temperature, the front corresponding feature points identify consumption gradually higher and lower average PPD. The same can be done by considering a single front. On it in fact, at equal flow temperature, increasing the temperature imposed on the thermostatic valve there will be more and more consumption and lower average PPD.

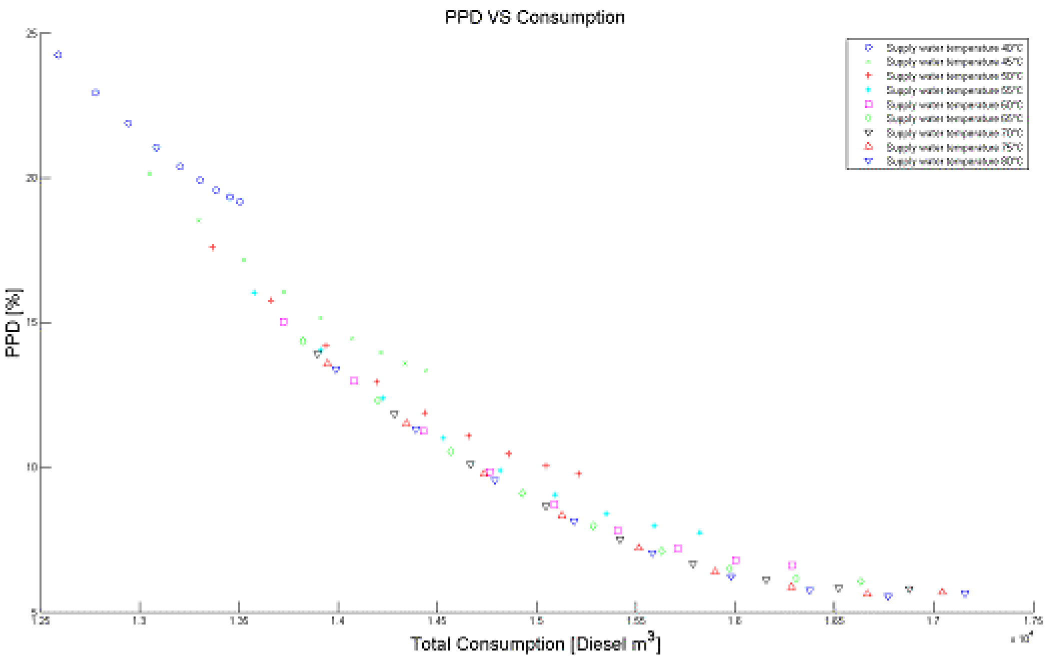



figure 5.53 : comparison of 9 different fronts with different supply water

By performing an enlargement in the area of interest it is possible to locate the point of the front corresponding to the baseline 21 ° C-60 ° C. It represents:

- Seasonal consumption: 15,710 $m^3$ of gas;
- PPD seasonal average 7.2%.

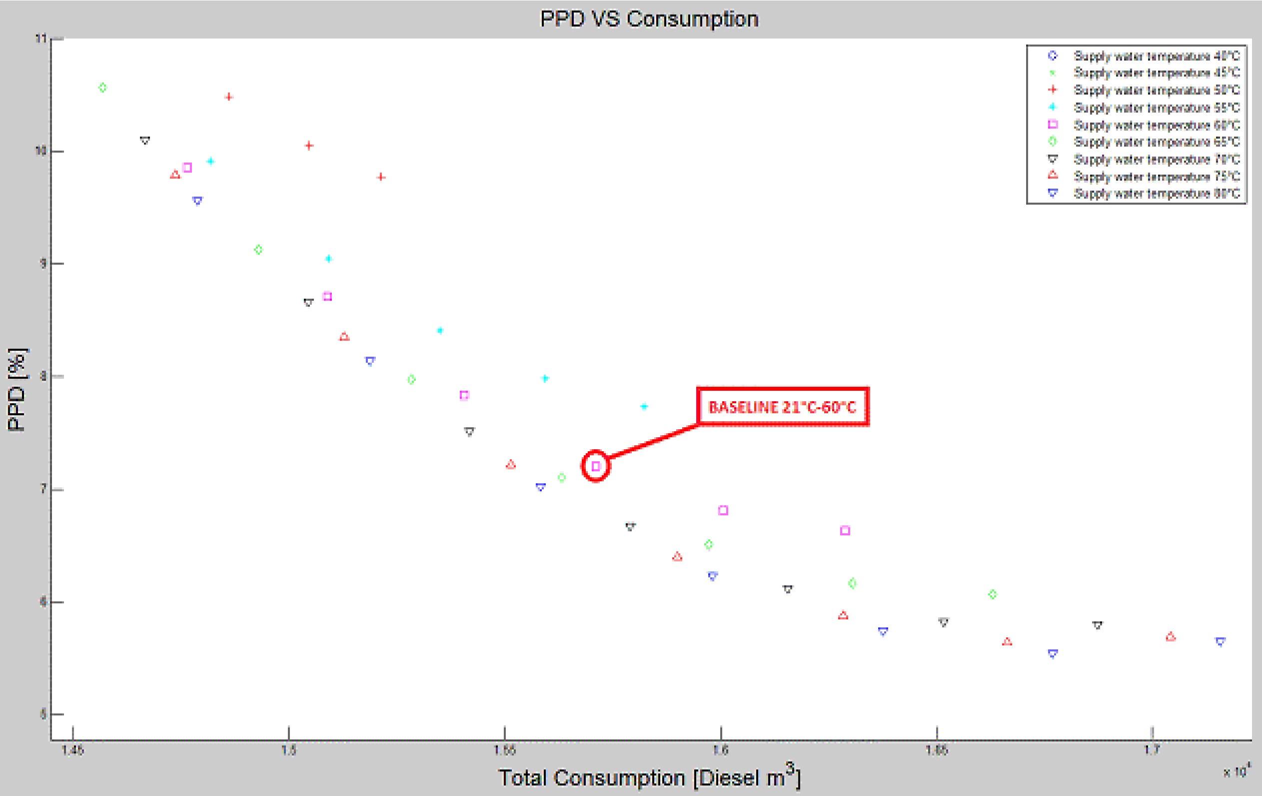


figure 5.54 : baseline identification

A first and quick observation allows to guess that the point in question is not a very good point. There is in fact a point belonging to another front, which presents, for the same PPD, a lower consumption. This point, highlighted in blue, corresponds to the torque set point 20 ° C-75 ° C and represents:

- Seasonal consumption: 15,520 m$^3$ of gas;
- PPD seasonal average 7.2%.

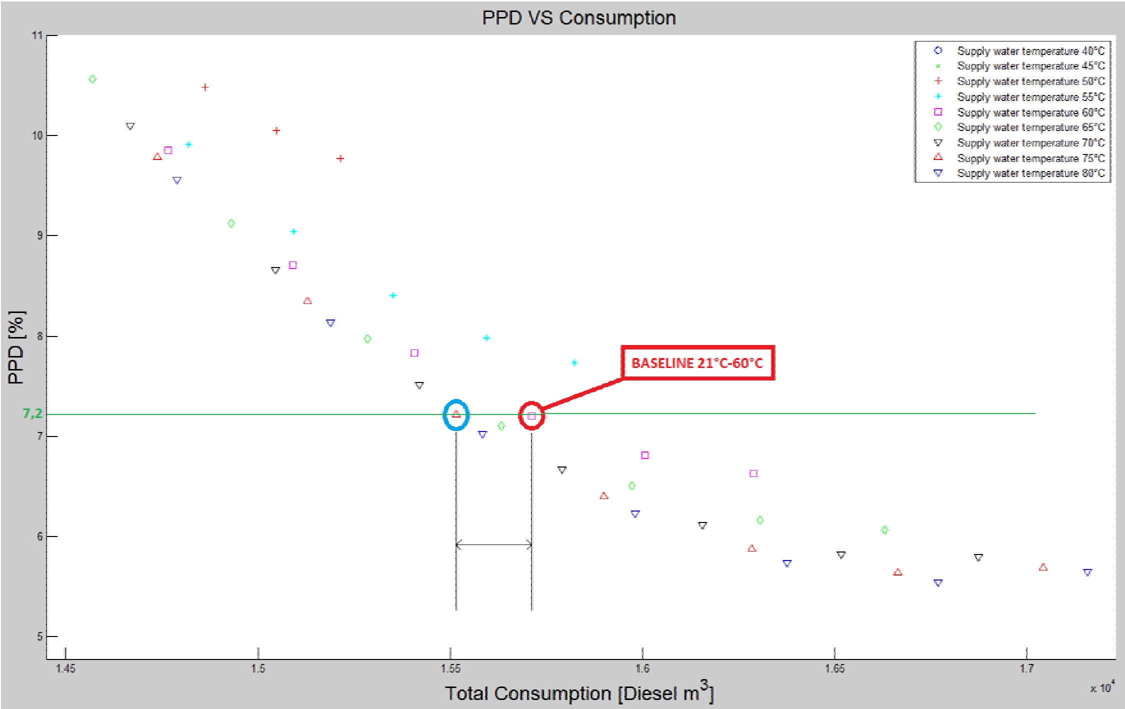



figure 5.55 : baseline comparison

However, the energy savings you get is almost negligible (1.2%).

To overcome this problem, let's choose a point that is at a higher PPD, always in compliance with UNI EN ISO 7730 therefore always below 10%.

The point in question, highlighted in gray corresponds to the torque set point 19 ° C-75 ° C and presents:

- Seasonal consumption: 14,740 $m^3$ of gas;
- PPD seasonal average 9.8%.

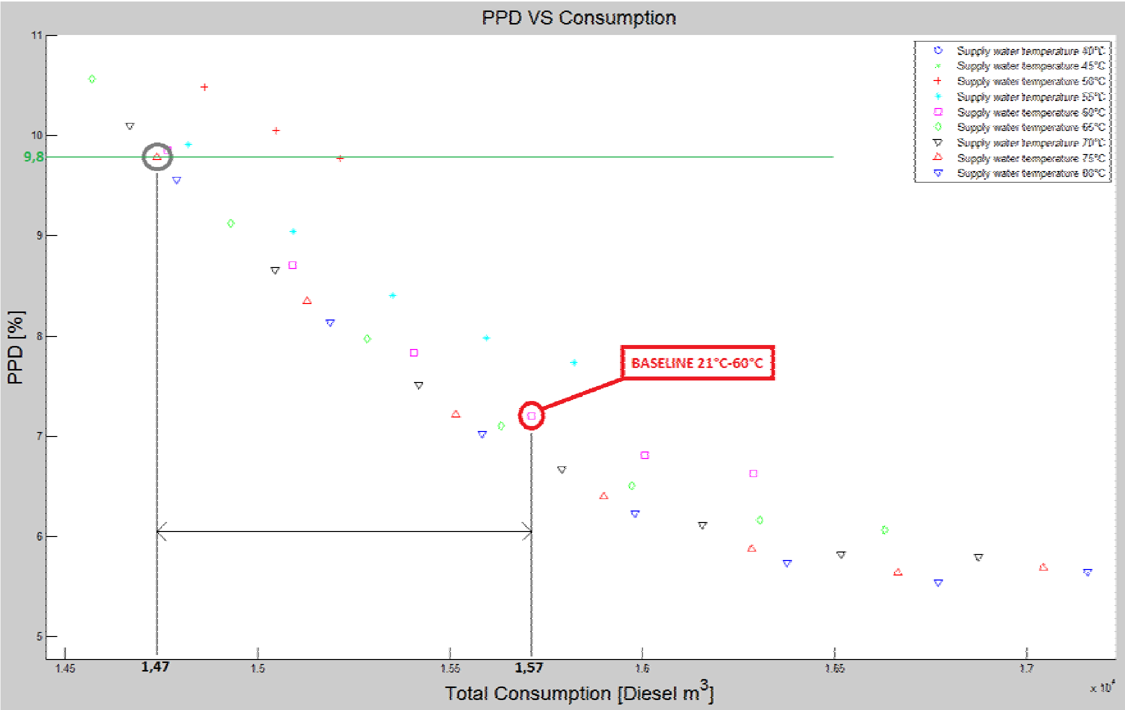



figure 5.56 : sesonal optimal point

By calculating the percentage increase of the PPD and the percentage decrease of energy consumption is possible to state that:

$$\nabla_{PPD} = 9{,}8 - 7{,}2 = 2{,}6$$

$$\nabla_{Consumption} = \frac{15710 - 14740}{15710} = 6{,}2$$

For the winter season considered, simulating 90 days, from December 21 to March 20, compared with an increase of discomfort 2.6%, it is possible to achieve energy savings of 6.2%. In addition, a daily check on the set point of thermostatic valves and water supply, together with an assessment taking into account also of the summer, could lead to a further increase in energy savings.

The second phase of the optimization focuses on daily optimization of the thermostats termovalvole setpoint and the flow temperature of the boiler. For computational reasons it has been chosen to simulate a shorter period compared to the previous (90 days). The daily optimization was made on 59 days and runs from 1 February to 31 March. For the aforesaid season, it was also repeated optimization seasonal. The margin improvement over the optimization consists in the adaptation of the seasonal adjustment as a function of external forcing (meteorological data). In particular, the external temperature has a considerable influence on the daily heat demand, then the adaptation of the setpoint settings on a daily basis may lead to actual savings in the face of a deterioration in the comfort during working hours almost negligible.

In order to identify a time slot of efficient regulation, they were defined and simulated different approaches:

- Daily ignition h24
- Daily ignition 2-14
- Daily ignition 6-14

The profiles ignition take into account the usage profile of users of the building, for which the power off has been scheduled at 14, while the switch-on time has been configured according to two different profiles so as to identify an ideal time window reduce the heat requirement without affecting comfort during working hours scheduled, or 8-14.

The optimization stage has been set by discretizing the search space:

| ***Variabile*** | ***Lower Bound*** | ***Upper Bound*** | ***Step*** |
|---|---|---|---|
| Thermostat SetPoint (°C) | 18 | 22 | 0.5 |
| Supplì water setpoint (°C) | 40 | 80 | 5 |

The optimization algorithm used, as in the F40 experimentation, is NSGA-II. Being the search space rather limited, the number of evaluations of the objective function has been limited considerably: it was used a population of 8 individuals for 4 generations. The figures show the Pareto fronts obtained with the different control approaches. It is clear that the outcome of the optimization is highly dependent on the weather: it happens that the same thermal energy consumption on different days involves a very different comfort. By comparing the optimal solutions obtained for the first 4 days of February with the outside temperature, you may notice that on February 1, relatively warm day, you get very low values of discomfort without requiring an excessive waste heat, while the February 4 to obtain the same level of comfort it is necessary about 50% of gas consumption.

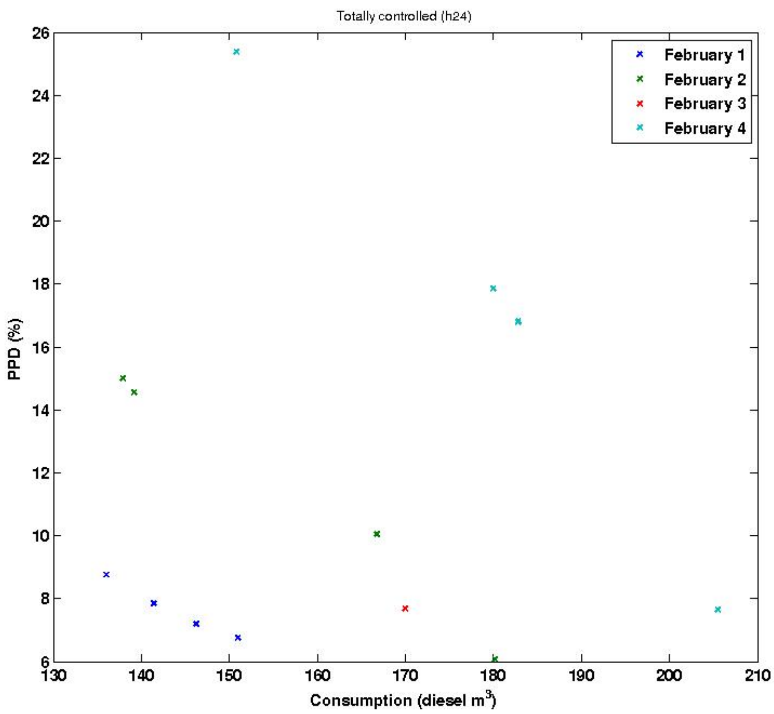



figure 5.57 : dayly optimization for h24 scenario

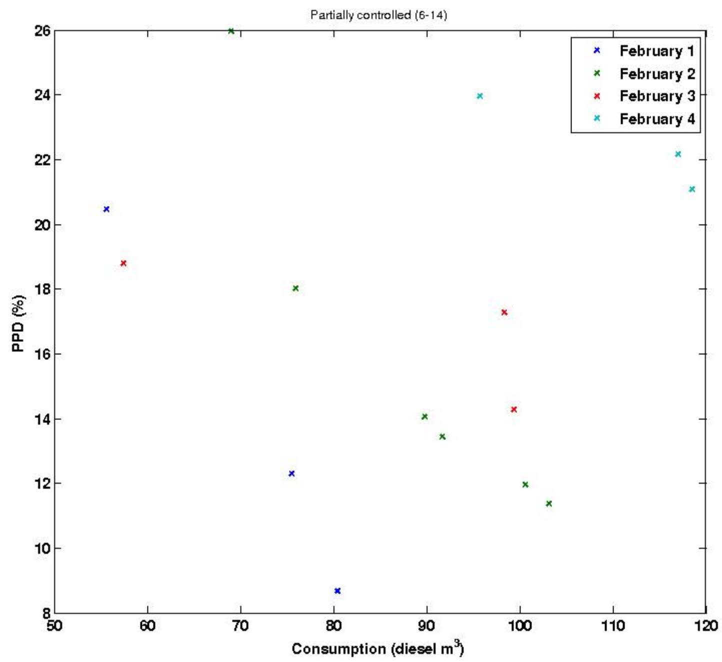



figure 5.58 : dayly optimization for 6-14 scenario

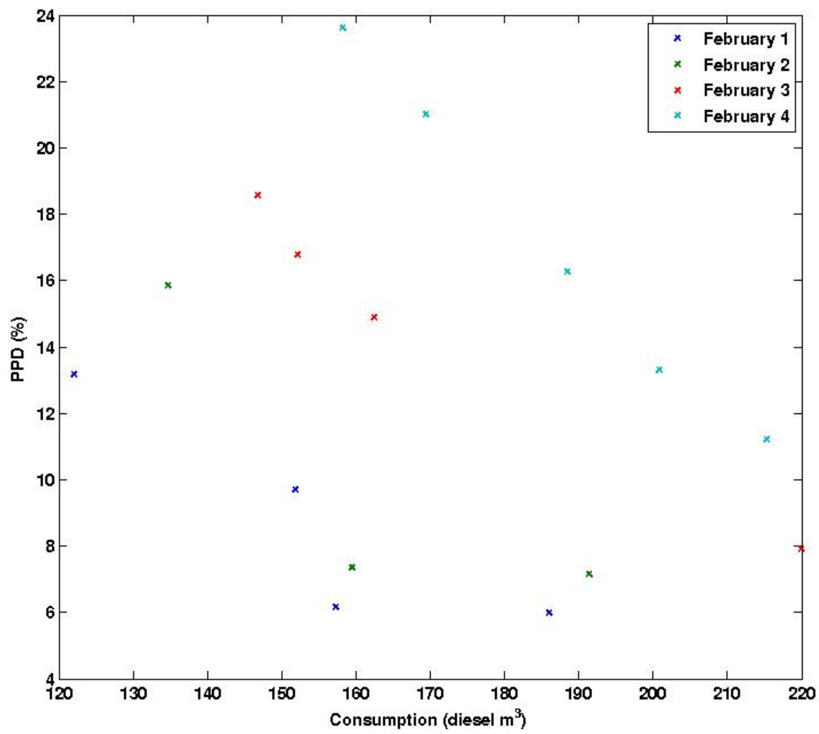



figure 5.59 : dayly optimization for 2-14 scenario

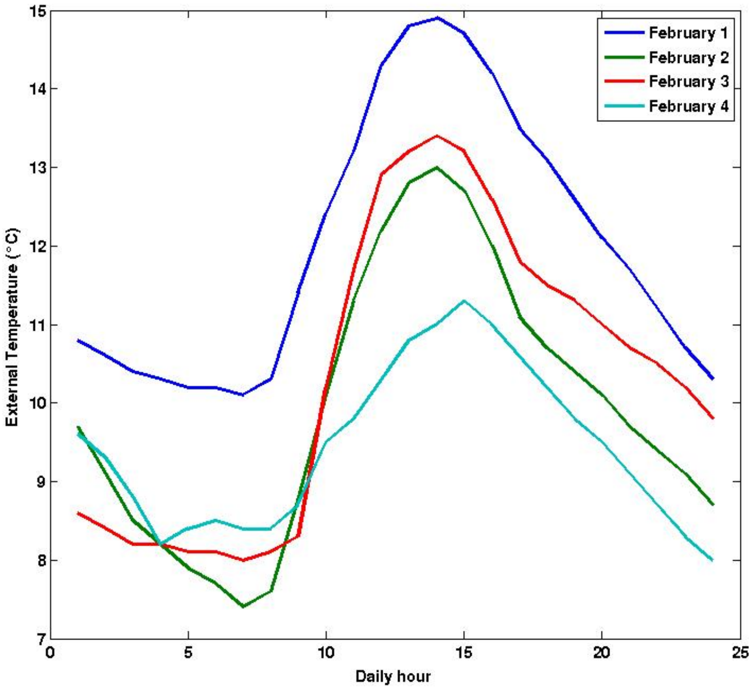



figure 5.60 : outdoor temperature

The next table summarizes the results, comparing them with the optimization and the seasonal baseline. The baseline applied (60-21 in the hours 6-14) in the real building is obtained by simulating the entire season with the same set point every day.

| | Baseline (h24) | Baseline (2-14) | Baseline (6-14) | Seasonal (h24) | Seasonal (2-14) | Seasonal (6-14) | Daily (h24) | Daily (2-14) | Daily (6-14) |
|---|---|---|---|---|---|---|---|---|---|
| **Supplied Water SP** | 60 | 60 | **60** | 75 | 75 | 75 | dynamic | dynamic | dynamic |
| **Thermostat SP** | 21 | 21 | **21** | 19 | 19 | 19 | dynamic | dynamic | dynamic |
| **Consumption ($m^3$)** | 9309 | 6477 | **5533** | 9146 | 6070 | 5221 | 8648 | 6120 | **5278** |
| **Mean PPD (%)** | 7,05 | 11,35 | **18,2** | 9,8 | 12,1 | 18.6 | 10,4 | 10,8 | **17,8** |
| **Saving** | | | | 1,6% | 6,3% | 5.6% | 7,1% | 5,5% | **4,7%** |

table 5.7: comparison of potential energy savings

In the table each optimization strategy is compared with the respective baseline in order to obtain the percentage of thermal energy spared. The applied baseline has proved not optimal because turning the heaters at 6 am, the plant fails to get the regime and does not guarantee adequate comfort to the occupants. The PPD is equal over 18%, abundantly beyond the threshold permitted by law.

The seasonal optimization, with heating active during the 24h presents, compared to an increase of PPD average of 2.75%, a decrease of energy consumption by 1.6%.

An improvement would be obtained by heating only within 2 to 14: this reduces the energy consumption of 6.3% compared to an increase of about 1% of PPD Avg.

The daily strategy, result of dynamic variation of the set point day by day, has resulted in energy savings of 7.1% when heated h24 and a 5.5% when heated 2-14. In both cases there was an increase of PPD average of 3% and 4%.

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# Chapter 6. Smart Building Networks Economics

The most significant request is now by municipalities, stimulated by a new approach to urban transformation that sees the local authority dialogue directly with the European community as the remarkable case of the Covenant of Mayors. The question is different in relation to the size and town vocation. In the case of large cities, the interest in these issues and the implementation of pilot projects is growing rapidly. The goal is to develop an innovative city model, sustainable and attractive place to invest. The question is both oriented to the construction of urban infrastructures and new services and is strongly innovation driven.

There are already areas recognizable of this new trend of big municipalities: design and implement genuine central city digital control (eg: urban dashboard), innovative and renewable power grids, functionalization of urban energy networks at the service of mobility ( eg. The smart lighting for the integration of public lighting and mobility), new public buildings with high efficiency up to the size of whole sustainable neighborhoods. Even tourism, which is one of the main economic lines in our country, is at the center of ideas and innovation, both in the field of urban mobility, the historical centers, both on the definition of new services for the use and protection of works of art works.

In the case of medium and small cities the focus is on the reduction of the main sources of expenditure in particular to achieve efficient and innovative systems for the management of public lighting, the efficiency of the public building heritage, the integration of renewable energy sources but also to improving the participation of citizens. All approaches emphasizes the need to combine innovation and competitiveness. In these cases, the expenditure limits imposed by the Stability Pact require municipalities the recourse to forms of funding; investment and therefore innovation must therefore be payback time limited, unlike the big cities for which you can promote medium-term projects with longer payback periods. These differences can be an advantage in terms of the methodology approach to the problem; small town then they prefer a design linked to more concrete aspects and competitive (enabling infrastructure, energy efficiency, solid business model) and in combination with the large urban centers is possible to formulate more ambitious development projects, which integrate existing technologies but are also projected towards more innovative horizons necessary to manage more complex scenarios.

The domestic offer is being articulated under the thrust of big players that, in fact, integrate SME systems for the delivery of new services; among these large companies stand out of the electric utilities companies and ICT networks. Among the most active are those in the world of electrical networks, those coming from the world of communications networks and those from the IT and consulting world. At present only a few big players (Telecom, IBM, ENEL) have an offer “smart city” more consolidated at an attractive level of integration in the energy and urban fabric in the e-government sector.

Many manufacturers of “vertical” systems and components: the most affected sectors are those of public lighting, automation, home automation, smart home appliances, automotive and mobility (including public and electric), the electronics and sensors , air-conditioning systems, and finally the world of sustainable construction. Finally, an important role is played by ESCO, multi-utilities, global service companies and municipal service managers. Many of these companies are integrating smart services within their supply and act as a vehicle of smart technologies that have been produced by the above mentioned companies.

The growing interest in energy saving and energy efficiency in cities are leading to an increased demand for automation systems in buildings, a market which in 2020 will touch one billion dollars.

Pike Research analysts have found that in the coming years, the intelligent automation systems for the management of the buildings will become even more popular, quadrupling their presence and bringing the market value to the billion dollars by 2020.

The report prepared by the company has estimated the present value of 291 million dollars in home automation services but, given the growing interest that companies are showing for automation systems, following the current development trend is expected exponential growth within the end of the decade.

While popular services currently can help companies reduce energy consumption and carbon emissions, the Pike report argues that large companies administrators will turn increasingly to Engineers of automation systems, so as to control the operation all equipment and optimizing consumption at any time, even remotely. “As the need for sophisticated building energy management systems grows worldwide, so grows the need for simpler solutions, turnkey solutions to unblock energy efficiency,” said senior research analyst Eric Bloom.

In this scenario, in collaboration with the faculty of Economics of University La Sapienza [1], a path of development of a Smart Cities (focussed on Energy and Buildings) projects assessment methodology is initiated, ie of a set of standard parameters with which projects can be evaluated.

Therefore, the main goal of this part of the work is the development of a tool for a common evaluation of the financial sustainability of smart cities projects.

## *6.1 The overall scenario*

For institutional investors the main obstacle to the financing of energy efficiency projects is represented by the “standardization” of the interventions, both on the energy / environmental plan both on the economic and financial evaluation plan.

The development of the methodology of a Smart City/Energy project meant to collect, through a common decoding, a set of initiatives responding to the different actors involved in the project. They were identified as the main actors involved:

- The end users, ie the municipalities, citizens, private actors (urban utilities, companies, etc.)
- Companies that implement the project and manage the infrastructure built
- The project’s financiers system
- The central and local government which realizes a policy

Each of these actors defines the “interests” in indicators that can be qualitative or quantitative.

Business cases also show important elements for the identification of the project results, such as:

- The product service
- The identification of the type of industrial chain involved and the main technologies used
- The territorial scale
- The order of magnitude of energy saved and tons of CO2 saved
- The reference economic scale
- The economic investment recovery mechanism hypothesized

The next step, which qualifies a business case and evaluates the expected benefits at the aggregate level, is the assessment of the annual “theoretical” replicability considering a period of time from 2014 to 2020, namely the number of situations on the Italian territory, for which is “theoretically” applicable the business case in question. This step is critical to move from the micro to the macro-economic importance evaluation.

For each Business Case (BC) it has been evaluated the "real" replicability, namely the number of cases on the Italian territory, for which, given the situation at hand, there are economic, structural conditions because the BC may be applied and develop.

For each BC it was defined then, made 100% of the theoretical replicability, the percentage of real annual replicability, considering a period from 2014 to 2020. It was also evaluated the impact of the policy actions on the real replicability, as for example, the introduction of regulatory obligations, which require the use of efficient technology, energy efficiency, energy saved direct incentives, tax reductions and charges on electricity tariffs / gas, easier access to credit to finance the efficient technological intervention, the elimination of barriers authorization, to direct actions to offer development, the development of financial products in which they might be involved public facilities (such as the Cassa Depositi e loans).

Finally, it was estimated that the total impact of the actual replicability of each BC can determine on the Italian system, in terms of reducing energy consumption, environmental impact and economic and cost-benefit ratio, ie the ratio between the costs incurred by the country system (policy) and "externalities" such as reducing energy consumption and environmental impact. The projection of these results is also essential in order to identify the best financing instruments.

Therefore, improving energy efficiency implies almost always a trade-off between investment and current expenditure. Businesses (and often families) therefore need to borrow to carry out energy saving measures; and that, often, it can be difficult. Bankability of energy efficiency projects has been very difficult as the use of innovative technologies in complex industrial processes creates difficulties, as well as process, even risk-assessment by banks, creating a need to find other financing forms. However, in recent years, banks are focusing on energy efficiency. It's the same Italian Banking Association (ABI), which provides an important fact: in the period from 2007 to 2012, banks have given loan of around 25 billion euro, of which over 12 billion in the past two years. The role of banks in the development of a green economy does not reveal itself only in terms of financing but also through the implementation of green projects in-house, both in terms of process optimization and investments made at the park managed real estate. Therefore, energy efficiency is a topic characterized by aspects of great interest. The concept of saving is a strong point of attraction, due to the cost savings convergence and primary resources, environmental and energy.

However, there are also critical issues, such as the economic situation, uncertainty and fragmentation in the regulatory framework. A weak point is also in the fact that to put in place a structure within the bank, able to understand a business model and target market, it is necessary that the initiatives dimensions are such as to justify ' intervention of a specialized structure. And so there should find a common language between companies and banks. It is therefore recommended an aggregation of significant size so that the investment banking world can enter this fields involving skills. The hope is that operators, banking and industrial system and normative-regulatory system are able to build a closed model sufficiently standardized to be understood and reproduced. Banks, examining a project, make a corporate valuation of the company, essential for understanding the reliability, the life of the plant pending, the user and the company. This goes with a project evaluation that puts the bank in a position to understand the mechanisms, estimate flows expected on the basis of the achievable savings and build an ad hoc funding. Where present, there is need to have a certain duration of the incentives, whether as a result return on invested capital and is the light of the reimbursement of the debt contract with the bank to finance the investment. For financial institutions, the problem is not the quantum of the incentive but the certainty that is guaranteed. For the bank it is essential an evaluation centered on the quality of the project and its ability to generate cash flows over time which can guarantee the debt service. The revenue streams will have to be assured in time and not be influenced by external events in their amount, so as to ensure the effective armouring of the project to the credit institution, which constitutes the basic prerequisite for its bankability. In general, however, going beyond the above-mentioned problems, according to financial institutions will be the green economy sector to boost investment and to contribute to economic recovery because during the crisis, this sector has made the largest investments in the territory, in contrast with the general economic trend. The recognition also from the financial system of the importance of energy for economic recovery is doubly important because in the value chain of energy efficiency sector is characterized by a strong presence of Italian companies.

## *6.2 Methodology description*

The proposed method is a first attempt to model and quantify the most important technical-economic variables in order to examine the economics of different intervention scenarios in a "building network management" to different scales and for different application areas. The analyzer is focused on"offices" and "schools."

This tool is designed taking as a model a number of interventions made on the F40 building (building highly representative offices of the sector). This building, which is part of the experimental project of the Smart Village in ENEA Casaccia, is being studied for several years in order to validate on a real case methodologies developed, oriented to the integrated management of a network of buildings, which is was made possible thanks to the studies carried out on the cluster, that is, on a network of nine buildings that are always part of the Smart Village project. The extension of the results at larger scales is very plausible but should be postponed to a wider coverage (at least 20-30 buildings) because it can be considered stable and inclusive of different types of buildings. The results so far obtained are therefore related exactly to the extrapolation of this building (all data were normalized) on identical buildings networks whose characteristics can be described parametrically.

The purpose of the simulator is to show, depending on the user's preferences, a series of economic results which allow to evaluate the implementation of monitoring and control systems for the management of a network of buildings. Such energy management in buildings aims to optimize energy consumption making them more efficient and is based on a diagnostic system and centralized optimization that could lead to significant energy and cost savings with investment costs being based mainly on automation and intelligence.

The user, who in turn insert the inputs into the computer, will be able to observe the behavior of a network of buildings with the same characteristics, which will be described in the following paragraphs. The computer, at the time, is limited to the fact that the network of buildings has characteristics identical for all; But you can get more detailed results by treating each building separately and then inserting into computer inputs refer to individual buildings. In addition, the computer is designed for the tertiary sector and in particular provides the results of a network of buildings that may be related to both offices at both schools. The choice between offices and schools involves several logical systems, such as for schools will provide different logical as regards the electrical equipment and it must be set to zero because the cooling is not provided in them.

This calculator is developed on five sheets, that will be covered in detail in the following paragraphs:

- INPUT SHEET
- COST SHEET
- CONSUMPTION & SAVING SHEET
- ECONOMIC ANALYSIS SHEET
- SUMMARY SHEET

### 6.2.1 Inputs

The first sheet shows all the inputs that the customer / user must enter to use this calculator. The inputs, which refer to the structural characteristics of the buildings, hours of work, to electronic equipment that are used and the system you choose to install, have been grouped into categories:

1. REFERENCE BUILDING

2. INSTALLATION
3. JOB
4. EQUIPMENT and TECHNOLOGIES
5. HEATING
6. COOLING

1. Reference Building

- Type of buildings: in which you have the chance to make a selection between offices and schools.
- Sector: where you have the option to choose between public or private sector.
- Number of buildings: that allows to have a standard calculation of a network of buildings assuming that they are all with the same characteristics.
- Number of Sites of implementation: the site can be identified, for example in two buildings that are close.
- No. of floors per building: in this cell, if the buildings are not all the same and so do not have the same number of floors you have the possibility to insert a mathematical average.
- Number of floor areas: with a number of flat areas means or an entire floor or a set of rooms, for example four, which constitute a zone, and thus have more zones for each floor.
- Square meters average per floor
- Number of offices for building / Number of classes per school

2. Installation

- Monitoring: that can be done to the building level or area level. The higher the level of detail the greater the ability to monitor in particular the buildings and get more data streams that allow us to analyze the behavior of the network, monitoring of power consumption and have savings on maintenance
- Control: When the call is monitored for level building you can choose between control or no control at the building level; however if it is done for a monitoring zone level you can choose between no supervision or control at the level of building or at the zone level or room level. The higher the level of detail greater the energy savings that can be obtained.
- System: refers to the choice of the network system where you can choose from the hosting option in the cloud and on-site installation of the server.

3. Job

- Number of employees per building
- Working Hours
- Opening hours: (it has been determined that the opening hours are greater than working ones)

- Working days a week
- Working days per year

4. <u>Equipment and technologies</u>

- Number of seats for building
- Equipment supplied per seat
- Percentage of working places that can be turned off at night
- Type of lamps: LED or incandescent lamps or CFL
- Advanced: Computer Power (W)
- Advanced: Power equipment supplied (W)

5. <u>Heating</u>

- Distribution System Heating: Options are radiant bodies or fan coil or Split or Fan Coil + ATU or ATU, which will be chosen based on the type of electric and thermal system installed and vary by the type of operation and fuel.
- Heating Oil: for radiant bodies, Fan Coil, Fan Coil + ATU, ATU selection will be made on gas or diesel or electric; as regards the Split there is only one choice, which is the electric.
- Specific primary energy (space heating) – Eph (kWh / m2a)

6. <u>Cooling</u>

- Distribution System Cooling: Fan Coil or Split
- Efficiency (Energy Output / Energy Input)
- Housing Specific Energy Requirement (summer cooling) – Ec (kWh / m2a)

### 6.2.2 Costs

The second sheet lists all the costs that will make up the CAPEX, ie the invested capital, and the OPEX, and thus the working or management capital (they are the costs that will be incurred every year).  The mai costs are : sensors, installation, operating

<u>1. sensors costs</u>

The costs of the sensors have been divided according to their use as monitoring or control; They were also divided according to level of intervention (for building, area, room) to calculate the number.

The sensors installed for monitoring, which therefore allows the transmission of data in order to make diagnostic, are (in brakets the unit cost):

- Network analizer (1200€)
- Thermal energy counter (2500€)
- Presence sensor (55€)
- Temperature/Umidity sensor (130€)
- Communication module (200€)
- Remote control board (450€)

The installation of these sensors varies according to the type of detail that is chosen , that is at building level or area level, and it is:

| ***Number*** | |
|---|---|
| ***Building level*** | ***Area level*** |
| 40000 | 60000 |
| 20000 | 0 |
| 20000 | 60000 |
| 20000 | 60000 |
| 20000 | 60000 |
| 40000 | 60000 |

Table 6.1 : sensors costs

Therefore the total costs are :

| ***Building level*** | ***Area level*** |
|---|---|
| 48000000 | 72000000 |
| 50000000 | 0 |
| 1100000 | 3300000 |
| 2600000 | 7800000 |
| 4000000 | 12000000 |
| 18000000 | 27000000 |

Table 6.2 : total costs

The actuators which allow control and optimization are (in brakets the unit cost):

- Electrical lines controller (1770€)
- 3 way valve controller (5600€)
- winter conditioning controller (400)

- summer conditioning controller (0)
- Temperature remote control (0)
- Lighting switch within presence sensor (250€)
- EMF control (50€)

The installation of these sensors varies according to the type of detail that is chosen , that is at building level, area or room level, and it is:

| ***Number*** | | |
|---|---|---|
| ***Building level*** | ***Area level*** | ***Room level*** |
| 1 | 3 | 0 |
| 1 | 3 | 0 |
| 0 | 0 | 50 |
| 0 | 0 | 50 |
| 0 | 0 | 50 |
| 0 | 0 | 62 |
| 0 | 0 | 50 |

Table 6.3 : sensors number

Therefore the total costs are :

| ***Building level*** | ***Area level*** | ***Room level*** |
|---|---|---|
| 1770 | 5310 | 0 |
| 5600 | 16800 | 0 |
| 0 | 0 | 20000 |
| 0 | 0 | 0 |
| 0 | 0 | 0 |
| 0 | 0 | 15500 |
| 0 | 0 | 2500 |

Table 6.4 : total costs

A summary table gives the number of required sensors and its total cost depending on the type of installation and the type of activity (monitoring only or monitoring flanked control).

| Type | Monitoring | Control | total |
|---|---|---|---|
| Costs | 12290 | 67480 | 79770 |
| Num of sensors | 23 | 270 | 293 |

Table 6.5 : summary of costs

2. installation costs

There are reported both those related to the installation of sensors and those of the network. As regards the installation of sensors, there have been taken into account the costs of planning, installation and testing, audit, diagnostics calibration and optimization calibration. The network installation costs depend on the type and the features of the monitoring software / diagnostics and installation of the supervision system.

Costs of installation include:

- Design costs: that is 6% of equipment costs : 4786,2
- installation and testing costs that are 40% of the equipment costs : 31908
- Costs for the Audit: which are 4% of the equipment costs : 3190,8
- calibration costs for diagnostics: which are the 5% of the cost of equipment.: 614,5
- calibration costs for the control: which are the 10% of the cost of equipment.: 6748

The installation costs of the network are composed:

- In the case of hosting in the cloud for monitoring are measured:
  - BEMS software module for monitoring and diagnostics : 10000
  - BEMS equipment : 10000
  - BEMS license : 30000
- In the case of hosting in the cloud, and you also take into account costs of monitoring and control for:
  - NIS Software : 10000
  - Costs for the installation and testing of the supervision system: 5000
- In case of installation on site for monitoring:
  - BEMS software module for monitoring and diagnostics :10000
  - Server BEMS : 9583
  - BEMS equipment (es. PLCM) : 10000
  - BEMS license : 30000

3. operating costs

In the case of hosting in the cloud for monitoring:

- The cost of the Hosting Service : 10000
- The cost of the BEMS annual fee for monitoring and diagnostics : 220
- The cost for the maintenance of the BEMS : 10000

In the case of Hosting in the cloud for monitoring and control:

- Annual fee of the supervision system for control and optimization : 6000

In the on site monitoring:

- The cost of the BEMS annual fee for monitoring and diagnostics : 10000
- The cost for the maintenance of the BEMS : 220

In the case in place for monitoring and control:

- Annual fee of supervision system for control and optimization : 6000

At the end the sheet shows the total costs, the CAPEX and OPEX, ie respectively the capital that you have to invest and operational costs.

CAPEX = 192017,5

OPEX = 26220,4

In particular, the following is a summary that allows to see details of items that make up the capital invested depending on the choices.

So the voices that make up the investment are:

- the cost of the sensors, which will vary based on the type of system that you decide to install (only monitoring or control).
- installation costs related to sensors if you only make monitoring
- calibration costs when you control
- the cost of installation of the network.

Specifically, network costs reveal four types of different scenarios based on user choices:

- network costs with an installed system in place for monitoring only (they are all the costs relating to the BEMS)
- network costs with a system installed within the control (are the costs relating to the Control System)
- network costs with a system installed in Cloud Hosting for only monitoring (are all the costs relating to the BEMS)
- network costs with a system installed in Cloud Hosting with control (are the costs relating to the Control System)

| | |
|---|---|
| Sensors | 79770 |
| Installation | 40499,5 |
| Control calibration | 6748 |
| Network (monitoring) | 50000 |
| Control (hosting in cloud) | 15000 |
| Control (on site) | 0 |
| TOTAL | 192017,5 |

Table 6.6 : CAPEX

As you can see in detail in the table below, the operational costs vary with the choice of doing a monitoring system or several monitoring and control and the network system selected.

| | |
|---|---|
| Networking (monitoring) | 20200,4 |
| Control (hosting in cloud) | 0 |
| Control (on site) | 6000 |
| TOTAL | 26220,4 |

Table 6.6 : OPEX

### 6.2.3 Consumption & Savings

The various savings that are derived from different logic adopted are:

- Energy on Demand
- Optimization

The Logics of Energy on Demand are to provide the energy you need in the time and place in which you require. This results in significant energy savings because it allows to make services more efficient and reduce waste. It also allows to have a savings thanks to the fact to review the contract with suppliers of electrical or thermal energy, as for example by requiring the energy at certain times is cheaper than others. The Logics of optimization are those described in chapter 5. Below the percentages of savings resulting from Energy on Demand and the Optimization (as the average between winter and summer season), based on the level of detail of the intervention in the real case considered with measured data.

| | Saving % | | | Saving kWh | | |
|---|---|---|---|---|---|---|
| | Building | Area | Room | Building | Area | Room |
| Energy on demand | 6% | 12% | 16% | 18000 | 36000 | 48000 |
| Optimization | 14% | 14% | 14% | 42000 | 42000 | 42000 |
| TOTAL | 20% | 26% | 30% | 60000 | 78000 | 90000 |

Table 6.7 : Energy savings

Here the consumption measured in the study case

| | Yearly Consumption (kWh) | Yearly cost |
|---|---|---|
| Electricity (lights, emf,fans) | 84612 | 15230 |
| Heating (gas) | 50400 | 32256 |
| Cooling | 300000 | 54000 |
| TOTAL | 417732 | 101486 |

Table 6.8 : Energy consumption

### 6.2.4 Economic Analysis

In this section a series of calculations and economic indicators with the corresponding graphs on cash flows are reported.

Thus, there are the main results of the previous pages, which are dependent on the levels of monitoring and control and are also taken into account other data such as energy costs, their respective rates of increase and the discount rate.

The electricity cost of € 0.18 has been taken by ENEA documents.

The cost of gas refers to 2014 was taken from the site of Enel, in particular by referring to the value for the month of August 2014 was made an average of all the costs of the various regions, coming to a result of 0.64€.

The rates of increase of the electricity and gas costs have been taken on the Authority's website for electricity, gas and water system; and, in particular, they were calculated:

Increase rate of electricity cost = (cost 2013 / Cost 2004) - 1 = 5.5%

This calculation was made on a report in electricity costs over the last nine years.

Increase rate of gas cost = (cost 2013/2009 cost) - 1 = 7.6%

This calculation, however, was made on the basis of a ratio of gas costs over the last five years.

Lastly, the discount rate of 0.4% was taken from an internet search and refers to 2014.

| | |
|---|---|
| INVESTMENT | €192.018 |
| ELECTRIC SAVING | 116.667 |
| GAS SAVING | 15.120 |
| OPEX | €26.220 |
| ELECTRICITY COST (€/kWh) | 0,18 |
| ELECTRICITY COST INCREASE RATE | 5,5% |
| GAS COST (€/M3) | 0,64 |

| | |
|---|---|
| GAS COST INCREASE RATE | 7,6% |
| DISCOUNT RATE | 0,4% |
| WHITE CERTIFICATES VALUE | €144 |
| MAINTENANCE SAVING | €8.466 |

Table 6.9 : summary of the main economic fateures

Moreover, a set of financial results and profitability ratios for assessing whether the investment convenience are given. The years considered refer to an estimate of the average life of the sensors set to 15 years.

The electrical and thermal savings are derived from the total electrical and thermal savings previously reported and were calculated taking account of the cost of electricity and gas and the rate of increase of the cost of electricity and gas;

According to the following formula

$$(R.En * C.En) * (T+1)^n$$

where

R.En = electricity savings (kWh) or heat (kWh)

C.En = cost electricity (kWh)

T = rate of increase in electricity cost (€ / kWh) or thermal (€ / m3)

n = year

Moreover, the White Certificates have been considered.

The promotion of energy conservation through the mechanism of white certificates (also known as Energy Efficiency) has been provided by the Ministerial Decrees of 20 July 2004 (dm 20.7.04 electricity, dm 20/7/04 gas and subsequent amendments).

The decrees require that each year are set mandatory targets for savings, to final consumers, for distributors of electricity and natural gas distribution companies. The energy savings achieved as a result of interventions for improving energy efficiency in end-use is rewarded by the award of white certificates, which can be marketed. The companies can fulfill their obligation realizing energy efficiency improvement measures entitling to certificates, or buy such securities from third party companies. A certificate equivalent to the saving of a tons of oil equivalent (TOE).

Initially assigned to the AEEG, from February 2, 2013 the business of management, evaluation and certification of the related savings to energy efficiency projects submitted under the energy efficiency certificates mechanism has been transferred from the Energy Services Operator (ESO), in implementation of article 5, paragraphs 1 and 2 of the interministerial Order of 28 December 2012.

The possibility of exchanging white certificates allows distributors to comply with the obligation imposed by the decrees at the lowest cost, given the choice between directly realize the intervention or purchase an equivalent amount of certificates on the market. The sale of white certificates can take place through bilateral contracts or in a special market set up by GME (Electricity Market Operator).

The efficiency improvement interventions can be made by distributors directly or through subsidiaries, and companies in the field of energy services (ESCO) licensed.

There are four types of intervention, respectively, for savings of: electricity, natural gas, other fuels, fuels for transport.

Italy is the first country in the world to have applied the white certificate mechanism for the promotion of energy efficiency in end uses. Subsequently, France has applied a similar mechanism but different in scope and regulation of exchanges, which are bilateral. In the UK it has been in existence for many years of energy saving obligations on electricity sales companies and natural gas, but in this case the bilateral trade must first be approved by the regulator. Our white certificates mechanism and its normative regulation have been thoroughly investigated and analyzed by the European Commission, the International Agency for Energy and of a growing number of countries, both in Europe, and outside Europe (USA, Australia, Japan, Korea).

The EU Directive 32/2006, the European Commission has explicitly indicated the white certificates as one of the tools used to achieve the objective of reducing energy consumption by 2016 for a total value equal to 9% of the annual consumption of the 2002-2007 five-year period ( for Italy 10864982 TEP), and it predicted that in 2011 the same Commission to consider the introduction of a European white certificates market. ENEA is fully involved in the management mechanism of white certificates by the Authority for Electricity and Gas.

For 2014 it has been considered TEP 1 = 144 €.

This type of incentive is valid only for the first 5 years.

Based on fuel consumption you can be obtained a quantity of TEP that goes based on the achievement of a certain level of consumption for both electricity that for fuels which is respectively of 5347.59 kWh and 11,628 kWh.

Total white certificates for fuel for a year = Total Fuel Savings (kWh) kWh /11.628

Total white certificates for electrical = Total Electricity Savings (kWh) kWh /5.347,59

Total white certificates Savings = Total white certificates for fuel for a year + Total white certificates for electrical

Total white certificates per year = 144 * Total savings white certificates

Total white certificates for 5 years = Total white certificates per year * 5

| year | ELECTRIC SAVING | GAS SAVING | TOTAL ENERGY SAVINGS | MAINTENANCE SAVING | WHITE CERTIFICATES | TOTAL SAVINGS |
|---|---|---|---|---|---|---|
| **0** | € 0 | € 0 | € 0 | € 0 | € 0 | € 0 |
| **1** | € 22.155 | € 10.412 | € 32.567 | € 8.466 | € 5.014 | € 46.047 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **2** | € 23.374 | € 11.204 | € 34.577 | € 8.466 | € 5.014 | € 48.057 |
| **3** | € 24.659 | € 12.055 | € 36.714 | € 8.466 | € 5.014 | € 50.194 |
| **4** | € 26.015 | € 12.971 | € 38.987 | € 8.466 | € 5.014 | € 52.467 |
| **5** | € 27.446 | € 13.957 | € 41.403 | € 8.466 | € 5.014 | € 54.883 |
| **6** | € 28.956 | € 15.018 | € 43.973 | € 8.466 | € 0 | € 52.440 |
| **7** | € 30.548 | € 16.159 | € 46.707 | € 8.466 | € 0 | € 55.173 |
| **8** | € 32.228 | € 17.387 | € 49.616 | € 8.466 | € 0 | € 58.082 |
| **9** | € 34.001 | € 18.709 | € 52.710 | € 8.466 | € 0 | € 61.176 |
| **10** | € 35.871 | € 20.130 | € 56.002 | € 8.466 | € 0 | € 64.468 |
| **11** | € 37.844 | € 21.660 | € 59.504 | € 8.466 | € 0 | € 67.970 |
| **12** | € 39.925 | € 23.307 | € 63.232 | € 8.466 | € 0 | € 71.698 |
| **13** | € 42.121 | € 25.078 | € 67.199 | € 8.466 | € 0 | € 75.665 |
| **14** | € 44.438 | € 26.984 | € 71.422 | € 8.466 | € 0 | € 79.888 |
| **15** | € 46.882 | € 29.035 | € 75.917 | € 8.466 | € 0 | € 84.383 |
| **TOTAL** | € 496.464 | € 274.066 | € 770.530 | € 126.991 | € 25.070 | € 922.591 |

Table 6.10 : economic savings

Then,

| **year** | **INVESTIMENT** | **OPERATING COSTS** | **TOTAL COSTS** |
|---|---|---|---|
| **0** | € 192.018 | € 0 | € 192.018 |
| **1** | € 0 | € 26.220 | € 26.220 |
| **2** | € 0 | € 26.220 | € 26.220 |
| **3** | € 0 | € 26.220 | € 26.220 |
| **4** | € 0 | € 26.220 | € 26.220 |
| **5** | € 0 | € 26.220 | € 26.220 |
| **6** | € 0 | € 26.220 | € 26.220 |
| **7** | € 0 | € 26.220 | € 26.220 |
| **8** | € 0 | € 26.220 | € 26.220 |
| **9** | € 0 | € 26.220 | € 26.220 |
| **10** | € 0 | € 26.220 | € 26.220 |

| | | | |
|---|---|---|---|
| **11** | € 0 | € 26.220 | € 26.220 |
| **12** | € 0 | € 26.220 | € 26.220 |
| **13** | € 0 | € 26.220 | € 26.220 |
| **14** | € 0 | € 26.220 | € 26.220 |
| **15** | € 0 | € 26.220 | € 26.220 |
| **TOTAL** | € 192.018 | € 393.306 | € 585.324 |

Table 6.10 : economic costs

| **year** | **TOTAL SAVINGS** | **TOTAL COSTS** | **NET PROFIT** | **NPV (Net Present Value)** | **DCF (DISCOUNTED CASHFLOW)** |
|---|---|---|---|---|---|
| **0** | € 0 | € 192.018 | -€ 192.018 | -€ 192.018 | -€ 192.018 |
| **1** | € 46.047 | € 26.220 | € 19.827 | € 19.748 | -€ 172.270 |
| **2** | € 48.057 | € 26.220 | € 21.837 | € 21.663 | -€ 150.606 |
| **3** | € 50.194 | € 26.220 | € 23.974 | € 23.688 | -€ 126.918 |
| **4** | € 52.467 | € 26.220 | € 26.246 | € 25.830 | -€ 101.088 |
| **5** | € 54.883 | € 26.220 | € 28.663 | € 28.096 | -€ 72.991 |
| **6** | € 52.440 | € 26.220 | € 26.219 | € 25.599 | -€ 47.393 |
| **7** | € 55.173 | € 26.220 | € 28.953 | € 28.155 | -€ 19.237 |
| **8** | € 58.082 | € 26.220 | € 31.861 | € 30.860 | € 11.622 |
| **9** | € 61.176 | € 26.220 | € 34.955 | € 33.722 | € 45.344 |
| **10** | € 64.468 | € 26.220 | € 38.247 | € 36.750 | € 82.094 |
| **11** | € 67.970 | € 26.220 | € 41.750 | € 39.956 | € 122.051 |
| **12** | € 71.698 | € 26.220 | € 45.478 | € 43.350 | € 165.401 |
| **13** | € 75.665 | € 26.220 | € 49.445 | € 46.944 | € 212.345 |
| **14** | € 79.888 | € 26.220 | € 53.667 | € 50.750 | € 263.096 |
| **15** | € 84.383 | € 26.220 | € 58.162 | € 54.782 | € 317.877 |
| **TOTAL** | € 922.591 | € 585.324 | € 337.267 | € 317.877 | |

Table 6.11 : economic indicators

NPV is based on the principle that an initiative deserves to be considered only if the benefits that may result are superior to the resources used. In the construction of the formula for calculating NPV it is part of the capitalization law adapting to operations that produce cash flows distributed over different periods. It is calculated as:

NPV = U / (t + 1) n

U = net profit

T = discount rate

n = year

DCF is a method of valuing a project, company, or asset using the concepts of the time value of money. All future cash flows are estimated and discounted by using cost of capital to give their present values (PVs). The sum of all future cash flows, both incoming and outgoing, is the net present value (NPV), which is taken as the value or price of the cash flows in question. Using DCF analysis to compute the NPV takes as input cash flows and a discount rate and gives as output a present value; the opposite process—takes cash flows and a price (present value) as inputs, and provides as output the discount rate—this is used in bond markets to obtain the yield.

DCF = NPV + FCn-1

FC n-1 = previous year's cash flow

PBP (Payback Period) is the return on investment and allows to assess how many years you can recover the invested capital. Then the repayment period is calculating the number of years needed to offset the investment through cash inflows; in practice it is the first deadline that is experiencing a sign reversal in cash balances. The PBP was calculated with a formula that allows the identification of the amount for the first year value becomes positive in the table of discounted cashflow.

IRR (Internal Rate of Return) is the rate for which NPV is null.

ROI (Return On Investment) is a return on capital of the invested it possible to assess how profitable the investment. According to this criterion, an investment is even more preferable to the less proves the repayment period.

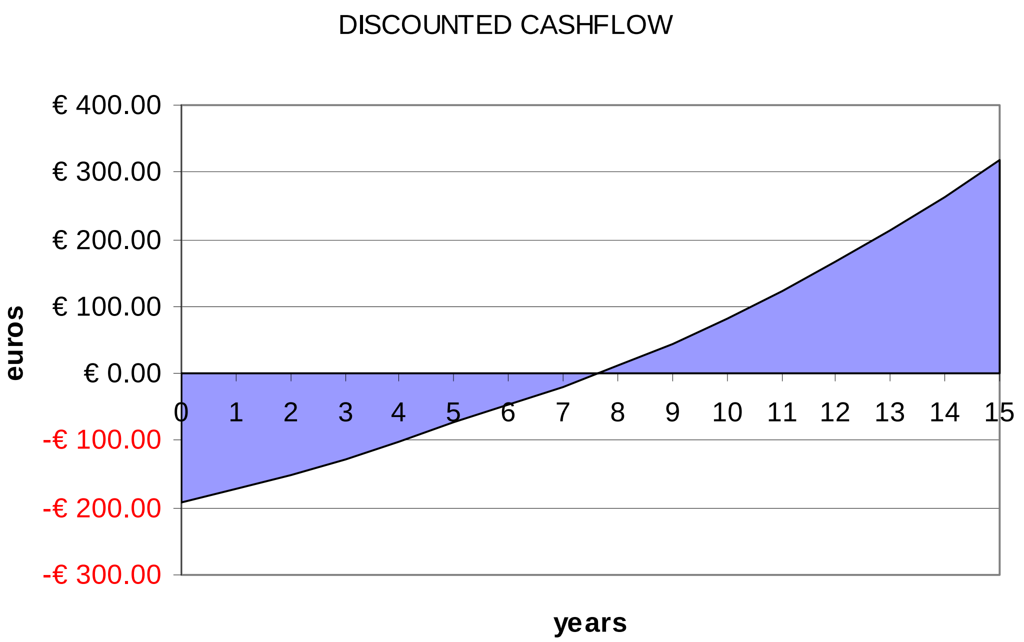



Figure 6.1 : DCF

Therefore, for this case study

**PBP=7,6 years**

**NPV=317877€**

**IRR=13.1%**

**ROI=166%**

## *6.3 Analysis of the network of buildings with increasing complexity*

The scenarios chosen to be compared aim to analyze the trend in the economy that assumes a network of buildings and show how increasing the complexity of the network affects the investment convenience.

There were then compared scenarios starting from a single building and gradually increasing with a network formed by 2, 5, 10, 20, 50, 100, 500, 1,000, 10,000 buildings.

The features of the network of buildings, technologies and systems adopted, are the same for all scenarios. In detail, the type of building into consideration concern the service sector and in particular the offices in the public sector, also the same inputs considered in the model, explained in the previous section have been set. As it regards the system chosen is the one that allows to make monitoring at a level area and a control with a level of the room; then it comes to install the technology, with an average life of installation of 15 years, which gives the opportunity to achieve energy savings through its control with an intervention level of greatest detail, namely the installation of sensors in the chambers / offices. In addition, the network system adopted is hosted in the cloud. Below the main characteristics are reported:

Type of buildings: OFFICES

Public sector

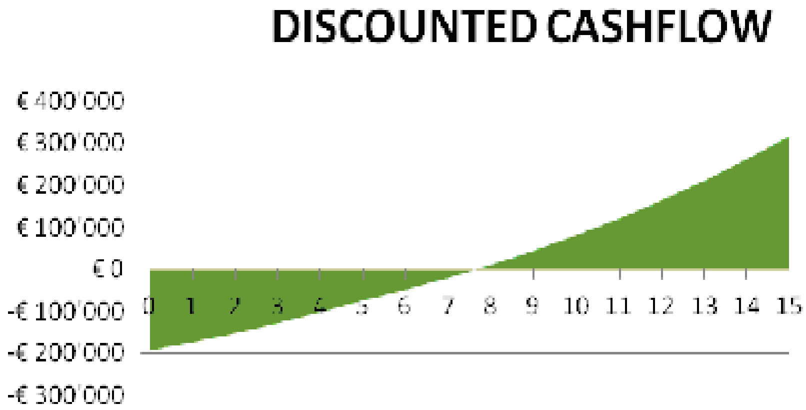
Monitoring at ZONE LEVEL + Control at ROOM LEVEL

System: HOSTING IN CLOUD

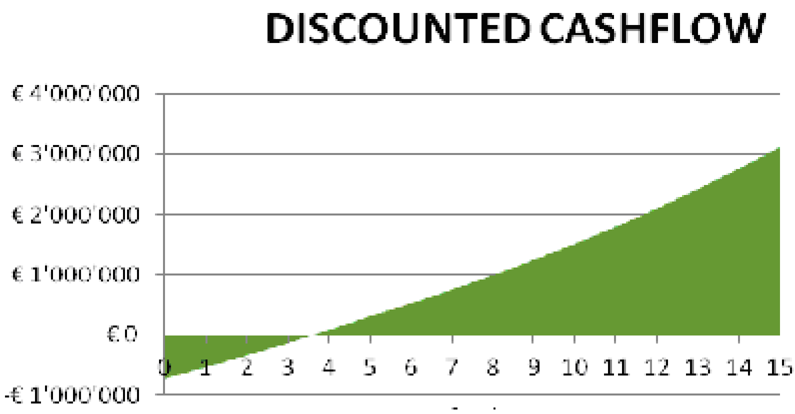
Average life installation (years): 15

The charts that follow shows the relationship between the discounted cashflow where on the vertical axis there are cumulative discounted cash flows and on the horizontal axis the years; This allows to easily see the return on investment, which is the break-even point between revenues and costs and therefore between positive and negative flows. In fact you can see that the red part are the cash flows before there is the payback mind those in green are the cash flows after the payback and therefore are all revenues that are paid to you by ' investment and that are precisely indicate the return or investiment.

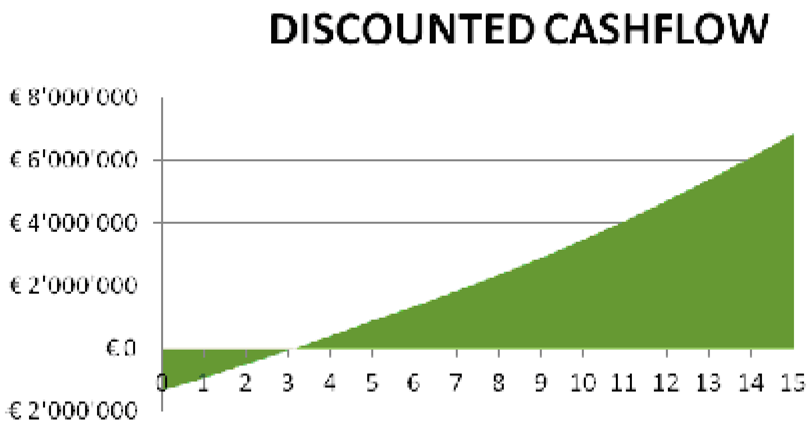
1 building



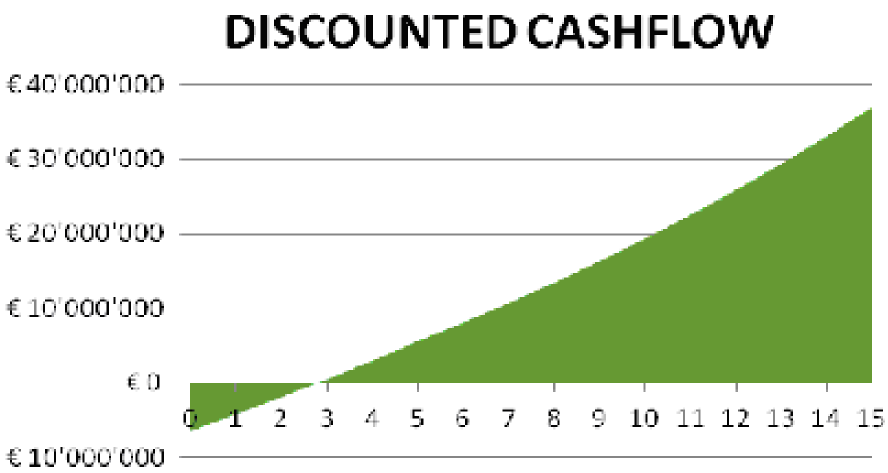

10 buildings



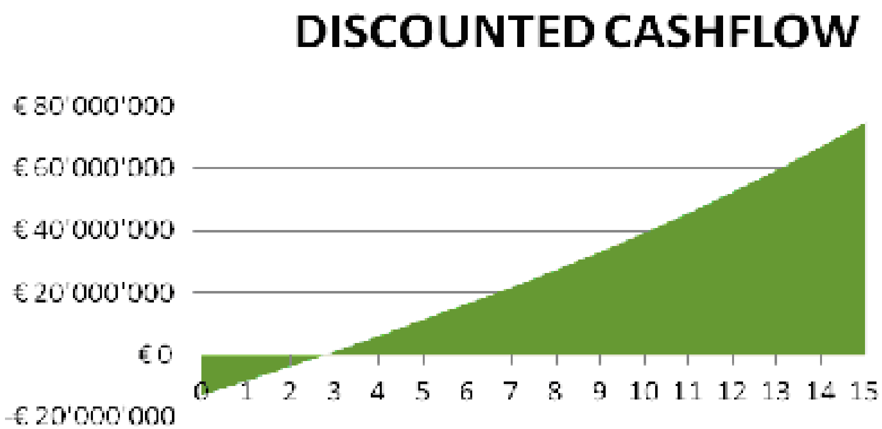

20 buildings



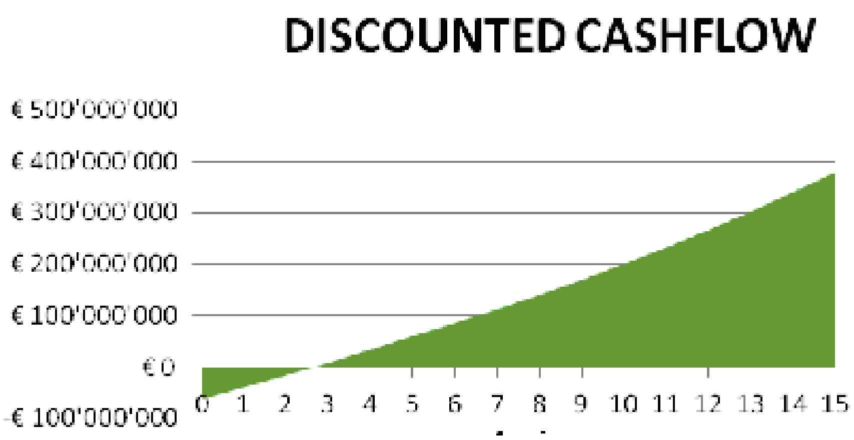
50 buildings



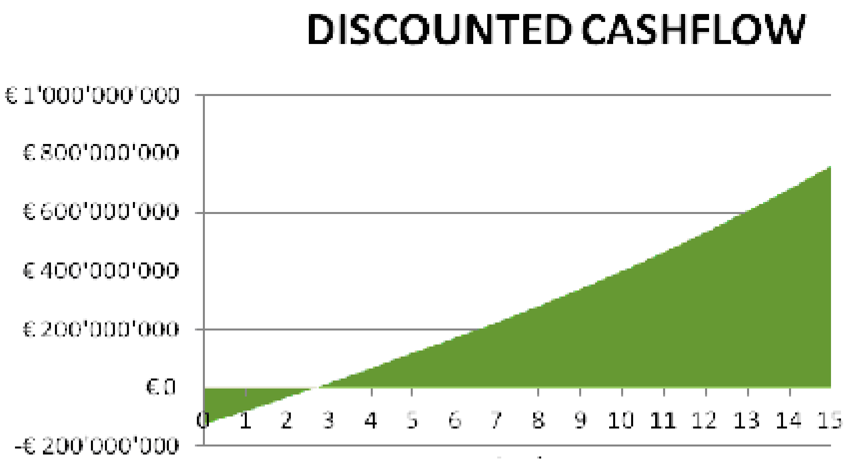

100 buildings



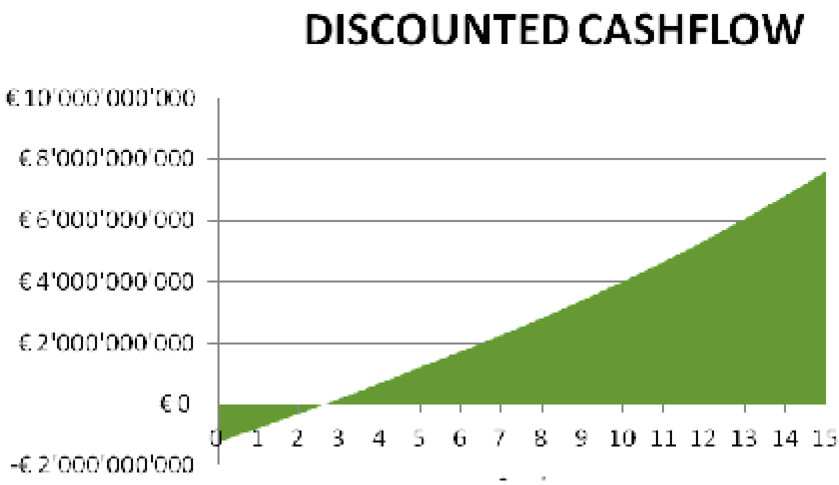

500 buildings



1000 buildings




10000 buildings




In comparing the various scenarios, we can see that there is a real convenience already investing in the management of a single building but emerges even more so as there is a considerable convenience in managing a network of buildings with a number of 10, and that goes gradually growing.

You may also notice that when you reach a network of 500 buildings it will start to stabilize the return on the two years and eight months, which is in fact also the same for a network of 1,000 and 10,000 buildings; but still we have a NPV and a ROI that continue to grow progressively.

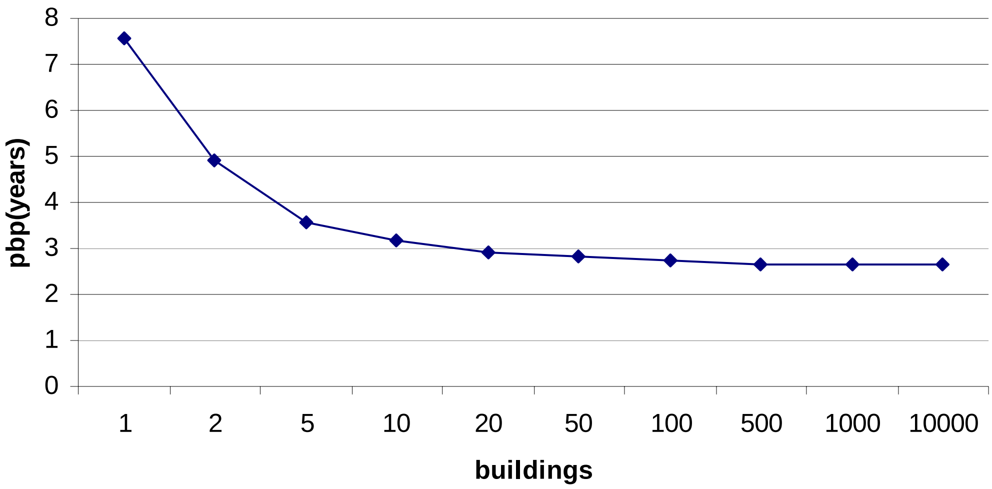



Figure 6.2 : payback period as function of the numeber of buildings

This curve shows the trend of return on investment as function of the number of buildings. In detail it shows that, for a single building there is a return on investment in seven years and seven months, for two buildings in four years and eleven months, for five buildings in three years and seven to ten buildings in three years and two months , and this seems to be the right network bandwidth from which to a good response on the capital that you invest.

The trend continues to decrease for a network of twenty, fifty and one hundred buildings with a PBP of two years and eleven months, respectively, two years and ten months and two years and nine months.

Finally, the curve tends to level off when the network comes to a complex of five hundred buildings with a return in two years and eight months, which remains the same even for a network of a thousand and ten thousand buildings.

Also, from the table given below it can be seen this trend. Comparing these scenarios and taking into account in particular the NPV and the ROI that are both positive and greater than zero and one, respectively, and therefore a convenience to invest, they have a significantly increasing trend with the increasing network of buildings . This can be found for a number of buildings amounting to five hundred, thousand and ten thousand which have an investment return equal to two years and eight months, but the profitability ratios continue to grow albeit with a minor trend.

| BUILDINGS | INVESTIMENT | TOTAL SAVINGS | TOTAL COSTS | NET PROFIT | PBP | NPV | IRR | ROI |
|---|---|---|---|---|---|---|---|---|
| 1 | € 192.018 | € 922.591 | € 585.324 | € 337.267 | 7 Y 7 M | € 317.877 | 13% | 166% |
| 2 | € 329.035 | € 1.845.182 | € 823.632 | € 1.021.550 | 4 Y11 M | € 973.634 | 21% | 296% |
| 5 | € 720.088 | € 4.612.954 | € 1.344.148 | € 3.268.806 | 3 Y 7 M | € 3.129.855 | 30% | 435% |
| 10 | € 1.359.720 | € 9.225.908 | € 2.076.145 | € 7.149.763 | 3 Y 2 M | € 6.855.277 | 34% | 504% |
| 20 | € 2.632.493 | € 18.451.815 | € 3.449.154 | € 15.002.661 | 2 Y 11 M | € 14.394.310 | 34% | 547% |
| 50 | € 6.444.699 | € 46.129.538 | € 7.447.059 | € 38.682.480 | 2 Y 10 M | € 37.129.084 | 38% | 576% |
| 100 | € 1.279.656 | € 92.259.077 | € 14.035.699 | € 78.223.378 | 2 Y 9 M | € 75.092.647 | 39% | 587% |
| 500 | € 63.603.630 | € 461.295.384 | € 66.400.467 | € 394.894.918 | 2 Y 8 M | € 379.134.856 | 39% | 596% |
| 1000 | € 127.112.440 | € 922.590.768 | € 131.727.867 | € 790.862.901 | 2 Y 8 M | € 759.312.172 | 40% | 597% |
| 10000 | € 1.270.269.994 | € 9.225.907.685 | € 1.306.355.424 | € 7.919.552.261 | 2 Y 8 M | € 7.603.729.939 | 40% | 599% |

Table 6.12 : economic indicators

## *6.4 Economic Analysis of a model for the management of a network of school buildings*

The characteristics chosen for these scenarios remain those of the reference model with the main features as : a system that allows to do both monitoring and control, network of 10 buildings. The latter choice is derived from the previous analysis, and is originated precisely the fact that the effective convenience when investing in this kind of system starts just when the network of the buildings that are managed starts to be equal to ten.

MAIN FEATURES:

System: Monitoring + Control

Smart Building Network: 10

The capital that needed to invest in this particular case is € 1,807,720. From this is obtained a annual electricity savings of 708 061 kWh and a saving of 302,400 m3 gas, and this can be viewed by the table which follows.

| | |
|---|---|
| **Investment** | €1.807.720 |

| | |
|---|---|
| **Electric Saving (kWh)** | 708.061 |

| | |
|---|---|
| **Gas Saving ($m^3$)** | 302.400 |

In the table that follows there are reported the results of the most important results that allow to analyze the investment convenience.

| | |
|---|---|
| **YEARS** | 15 |
| **ELECTRIC SAVING** | € 3.013.084 |
| **GAS SAVING** | € 5.481.314 |
| **TOTALE ENERGY SAVINGS** | € 8.494.398 |
| **TOTAL MAINTENANCE SAVING** | € 1.206.080 |
| **TOTAL SAVINGS** | € 9.700.478 |
| **INVESTMENT** | € 1.807.720 |
| **OPERATING COSTS** | € 716.424 |
| **TOTAL COSTS** | € 2.524.145 |
| **NET PROFIT** | € 7.176.333 |
| **NPV** | € 6.855.351 |

Table 6.13 : economic indicators

The table below, shows the results obtained from the calculations, key ratios and profitability, such as the NPV amounting to € 6,855,351 which is positive and high, and a 25.3% IRR confirms that the convenience investment. Also shows a return of capital invested in 4 years and 5 months and an ROI of 379%.

| PBP | NPV | IRR | ROI |
|---|---|---|---|
| **4,38** | **€6.855.351** | **25,3%** | **379%** |

Table 6.14 : economic indicators

## *6.5 Analisys for national replicability*

This economic analysis, on a network of 20,000 buildings in the public sector, intends to verify the extension of the energy management model of a network of buildings, whether it is convenient investment and thus ascertain the replicability at the national level the Government offices.

What emerges from an investment of € 2.655.644.997, in a management system that is a zone-level monitoring that a room-level control and then a management system at the highest level of detail possible, is a electrical savings of 2,333,334,200 kWh a year and a heat saving of 302.4 million m3 per year.

| | |
|---|---|
| **Investment** | € 2.655.644.997 |

| | |
|---|---|
| **Electric Saving (kWh)** | 2.333.334.200 |

| | |
|---|---|
| **Gas Saving (m3)** | 302.400.000 |

The following tables report the results in individual years, with an average life of the adopted technologies of fifteen years.

The table below shows in detail the electrical savings and gas and the total of energy savings, which are the sum of the electrical and thermal savings.

Moreover, there are the total of the savings on maintenance and the total savings.

| YEAR | ELECTRIC SAVING | GAS SAVING | TOTAL ENERGY SAVING | TOTAL MAINTENANCE SAVING | TOTAL SAVING |
|---|---|---|---|---|---|
| **0** | € 0 | € 0 | € 0 | € 0 | € 0 |
| **1** | € 443.100.165 | € 208.244.736 | € 651.344.901 | € 169.320.954 | € 820.665.855 |
| **2** | € 467.470.674 | € 224.071.336 | € 691.542.010 | € 169.320.954 | € 860.862.964 |
| **3** | € 493.181.561 | € 241.100.757 | € 734.282.318 | € 169.320.954 | € 903.603.272 |
| **4** | € 520.306.547 | € 259.424.415 | € 779.730.962 | € 169.320.954 | € 949.051.916 |

| | | | | | |
|---|---|---|---|---|---|
| **5** | € 548.923.407 | € 279.140.671 | € 828.064.077 | € 169.320.954 | € 997.385.031 |
| **6** | € 579.114.194 | € 300.355.362 | € 879.469.555 | € 169.320.954 | € 1.048.790.510 |
| **7** | € 610.965.475 | € 323.182.369 | € 934.147.844 | € 169.320.954 | € 1.103.468.798 |
| **8** | € 644.568.576 | € 347.744.229 | € 992.312.805 | € 169.320.954 | € 1.161.633.759 |
| **9** | € 680.019.847 | € 374.172.790 | € 1.054.192.638 | € 169.320.954 | € 1.223.513.592 |
| **10** | € 717.420.939 | € 402.609.923 | € 1.120.030.862 | € 169.320.954 | € 1.289.351.816 |
| **11** | € 756.879.091 | € 433.208.277 | € 1.190.087.367 | € 169.320.954 | € 1.359.408.322 |
| **12** | € 798.507.441 | € 466.132.106 | € 1.264.639.546 | € 169.320.954 | € 1.433.960.501 |
| **13** | € 842.425.350 | € 501.558.146 | € 1.343.983.496 | € 169.320.954 | € 1.513.304.450 |
| **14** | € 888.758.744 | € 539.676.565 | € 1.428.435.309 | € 169.320.954 | € 1.597.756.263 |
| **15** | € 937.640.475 | € 580.691.984 | € 1.518.332.459 | € 169.320.954 | € 1.687.653.413 |
| **TOTAL** | € 9.929.282.483 | € 5.481.313.664 | € 15.410.596.147 | € 2.539.814.314 | € 17.950.410.461 |

Table 6.15 : economic savings

In the table below we can see the amount of invested capital in this network of 20,000 buildings and operating costs spread over the various years; Finally we find the total cost, which is the sum of investment and operating costs.

| YEAR | INVESTMENTS | OPERATING COSTS | TOTAL COSTS |
|---|---|---|---|
| **0** | € 2.655.644.997 | € 0 | € 2.655.644.997 |
| **1** | € 0 | € 4.716.958 | € 4.716.958 |
| **2** | € 0 | € 4.716.958 | € 4.716.958 |
| **3** | € 0 | € 4.716.958 | € 4.716.958 |
| **4** | € 0 | € 4.716.958 | € 4.716.958 |
| **5** | € 0 | € 4.716.958 | € 4.716.958 |
| **6** | € 0 | € 4.716.958 | € 4.716.958 |
| **7** | € 0 | € 4.716.958 | € 4.716.958 |
| **8** | € 0 | € 4.716.958 | € 4.716.958 |
| **9** | € 0 | € 4.716.958 | € 4.716.958 |
| **10** | € 0 | € 4.716.958 | € 4.716.958 |
| **11** | € 0 | € 4.716.958 | € 4.716.958 |
| **12** | € 0 | € 4.716.958 | € 4.716.958 |
| **13** | € 0 | € 4.716.958 | € 4.716.958 |
| **14** | € 0 | € 4.716.958 | € 4.716.958 |

| | | | |
|---|---|---|---|
| **15** | € 0 | € 4.716.958 | € 4.716.958 |
| **TOTAL** | € 2.655.644.997 | € 70.754.373 | € 2.726.399.370 |

Table 6.16 : costs

The following table shows the different positive and negative flows. In particular we can see the trend of net profit, which was derived from the difference between the costs and revenues of individual years, NPV and discounted cashflow, then all cash flows and related to each single year.

| **YEAR** | **NET PROFIT** | **NPV** | **DISCOUNTED CASHFLOW** |
|---|---|---|---|
| **0** | -€ 2.655.644.997 | -€ 2.655.644.997 | -€ 2.655.644.997 |
| **1** | € 815.948.897 | € 812.698.104 | -€ 1.842.946.893 |
| **2** | € 856.146.006 | € 849.337.714 | -€ 993.609.178 |
| **3** | € 898.886.314 | € 888.185.400 | -€ 105.423.779 |
| **4** | € 944.334.958 | € 929.375.492 | € 823.951.713 |
| **5** | € 992.668.073 | € 973.050.746 | € 1.797.002.459 |
| **6** | € 1.044.073.552 | € 1.019.362.886 | € 2.816.365.345 |
| **7** | € 1.098.751.840 | € 1.068.473.181 | € 3.884.838.526 |
| **8** | € 1.156.916.801 | € 1.120.553.059 | € 5.005.391.585 |
| **9** | € 1.218.796.634 | € 1.175.784.771 | € 6.181.176.356 |
| **10** | € 1.284.634.858 | € 1.234.362.087 | € 7.415.538.443 |
| **11** | € 1.354.691.363 | € 1.296.491.044 | € 8.712.029.487 |
| **12** | € 1.429.243.542 | € 1.362.390.746 | € 10.074.420.233 |
| **13** | € 1.508.587.492 | € 1.432.294.209 | € 11.506.714.441 |
| **14** | € 1.593.039.305 | € 1.506.449.272 | € 13.013.163.714 |
| **15** | € 1.682.936.455 | € 1.585.119.563 | € 14.598.283.276 |
| **TOTAL** | € 15.224.011.090 | € 14.598.283.276 | |

Table 6.17 : economic indicators

From the table and the discounted cashflow chart we can see the results coming from this investment.

In particular we can see that in order to manage a complex network of 20,000 buildings it will be needed to have available a € 2.655.644.997 capital and OPEX costs for a total of € 2.726.399.37 and the centralized automation system achieved total savings equivalent to € 15.410.596.147.

All this leads to a total net profit of € 15.224.011.090 and a total discounted profit of € 14.598.283.276.

The result is a PBP of 3 years and 1 month a NPV of € 14.598.283.276, a 35.1% IRR and an ROI of 550%.

From all this and especially by the various financial and economic indices, above, you can get to argue that there is a considerable advisability of investing in this energy management in buildings, because there is a positive NPV and extremely high and thus satisfactory, confirmed by a IRR positive and you recover the investment as early as the third year and then you have a 550% return on invested capital, amounting to € 14,606,047,483.5, which is derived from the years that remain after recovery.

| | INVESTMENT | TOTAL SAVINGS | TOTAL COSTS | TOTAL PROFIT | PBP | NPV | IRR | ROI |
|---|---|---|---|---|---|---|---|---|
| ROOM LEVEL | € 2.655.644.997 | € 15.410.596.147 | € 2.726.399.370 | € 15.224.011.090 | 3,11 | € 14.598.283.276 | 35,1% | 550% |

Table 6.18 : economic indicators

This can be viewed more easily in the figure below, where it is easy to notice the break-even point at 3 years and 1 month, so the point where you reset the X axis the investment as it leads the recovery of it.

From this analysis we conclude that it would be appropriate to invest in this type of management, and at this level of intervention detail and that is therefore feasible to adopt it even nation wide on public offices.

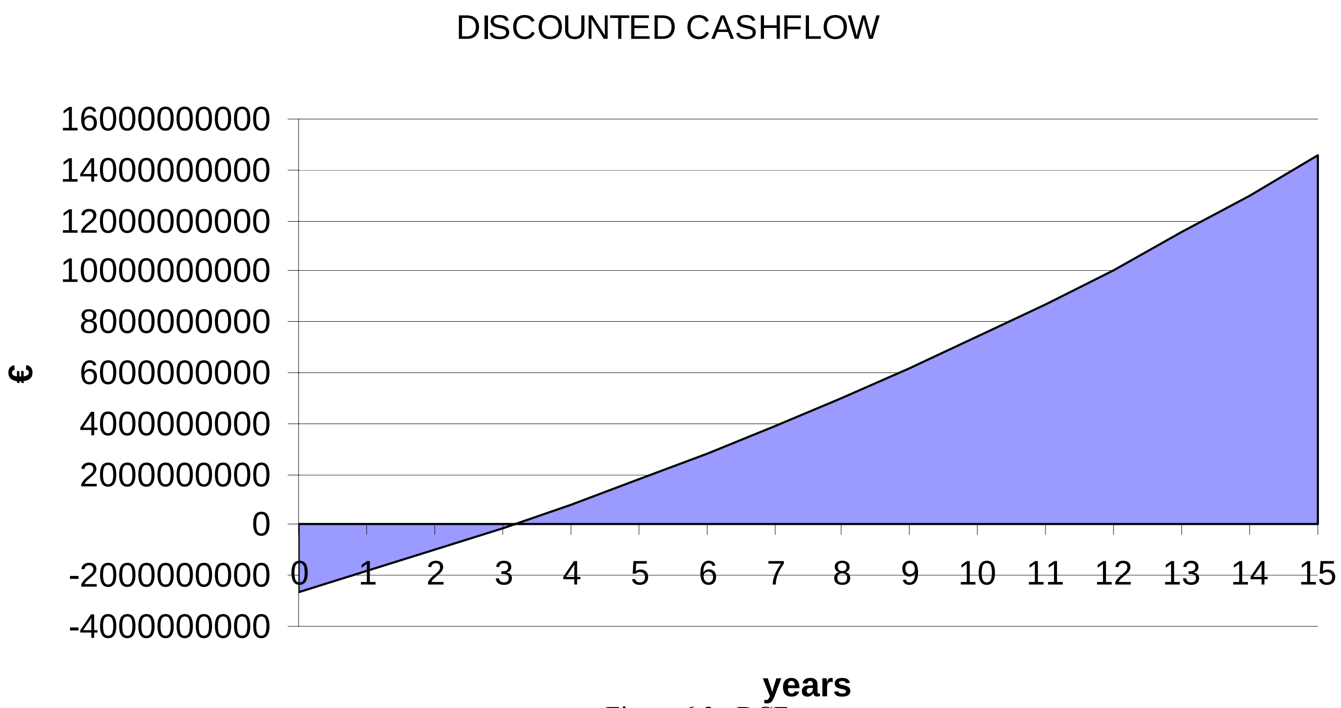



Figure 6.3 : DCF

## *6.6 Final remarks*

The proposed control systems allow to save energy and improve productivity by creating an environment of comfortable work and the optimization of integrated solutions for building management improves energy management. "Optimization" is synonymous with energy savings.

The energy management system of buildings is critical to any strategy of lowering energy consumption and maintenance costs and are designed to offer complete control of the technological systems of the building.

This system thus leads to an increase of the information level of confidence that they are in support of the decision makers, for improved efficiency and significant cuts in unnecessary energy costs, an efficient KPI monitoring energy performance and establish and follow goals environmental responsibility.

The main results arising from this study are the various economic analysis derived from examining various types of scenarios, ranging to indentificare especially different trends of the complexity and breadth of the networks and buildings of different choices that you can make on the management system and then based on the level of detail and intervention that takes into account and the network system.

In the case of the analysis made on the progress of increasing the building network complexity arises that, in comparing the different scenarios, that there is a real convenience already investing in the management of a single building but still emerges more that there is a significant convenience in managing a network of buildings with a number of 10, and that goes gradually growing.

When you get to a network of 500 buildings will start to stabilize the return on the two years and eight months, which is in fact the same even for a network of 1,000 and 10,000 buildings; but still we have a NPV and a ROI that continue to grow progressively.

In the economic analysis carried out for the management of a network of ten school buildings it emerges from the results obtained, especially from key ratios and profitability, such as the NPV which was positive and high, and a IRR confirms that the investment convenience. Also shows a return of capital invested in 4 years and 5 months and an ROI of 379%. The results obtained allow to certify the advisability of investing in an energy management of a network of ten buildings for school use.

In the analysis of replicability at the national level public offices, it emerged that in order to manage a complex network of 20,000 buildings it will be needed to have available a € 2.655.644.997 capital and OPEX costs for a total of € 2.726.399.37 and thanks to this centralized automation system are achieved total savings equivalent to € 15.410.596.147.

All this leads to a total net profit of € 15.224.011.090 and a total discounted profit of € 14.598.283.276.

The result is a PBP 3 years and 1 month a NPV of € 14.598.283.276, a 35.1% IRR and an ROI of 550%.

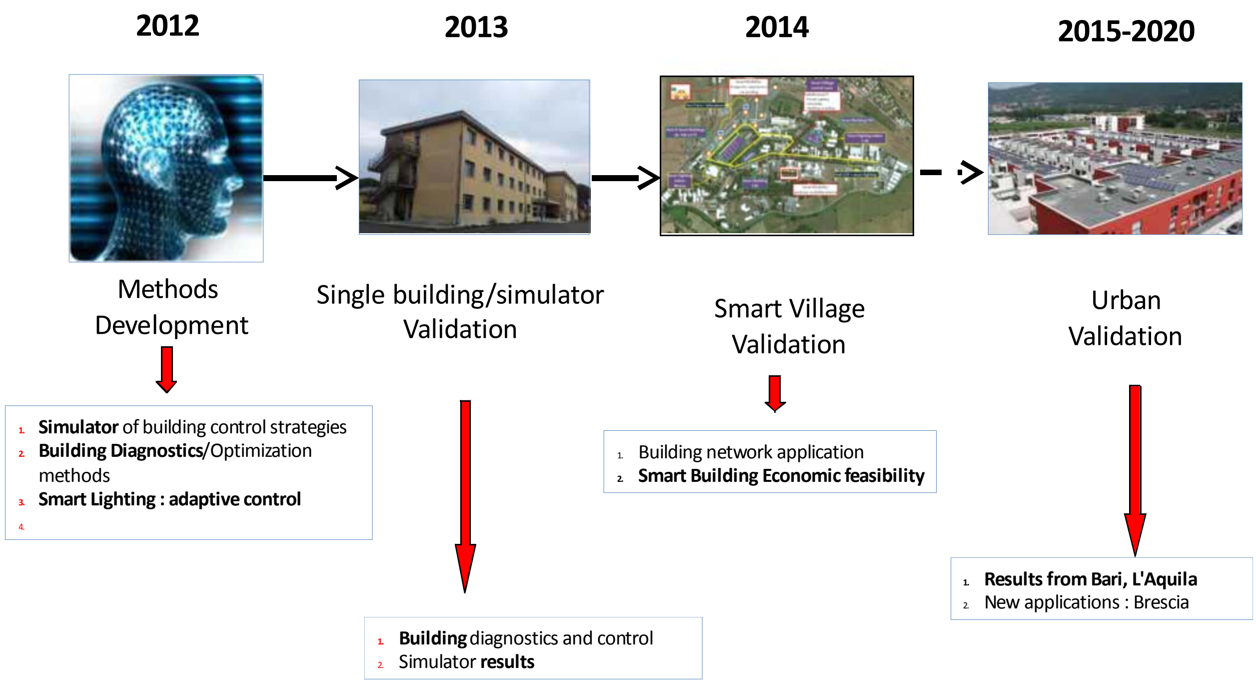
From all this and especially by the various financial and economic indices, above, you can get to argue that there is a considerable advisability of investing in this energy management in buildings, because there is a positive NPV and extremely high and thus satisfactory that it is confirmed by a IRR positive and you recover the investment already in the third year and has a margin of 550% on invested capital, amounting to € 14,606,047,483.5, stemming from the years that remain after recovery.

## *References*

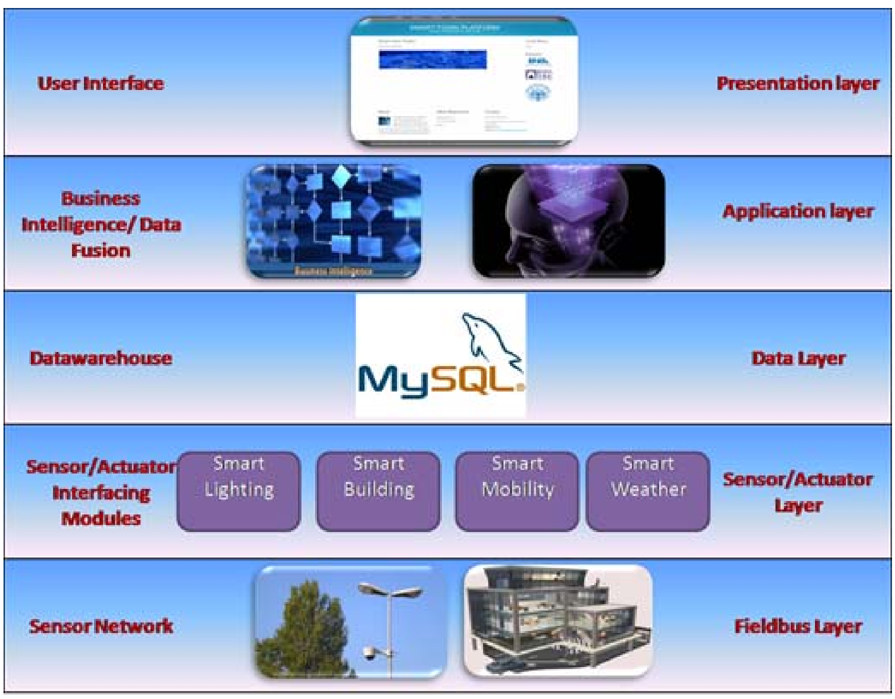

1. G.Martino "ANALISI TECNICHE ED ECONOMICHE DI UN MODELLO DI BUSINESS PER LA GESTIONE DI UNA RETE DI EDIFICI IN CONTESTI SMART CITIES", master degree thesis in Economics, Univiersity of Rome 'La Sapienza', 2014

# Chapter 7. Conclusions

In these 4 years study there have been addressed some issues connected to smart cities. Firstly it has been studied the overall framework, then the some methods concerning ICT, smart building network and smart lighting have been carried out and finally experimentation in real urban environment has been accomplished.

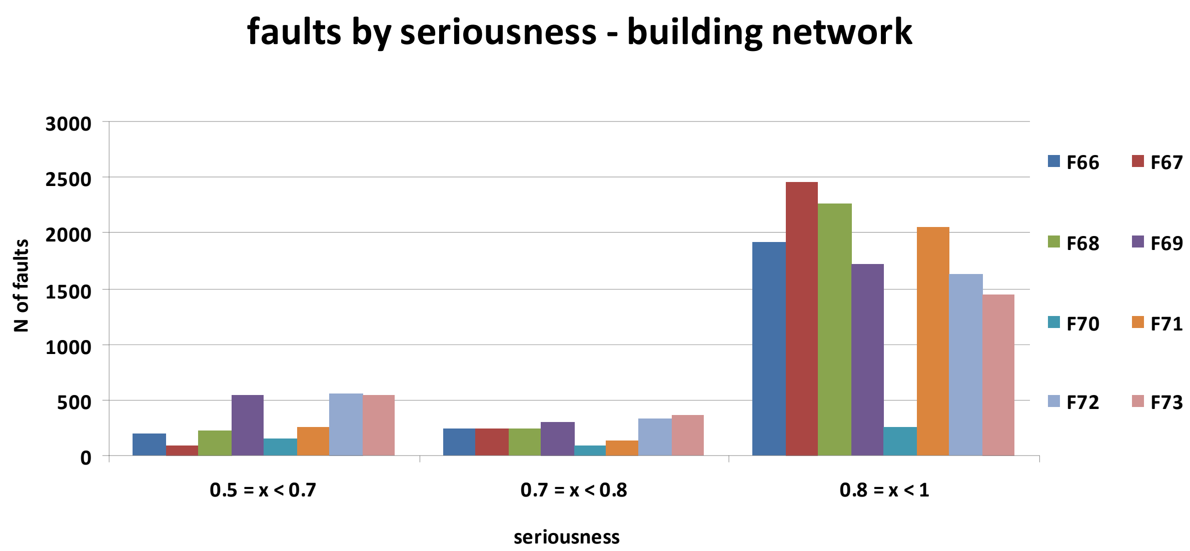


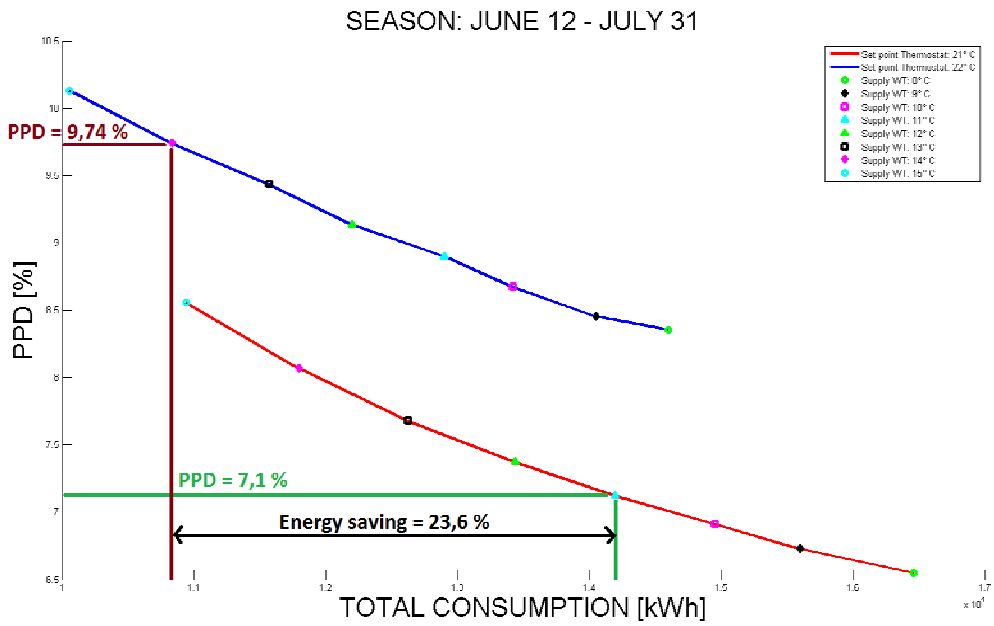

In particular, for ICT has been carried out a common structure which collects data form the different fields and implements some diagnostics and control strategies.



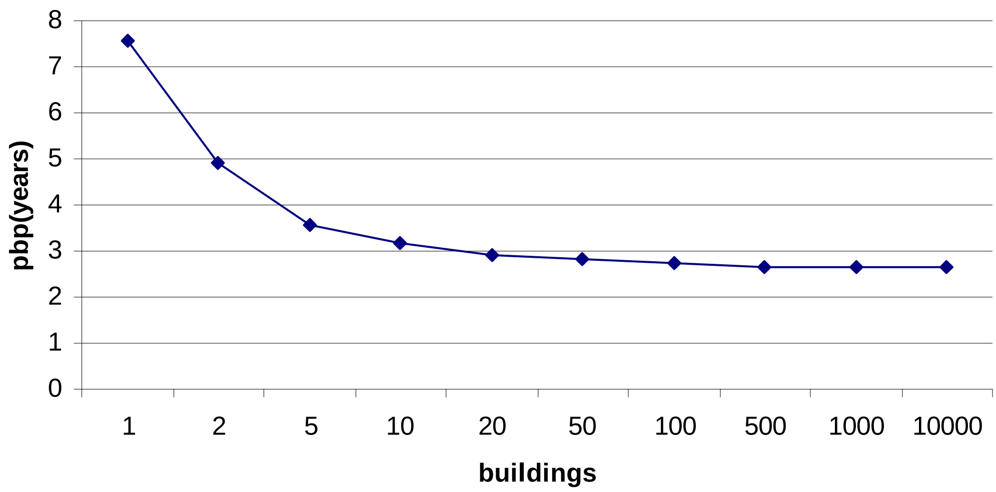
As regards smart lighting it has been carried out an adaptive control strategy which allows remarkable energy savings (30%) without decreasing the security level of the streets.

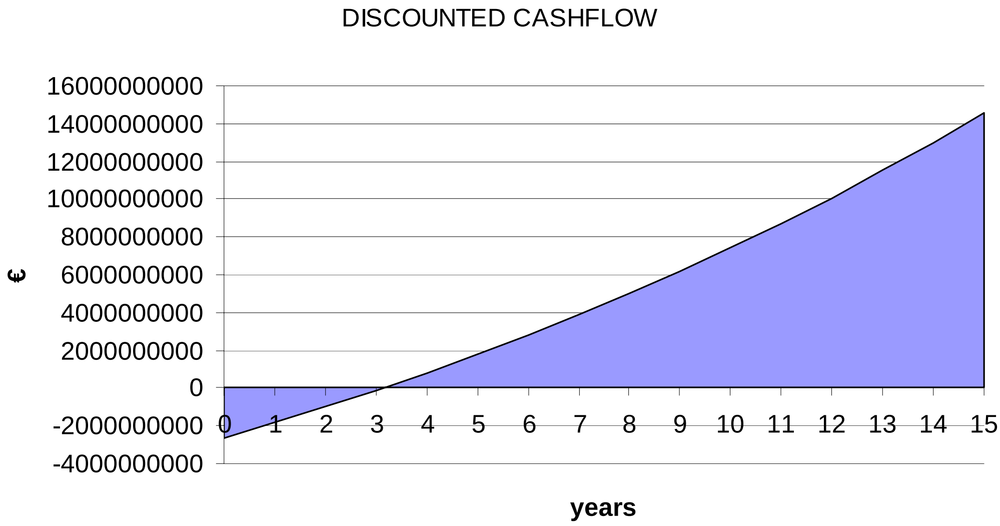
For the smart building topic, it has been implemented a diagnostic strategy to get thermal failures in a block of buidings and it has been studied a multi-objective strategy for energy optimization (with high potential savings for the summer season).




Moreover, it has been carried an economics study about the feasibility of the proposed smart building approach in order to validate its financial issues.




All these issues were connected to real life Smart Citiy projects and the main experimental fields were the ENEA-Casaccia Research Centre and the cities of Bari and L'Aquila.

Of course, this study cannot be exhaustive since the whole topic is too broad, it is just a contribution to the subject whose main original achivements can be summed up as follows :

- All data and algorithm implementations have been integrated in a common architecture on a distributed ICT grid infrastructure.
- The smart lighting approach has shown how new intelligent lighting systems can achive the goal of energy saving without affecting the safety of the citizens by means of 'energy on demand'.
- It has been carried out a Thermal Energy Fault Detection in a network of smart buidings using fuzzy techinques. The main novelty of this work refers, not on the methodology itself which is quite well established and mature, but on its application on a cluster of building sharing the same thermal energy network.

- As regards energy management in smart buildings, the main novelty of the work is to provide the day-ahead optimal thermal settings by keeping simultaneously into account energy consumption and occupant comfort.

- Since smart solutions for smart cities refer not only to integrated technologies, but also to economy and society, it has been developed a tool for a common evaluation of the financial sustainability of smart cities projects and it has been applied to the real situation of a smart building network and then scaled to wider scenarios.

## *7.1 Open Issues*

The work can be expanded in many directions, but firstly there still many important open issues to be tackled, related not only to technology but also to society, economics and government.

Here there are reported some contributions by experts on the field which address some of them and which I think are key points to be considered for the Smart Cities of the near future.

### 7.1.1 The problem of smart cities and connectivity

**by David Brunnen - Groupe Intellex**

No one should trash the efforts of innovators and determined community leaders working to make places easier to manage and more attractive for living and working. They are pioneers and, like all who dare to see things differently, they are battling against the odds.

The concept of smart cities is often described in terms of data collection and analytics. The extent to which “smartness” can be achieved is largely dependent on the enabling broadband qualities that link all manner of data feeds from across the city.

The smart city industry is awash with sensors and expectations of open data feeds from myriad public and private sector systems. Smart concepts encompass analytic engines to detect fine digital needles in giant data haystacks and also embrace the need for data integration standards and an urban operating system – a term coined by Living PlanIT SA, which created the first such system.

As for connectivity, we may perhaps be able to get by for now with the new narrowband (FTTC) that pretends to be broad and fibred but its quality, alas, is hobbled by having one leg shorter than the other and will never be able to run fast.

To properly qualify as “smart” requires something more than all that technology and digital expertise. To be smart, the place, the community, must have a leadership with the courage, confidence and authority to act on the outcomes. All that data is useless unless it is going to be used. The technology alone – even where connectivity allows its deployment – is insufficient without determined, action-orientated leadership.

In the management of any place, some data may demand immediate responsiveness. At the other extreme, some outputs may contribute to very long-term developments. Some responses may be obvious and immediate – dealing with imminent environmental disasters like blocked sewers or fluctuating transport demands when accidents occur.

But these are local operational matters that will keep the show on road. Bigger questions, like whether the entire place is heading down the right road, need deeper insights.

Applied smartness

It is only when leaders develop a framework for local economic and societal development that the smart city buzz can evolve into "intelligent communities". Which is why some would say the "city" tag is not helpful. True, cities are more complex, have bigger challenges and higher management overheads, but cities are collections of many (often overlapping) communities. What is needed in one quarter may be irrelevant for another. Similar challenges in economic and social wellbeing can be found in smaller towns and villages way beyond the city walls, but still a very strong part of the wider economy.

So, if the place has future-proofed broadband, sensors and open data feeds, the analytics engines and expertise, an urban operating system and a leadership with the capacity not only to respond but also to weld all the data sources and their owners into a co-operative team, how then can the community and its leaders focus on improving economic and social wellbeing?

That question has been studied for decades around the world – most notably by ICF, a foundation based in North America but with a global appreciation of community development.

Enabling intelligent communities

Some 20 years on, ICF has distilled the development essence of any community. It identifies six basic themes that make a real difference to economic success – for example, jobs growth – and social wellbeing. Two of those themes have already been mentioned – ubiquitous broadband and open data. The other four themes are:

1. Knowledge workforce: The most successful communities demonstrate an ability to develop local digital expertise at all levels of employment and across all sectors.

2. Digital inclusion: Successful communities do not leave this to chance or trust in the survival of the fittest. They have determined local policies and programmes to ensure that people do not get left behind in the new economy.

3. Innovation: How does that happen? It happens because those places work at building the innovative capacity of all enterprises, but particularly new businesses. Almost all the jobs growth in modern economies is generated by businesses with fewer than 50 employees. And, administratively, they also focus hard on local open data and local government processes to reduce costs and improve citizen and employee services.

4. Marketing and advocacy: And finally, something that sounds too boastful to be British, but, just as businesses need to project their brands and reputation, so it is that really successful communities find the time and effort to explain to the wider world – and investors – how they are building truly great places to work and live. Many of the acclaimed happiest places are those where people can live and work in the same community, eliminating the inefficiencies of commuting.

All this, and more, is explained in ICF's 2014 publication Brain Gain, and ICF now offers communities the opportunity of holding Community Accelerator master classes customised to meet their local needs and priorities.

### 7.1.2 The stupefying smart city

**Richard Sennett - LSE and New York University.**

Throughout the history of technology, new tools have come into being before people know how to use them well. This is the problem we face with today's new 'smart city' tools – the CCTV cameras, motion sensors, and computers capable of processing immense amounts of data. The problem is in a way understandable. It takes a long time and much experiment, entailing failure as well as success, to plumb a tool's possibilities. This was the case, for instance, of the hardened-edge scalpel, which appeared in the sixteenth century: surgeons required nearly a century to figure out best practices and innovative operations with a super sharp knife.

But tools for the smart city come with a sting in the tail. Their application can inhibit experiment by ordinary urbanites in their everyday lives. A large city can be thought of as a complex organism whose innards do not work perfectly in sync, whose parts do not add up to a unified whole. Yet there is something valuable just about these dissonances. They can create opportunities economically, when someone seizes on a market irregularity, while lack of coherent control enables personal liberty, and disorder might make subjective experience rich and multi-layered – at least novelists from Defoe to Proust hoped so. To take advantage of these possibilities, the big city needs to be learnt. The risk is that new technologies might repress the inductive and deductive processes people use to make sense, for themselves, of the complex conditions in which they live. The smart city would then become a stupefying smart city.

When a new tool proves deadening rather than liberating in use, our first instinct may be to blame the machine itself. That is what Lyon's silk weavers in the eighteenth century did; they attacked mechanised looms as 'perfidious works of the devil'. Instead of blaming the machine, we want to ask how the new urban technologies can be used more intelligently – which is more a question about urban planning and vision than about machinery. What kinds of urban design empower people in the street to experiment with their behaviour, and to draw their own conclusions from those experiments?

In the 1930s, urbanists like the American Lewis Mumford and architects like the Swiss Sigfried Giedion worried about machines and materials in relation to urban design. Mumford challenged the urban planners' uncritical embrace of the automobile; Giedion attacked the architects' conservative use of new building materials. Digital technology has shifted the technological focus to information processing. This can occur in handhelds linked to 'clouds' or in command and control centres. The issue is: who controls such information and how is this information organised? Which in turn raises new issues of urban design. The questions the technology poses are much more profound than which software to buy.

In this light, I want to make first a comparison between designs that create a stupefying smart city and designs that envision a stimulating smart city. By drawing this contrast, a formal issue then appears: that of the difference between a closed and an open system. And a social possibility emerges as well: the use of stimulating, open system technology to render the city more informal. My own comments here draw on a decade of research done by Urban Age on the visual and social conditions that can enable urbanites to take ownership over their lives.

#### Two Stupefying Smart Cities

Imagine that you are a masterplanner facing a blank computer screen and that you can design a city from scratch, free to incorporate every bit of high tech into your design. You might come up with Masdar, in the United Arab Emirates, or Songdo, in South Korea. These are two versions of the stupefying smart city, Masdar the more famous, or infamous, Songdo the more fascinating in a perverse way.

**Masdar** is a half-built city rising out of the desert, planning of which has been overseen by the master architect Norman Foster. The plan comprehensively lays out the activities of the city, in which technology monitors and regulates the function from a central command centre. This is to conceive of the city in

'Fordist' terms – that is, each activity has an appropriate place and time. Urbanites become consumers of choices laid out for them by prior calculations of where to shop or to get a doctor the most efficiently.

Such practical knowledge is always necessary; the question is how urbanites get it. Foster's idea is that there is a one-way flow from the central command centre (CCC) to the handheld. The handheld (that is, the urbanite) can report information, but the CCC makes the interpretation of what it means and how the handheld should act upon it. Masdar is an extreme in this, and also in conceiving that no knowledge of the city has to be fought for. So there's no cognitive stimulation through trial and error, no personal encounter with resistance. User-friendly in Foster's plan – expensive fantasy that it is – means choosing menu options rather than creating the menu.

There is a further issue here: creating a new menu entails, as it were, being in the wrong place at the wrong time. In nineteenth-century European cities, for instance, new markets for semi-legal goods developed at the supposedly dead zones near the city's walls; so in twentieth-century American cities like Boston, new 'brain industries' developed at the edges, in places whose zoning never imagined their growth. Foster's idea of the city on the contrary assumes a clairvoyant sense of what should grow where. Put crudely, Foster's city is over-zoned: the algorithms of the CPU do not envision their own violation.

**Songdo** represents the stupefying smart city in its architectural aspect. It is no accident that Songdo is so badly designed. The massive units of housing are not conceived as structures with any individuality in themselves, nor are the ensemble of these faceless buildings meant to create a sense of place. The structures are programmed simply as functions. Uniform architecture need not inevitably produce a dead environment, if there is some flexibility at the ground plane. In New York, for instance, the ground plane of essentially monotonous residential towers is subdivided into small irregular units, which yield, along the Third Avenue in the 1920s or again the 1960s to the 1990s, a sense of neighbourhood. But in Songdo, lacking that elemental principle of diversity within the block, there is nothing to be learnt from walking the streets. And user intelligence of urban space arises basically from ground-plane experience.

When working in Mumbai, Urban Age research found Songdo-like efforts at urban design to be counterproductive. In Mumbai's Dharavi slum, a city in itself of nearly a million people, many efforts have been made to erase the anarchy that seems to reign on the streets, to push the built environment upward, off the street, in order to make it more orderly. These efforts have largely failed, rejected by people who instead use their own street smarts for survival.

## A Smart Smart City

A more intelligent attempt to create a smart city comes from work currently under way in **Rio de Janeiro**. Rio existed long before the computer, and its history includes the appearance of massive poverty and of violent crime, but equally of complex and living tissues of local life. Its collective physiology is not that of a well-balanced organism, made worse by its topography, a city subject to devastating flash floods. Yet its inhabitants, struggling against the odds, have made a life for themselves which most of them prize.

The role of new information technologies in such a city could not be more different than that in cities designed from scratch like Masdar and Songdo. Led by IBM, with assistance from Cisco and other subcontractors, the technologies have been applied to forecasting physical disasters, to coordinating responses to traffic crises, and to organising police work on crime. The new command centre for these activities, IBM's local director tells us, looks forward to getting the city in reasonable condition to host the next Olympic Games. To make this centre work has required more political effort than sheer technological innovation, since Rio's government bureaucracy has been a landscape of isolated silos; the implementation of new technology has required an engaged mayor.

The advent of computerised information sharing has not been entirely benign, in the eyes of some citizens, since the police can now be more coercive more effectively – and technological modernisation, like other forms of modernisation, can be used as a cover for disempowering or physically dispossessing the poor. Still, the principle of machine use here is coordination rather than prescription, as were the cases in Masdar and Songdo. The technology is meant to be responsive to conditions not of its own making.

It could be objected that this comparison is unfair. Would not people in the favelas prefer, if they had a choice, a pre-organised, already-planned place in which to live? The research Urban Age has carried out over the last years suggests that once urbanites rise above the poverty level, they in fact don't. The prospect of the orderly city has not be a lure for voluntary migration, neither in the past to European cities, nor today to the sprawling cities of South America and Asia. If they have a choice, people want a more open, indeterminate city in which to make their way: that is how they can come to take ownership over their own lives.

## Open and Closed Systems

There is a formal issue involved here: the contrast between the determinative and the coordinative use of technology shows at a deeper level the difference between a closed and an open system. Put simply, a car engine is a closed system while a discussion is, or should be, an open system. More detailed, in a closed system unforeseen activity is either integrated into the existing rules – the algorithms – of the system, or expelled as irrelevant 'noise'. Both feedback loops and exclusion help the closed system maintain its equilibrium. Whereas in an open system, balance is not so much the aim: the system is programmed to evolve, being open to the unforeseen, changing its very structure as it absorbs new data. 'Noise' is valued. Yet another way to think about the difference is that open and closed equate linear and non-linear. In a closed system, when change occurs it is meant to happen in a one-after-another problem-solving fashion, whereas the process of change in an open system does not try to resolve all conflicts; its greater emphasis on chance means that the system inhabits non-linear time.

Cities are open, non-linear systems. They grow in unpredictable ways, which would be missed by closed-system thinking. For instance, increasing population density in cities follows an erratic, non-linear path – even more so in today's Asian and Latin American megacities than in the European cities of the nineteenth century. It would be bad science if we tried to model this growth using closed-system concepts of equilibrium and integration. Again, at a certain point large size and high density make for new urban forms; Rio is something more of a public realm than the addition of all its individual streets. The danger of much closed-system urbanism is to treat the city instead as nodes and locales that can be added up, a linear progression up from the small to the large or down from the large to the small. Exactly this kind of urbanism appears in the planning of Masdar and Songdo.

## Informality

In sum, a better use of new technologies would focus more on coordination than on command, and it would suppose an evolutionary, open system rather than a steady-state, closed system. Further, smart-smart urbanism should follow specific planning principles, privileging the complexity of ground-plane design, recognising the cognitive value of pedestrian experience. The result would be that technology might aid informal social relations rather than repress informality in the name of coherent control. The use of Facebook in the Arab Spring of 2011 is an obvious and extreme example of doing so, but in more peaceful urban conditions why should we want to marry the technological and the informal?

Informal social processes are the genius of the city – the source of innovation economically and the foundation of an arousing social life. Technology must be part of the process of giving the city that informal energy – and can do so, if we think of our new technological tools as enabling the open systems of the city.

### 7.1.3 Smart Cities: technology challenges

**Interview to Rodger Lea – Sense Tecnic Systems Inc**

Q : As a faculty member at the University of British Columbia and President and CEO of Internet of Things platform company Sense Tecnic, you spend a lot of time in Vancouver, the third-largest population center in Canada. What do you see as the biggest challenges facing Vancouver and other cities around the world in the near future? How can making cities "smart" help?

A : Vancouver, like all cities is having to do more, with less. Citizens want more from their cities, more services, more access and even more control. However, like all cities, Vancouver has less budget and fewer resources to meet the growing needs. The only solution to this is to be smarter about the way the city uses technology to meet needs. So for me a smart city isn't so much about smart infrastructure, smart meters, smart parking, it's about working smarter to better meet the needs of the citizens. Of course that often means more efficiency, but it also means engaging citizens to better understand their needs and looking for ways of doing more, with less – that is, being smarter!

Q : What do you consider to be the major technological challenges currently holding back the development of smart cities? How do you think these challenges should be addressed?

A : I think most of the issue around smart cities are **not strictly technologies** issues – I think the technology is at a stage where we can do most of the things we want to. The problems are more around exposing data, sharing data and using the data – this comes in two area:

**Infrastructure data**: most infrastructure data in a city is still locked away. Open data has only scratched the surface of 'freeing' this data. We need better and cheaper solutions to allow cities and infrastructure maintainers to get their data out and expose it.

**Citizen data**: Citizen data is the gold standard of city data – it's a ground truth for peoples wants, activities etc – yet people are often unwilling to share data because they are concerned about privacy and trust issues. We need to develop trusted data brokers that will allow citizens to have confidence that they have complete control of what data they share, who uses it and if they want to, that they can revoke that data sharing.

Q : Both as a systems researcher and as an executive at Sense Tecnic, you have been deeply involved with developing platforms that support Internet of Things application development and deployment. What is the biggest recent innovation towards enabling general-purpose infrastructure for IoT applications? What is holding it back?

A : A combination of cloud computing and open source technologies have led to the recent explosion of the **IoT**. It's now possible to develop significant technology platforms and IoT solutions without massive investment. This has allowed many small startups and small tech companies to quickly develop innovation platforms and IoT solutions that in the past would have only been possible for well funded large scale corporations. For me, these are the two greatest tech enablers that have made the IoT space so exciting and innovative.

Q : You have also been involved with interoperability efforts. What is the state of interoperability in the Internet of Things? Where will solutions come from, academia or industry?

A : IoT **interoperability** is at still a very early stage. Most technology waves go through a similar innovation cycle – often referred to as the innovation S curve. There is a rapid explosion of innovation, many new systems and solutions appear on the market, and companies scramble to promote their approach. During this phase, **standardization** is hard and often gets overtaken by events. As the rate of innovation levels off (top of the S curve) standardization efforts are possible – they are usually led by companies with strong market positions as they try to impose a de-jure or de-facto solution. At the moment, the IoT space is still to early for clear standards and is somewhat chaotic. Although I'd argue there's no possibility of comprehensive standards being accepted at this stage, there is a possibility for high level frameworks that provide some degree of standardization. The work I have been involved in on HyperCat is a good example of that. HyperCat is a high level mechanism to allow IoT systems to expose their catalogues of things – however it's really just a simple framework, it doesn't go beyond a basic ability to find and query. The details of the actual formats and the APIs are left to the underlying system. This, I think, is the best approach when innovation is still underway because it doesn't stifle the innovation.

Q : You are organizing the Vancouver hackathon and have organized smart city hackathons in the past. What motivated you to get involved with these events?

A : I have two main motivations. Firstly, as a principal of Urban Opus, a non-profit aimed at kickstarting Smart City solutions in Vancouver, I'm interested in **bringing together stakeholders** in the city to explore solutions. These can be cities of non-profits who have problems, challenges and issues they need help with, as well as tech companies, makers and hackers who want to use their skills to help solve these problems. Hackathons are a great way to bring these groups together and to seed the ideas. In our Urban opus model, we then take those seed ideas and try to form properly funded project sto move the solutions forward.

My second motivation is selfish, I'm a techie at heart and I enjoy seeing people use technology to help solve problems. Hackathons are great fun, lots of energy, lots of great ideas and it's always surprising what comes out of them.

Q : Do you have a challenge for the participants of this smart cities hackathon?

A : We had a number of specific challenges that we set, however Urban opus had two overarching themes.

Find ways to **engage citizens** and look for opportunities to gather data that citizens were comfortable making available because they could see the benefits from doing so.

Aim to source both citizen, open and company data and push it to the Urban Opus data hub as a resource for the metro Vancouver region to use to foster further Smart City services.

### 7.1.4 Smartly Opening Up City Data

**By Rosaldo J. F. Rossetti – IEEE Readings on Smart Cities, Vol. 1, Issue 4, April/May 2015**

**Open data** has a great catalysis potential in the Smart Cities' pursuit of innovation. Recent developments towards opening up data in the process of urban "smartification" have demonstrated that making machine-readable information freely available can foster citizen empowerment, enhance public services through participation, leverage new business models, and ultimately change the paradigm on which governments operate. However, many issues still remain to be appropriately addressed so that open data can be explored to its full potential. This issue of our Readings on Smart Cities starts our discussion on open data, its role in the urban smartification process, and issues demanding appropriate attention from all open data stakeholders.

In their work on "Unlocking the Value of Open Data with a Process-Based Information Platform," Masip-Bruin and colleagues [1] discuss undesirable side effects of current strategies to open up and effectively use data. Authors list lack of data quality, incompatible data formats and access methods, and various semantic interpretations of data as some of such adverse outcomes, which consequently avoid open-data stakeholders to offer citizens and business value-added applications and services. To address these issues and make open data actionable, they also propose a systematic value-creation process that helps stakeholders identify the most suitable information assets and convert them into forms that can be more consumable by users. Their platform leverages open data on features such as data quality assessment, data homogenization for uniform access, data correlation and semantic adaptation, and secure data access. Gkoulalas-Divanis and Mac Aonghusa [2] emphasise that an important characteristic of open data environments is that once published, it is difficult to anticipate how the data will be used, and that linking innocuous datasets together may lead to serious privacy violations. Authors then provide an introduction to data privacy and present some popular privacy models that have been proposed for privacy-preserving data publishing and knowledge hiding. Their work focuses on strengths and limitations of such models, and explains the important challenges that open data platforms introduce with respect to data privacy. In a rather practical perspective, Motta, Sacco, and Belloni [3] present their on-going research and development of IRMA, an Integrated Real-time Mobility Assistant. IRMA architecture consists of a smartphone application and a set of web services to gather and interpret any relevant source of information, which includes open data, crowd data and big data. Authors make use of the General Transit Feed Specification (GTFS) to access open data, which defines a common format for sharing public transportation schedules and associated geographic information. Through such specification public transit agencies can publish their transit data allowing developers to write applications that consume that data in an interoperable way.

Indeed, "open data are increasingly generating new business worldwide, providing citizens with a wealth of information that they can combine and aggregate in unprecedented ways" [2]. Although the recognised potential benefits of open data are enormous, many issues remain to be appropriately addressed by all open data stakeholders, such as governments, industry, application developers and citizens. Nevertheless, open data is definitely an important enabler of urban smartification contributing to innovation with citizen and business value-added applications and services.

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# Annex. Publications


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