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Analysis of the water consumption of the Scientific Campus – to step for the construction of a pilot of a Smart Water system

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Résumé

Ce travail fait partie d'un grand projet pour la mise en œuvre d'un réseau urbain intelligent sur le Campus de la Cité Scientifique qui est équivalent à une petite ville d'environ 25000 habitants. Le réseau intelligent comprend (i) la mise en œuvre d'une instrumentation pour le suivi en temps réel et le contrôle du réseau de distribution d'eau et (ii) le développement d'un système expert basé sur l'expérience développée par l'industrie de l'eau ainsi que sur des recherches fondamentales et appliquées pour la gestion optimale des systèmes complexes. L'un des enjeux majeurs de ce système concerne la gestion de la demande en eau. Ce travail a porté sur cette question. Il comporte une synthèse bibliographique et l'analyse de la consommation d'eau du Campus Scientifique.

Le travail est organisé en trois parties.

La première partie présente une analyse bibliographique des recherches sur la demande d'eau, la localisation des fuites d'eau et le développement des réseaux intelligents dans le secteur de l'eau. Des études de cas sont présentées pour illustrer l'application des innovations dans des projets réels.

La deuxième partie concerne la présentation du site du Campus, qui est utilisé dans ce travail de recherche. Ce site présente plusieurs avantages pour l'analyse de la demande en eau. Les bâtiments ont des usages variés: résidence, restauration, sport, administration, recherche, enseignement et enseignement / recherche. Le site est également équipé d'un système de télérelève (AMR). Les données de consommation sont disponibles pour les principaux bâtiments à différentes échelles de temps.

La dernière partie présente une analyse de la consommation d'eau des principaux secteurs du campus, qui couvrent les différents usages des bâtiments. L'analyse est menée à différentes échelles de temps: mensuelle, hebdomadaire, journalière et horaire. Il débouche sur l'établissement de profils de consommation des principaux bâtiments, qui seront ensuite intégrés dans le système intelligent de gestion de l'eau.

Abstract

This work is a part of a large project for the implementation of a smart water system in the Scientific Campus, which is equivalent to a small city with about 25 000 inhabitants. The smart water technology includes (i) the implementation of a real-time monitoring and control of the water distribution system and (ii) the development of an expert system based on the experience developed by the water industry as well as basic and applied researches for the optimal management of complex systems. One of the major issues in this system concerns the water demand management. This work concerned this issue. It included a literature survey and analysis of the water consumption in the Scientific Campus.

The work includes three parts.

The first part presents a literature analysis of researches ion the water demand, leakage localization and water smart grid. Case studies are presented for the illustration of the implementation of the latest technology and innovations in real projects.

The second part concerns the presentation of the site of the Scientific Campus, which is used in this research work. This site presents several advantages for the analysis of the water demand. The buildings have varied usages: students' residence, restaurant, sport, administration, research, teaching and teaching/research. The site is also equipped by an automatic metering reading (AMR). The consumption data is available for the main buildings at different time scales.

The last part presents analysis of the water consumption of the main sectors of the Scientific Campus, which cover different buildings uses: research, teaching, administration, residence and catering. Analysis is conducted at different times scales: monthly, weekly, daily and hourly. It results in establishing consumption profile of the main buildings, which will then be integrated in the smart water system of the Campus.

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General Introduction

Water is essential for life, health, economic activity and the well functioning of the ecosystem. According to the Organization for Economic Co-operation and Development (OECD), one billion people are currently without clean drinking water and 2.5 billion lack access to basic sanitation. Both polluted water and poor sanitation cause about 1.5 million child deaths per year and is the biggest source of child mortality along with malaria and malnutrition. Water management constitutes challenges at the local, national and international levels. Basic blocks for good water policy are well known, but we do need their real implementation to improve the population water access to safe and clean water.

The pressure on water resources is increasing dramatically as a result of increasing human activity (urbanization, industrial, agriculture and service development), climate change and environmental pollution. Sustainable water management requires the implementation of policies and strategies at the different levels of the water cycle: protection of water resources, treatment of water for clean and safe use, safe transportation of water for end-users, safe collection and transportation of used water and its re-use.

Water management in cities (urban areas) constitutes a particular challenge, because more than half of the world's population resides in cities and urbanization continues to highly increasing. Significant urban water investments are necessary to face this challenge. Both international and private-public cooperation is required to share experiences in the water management, in particular innovation in the fields of technology, management, governance and funding.

This work concerns the optimal management of the water distribution system, which is complex, because it is composed of high density of interconnected elements, such as pipes, storage facilities, pumps, valves, and other appurtenances with different ages and qualities. Although the size and complexity of drinking water supply systems vary dramatically, they have the same basic purpose: provide a safe potable water for domestic use, an adequate quantity of water at sufficient pressure for fire protection and an adequate water for industrial and services use. The essential parameters that describe the performance of water supply systems are: reliability, availability, safety and efficiency. Reliability concerns the probability that the system operates correctly; availability is related to the continuity of the water service, safety is related to the absence of hazardous consequences for the users and the environment and efficiency is related to the level of losses.

The work aims to implement efficient technology and latest innovations in the management of drinking water network. The high success of the smart grid concept in the improvement of the electrical grid management for both security and operating optimization is very encouraging for its implementation in the water distribution system. This implementation poses new challenges. It requires intensive research/development programs on water demand management, adaptation of the smart grid concept to water system and its implementation in cities.

The water demand management aims to conserve water by controlling demand through the application of measures such as regulatory, technological, economical and social at spatial and institutional levels. It aims to minimize the water losses in transport and storage systems and the reuse of water. Analysis shows that the pressure management is of great importance, in particular in reducing leakage. The water demand management is also crucial in determining the water prices and evaluating investment projects. Selected case studies showed different approaches used in the water demand management. Monitoring is largely used for the determination of the water demand. Analysis of recorded data allowed recommendations for the reduction of the water demand.

Water leakage constitutes also a major concern in the sustainable management of water resources. It results from the deterioration of the water distribution system, which could be caused by (i) physical factors related to pipes (material, age, diameter, thickness, ..) and joints, (ii) environmental factors, which concern trench backfill, soil type, climate condition and pipe location and (iii) operational factors such as water pressure, water flow velocity, water quality and internal corrosion. Leak detection is also of major importance. It includes leak localizing and leak location. The former aims at identifying the areas of leakage using mainly the District Meter Area (DMA). The latter is conducted using different technologies, mainly acoustic loggers, leak noise correlator, the ground radar, the gas injection and tracing techniques and the surface sensor array. Case studies showed methods used for the identification of the water losses. The DMA technology is largely used in these case studies.

The implementation of the smart water networks technology aims to conduct a real-time monitoring of the water distribution system (pressure, flow, water consumption, and water quality). It constitutes an efficient emerging technology for a rapid detection of the water leakage and contamination as well as for the reduction of the energy used in the water supply and for the improvement of the communication with end-users.

This work is a part of a large project for the implementation of a smart water system in the Scientific Campus which is equivalent to a small city with about 25 000 inhabitants. The work concerns the first phase of this project, which aims to collect and analyze the information on the water distribution system and water demand. The thesis is composed of three chapters.

The first part presents a literature analysis of researches and development in three fields: water demand, leakage localization and detection and smart grid for water management. Case studies will be presented for the illustration of the implementation of the latest technology and innovations in real projects.

The second part concerns the presentation of the site of the Scientific Campus – Lille1 University, which is used in this research work. This site is representative of a small town of about 25 000 inhabitants and 145 buildings for a total construction area of 323 000 m2. It presents several advantages for the analysis of the water demand and consumption. The buildings have varied usages: students' residence, restaurant, sport, administration, research, teaching, teaching and research. This variety of usage is particularly interesting for the analysis of the consumption profile. The site is equipped by an automatic metering reading

(AMR). The consumption data is available for the main buildings at different time intervals. A first analysis of the annual buildings consumption is presented.

The last part presents analysis of the water consumption of the main sectors of the Campus, which cover the different buildings uses: research, teaching, administration, residence and catering. Analysis is conducted at different times scales: monthly, weekly, daily and hourly. It allows establishing consumption profile of the main buildings at these time scales, which, will be then integrated in the smart water system of the Campus for the detection and localization of abnormal water consumption.

1 Chapter 1. Literature review: Water distribution challenges

1.1 Introduction

The pressure on water resources is increasing dramatically as a result of increasing human activity (urbanization, industrial, agriculture and service development), climate change and environmental pollution. The ability of countries to address the increasing water challenges depends upon their capacity to implement efficient measurements for the water resources management as well as for the water distribution system and wastewater treatment and reuse ***(Saito et al., 2012, Theo Spencer and Altman, 2010).***

This work concerns the water distribution system, which is generally complex, because it is composed of high density of interconnected elements, such as pipes, storage facilities, pumps, valves, and other appurtenances with different ages and qualities. Although the size and complexity of the drinking water supply systems vary dramatically, they have the same basic purpose: provide a safe potable water for domestic use, an adequate quantity of water at sufficient pressure for the fire protection and an adequate water for the industrial and services use (***Clark et al. 2004***).

The essential parameters that describe the performance of water supply systems are: reliability, availability, safety and efficiency. Reliability concerns the probability that the system operates correctly, availability is related to the continuity of the water service, safety is related to the absence of hazardous consequences for the users, while the environment and efficiency is related to the level of losses (***Misiunas, 2005)***.

In the following section, we present analysis of research works related to the following important issues for the management of water distribution systems:

- water demand,
- leakage,
- smart grid for water management

1.2 Water demand management

1.2.1 Presentation

Water demand management is one of the major components in the Integrated Water Resources Management, which is defined as a "management approach that aims to conserve water by controlling demand through the application of measures such as regulatory, technological, economical and social at spatial and institutional levels". It aims tat minimizing the water losses in the transport and storage systems and the reuse of water.

Over the past decade, great advancements have been achieved in the field of water demand management, which can be illustrated by many examples throughout the world where leakage and other forms of wastage have been significantly reduced through a range of water demand management interventions. Pressure management is considered as one of the most important water demand management interventions, and it is considered as the most effective cost measures to reduce leakage.

Within the framework of demand management, it is important to analyze and to understand the following characteristics of the water demand:

- How demand is formulated?
- Which factors control it?
- How demand responds to changes in income and relative prices?
- How the future demand will be shaped?

Analysis of the water demand is an essential component in designing effective water demand management. It is also crucial in determining the water prices and evaluating investment projects. Usually, the total water demand differs among different communities: It depends on the population, the geographic location, the climate, the extent of local commercial and industrial activity, and the cost of water (***Desalegne, 2005).***

Water consumption profiles of European users differ from those in the United States due to different factors such as: differences in users' habits and household and appliance characteristics.

1.2.2 Case studies

This section summarizes cases studies related to the management of the water demand conducted by some cities and campuses.

City of Athens (Bithas and Stoforos, 2006)

Bithas and Stoforos (2006) analyzed the domestic water demand in the city of Athens, which has specific characteristics such as: intensified scarcity, frequent and lasting drought periods, and expanding urbanization. Athens has a typical Mediterranean climate with a mean temperature of 18.5°C, a humidity of 50 % in July and an average maximum temperature of 31° in August. Analysis concerned the water domestic use, which includes households as well as small professional uses (commercial and institutional).
Domestic use accounted for 67% of the total water use in 1998 and therefore its evolution is crucial for the sustainable management of water in Athens. The demand for water in the city presents some interesting aspects, in particular the drought period of 1990-1993. From May 1990, emergency measures were taken: water prices were increased. Through strict administrative measures and extensive media coverage, the demand decreased steadily to reach its lowest level in 1993. In 1992, domestic water prices were increased by 100%. The scarcity of the water was becoming critical. In 1993, the legislation introduced quantitative limitations for the water use and high penalties in case of violation.

The residential water demand was described using the following function:

$$\mathbf{D_w} = \boldsymbol{\alpha} + \boldsymbol{\beta}\mathbf{i} \ln \mathbf{Pw} + \boldsymbol{\gamma}\mathbf{i} \ln \mathbf{In} + \boldsymbol{\delta}\mathbf{i} \ln \mathbf{X} + \boldsymbol{\varepsilon}\mathbf{i}$$

D_w designates the quantity of residential water demanded, Pw the water price, X the vector of other variables (weather variations) and ε the error term. The per capita real GDP was used for the income (In). Analysis showed that the elasticity of the residential water price is very low (-0.1); it could be partly explained by the fact that household expenditure on water constituted a very small fraction of the total expenditure. The income elasticity is equal to 0.7; it is higher than the price elasticity. Thus, as income increases, the demand for the residential water will increase by a smaller proportion. The elasticity of the weather variations is equal to 0.25, which means that the impact of the weather variations is more important than that of the water price.

Figure 1.1 shows a comparison between the actual and the fitted values of water consumption over the period 1981 – 1999. It can be observed that the simulations well capture the water consumption.

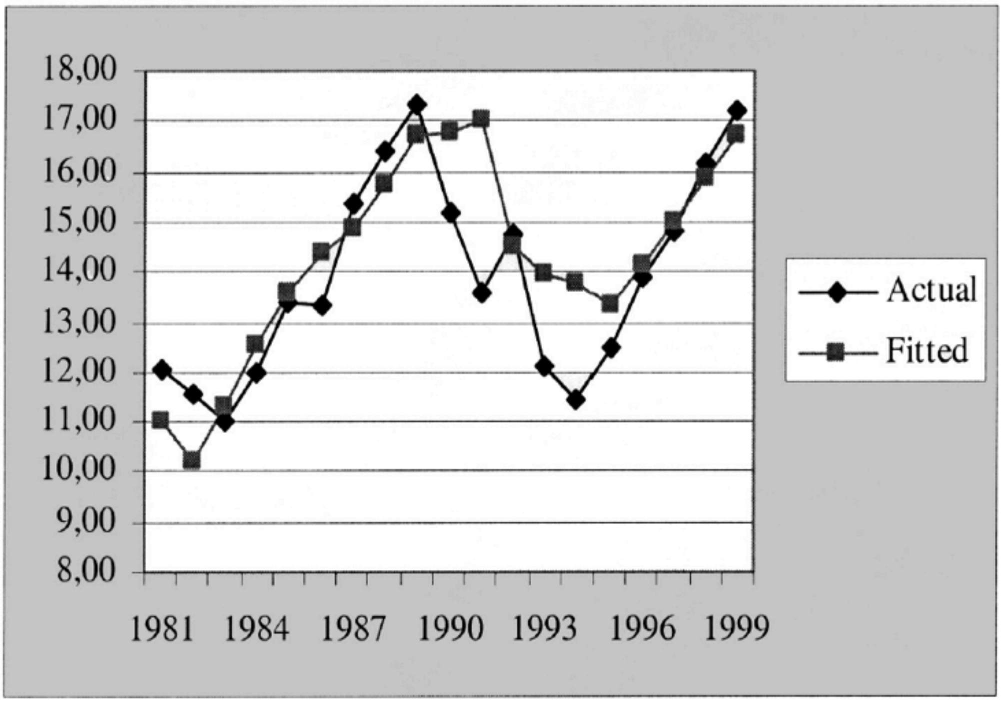

Figure 1.1 Simulation of the residential water consumption in the City of Athena (Bithas and Stoforos, 2006)

New Zealand (Roberti, Johannes, 2010)

Analysis of the water demand in New Zealand showed a continuing increase in the water demand. For example, about 62% of the water in Auckland is used in residential buildings. A detailed study was conducted to analyze how occupants in residential buildings use water. Results were used to network operators to rationalize choices between feasible options for improvements and upgrades inside residential buildings that could improve buildings' water use performance and reduce consumer demand for water.

Provincial cities in Greece (Gratziou et al. 2006)

Gratziou et al. (2006) analyzed several social factors that affect the water rates policy in provincial cities in Greece. They investigated the effect of the application of different tariffs on the water demand. The water demand function was developed on the basis of financial theory of water demand in regions with different economic and cultural characteristic correlating water consumption to consumers' income, type of residence and their cultural identity. They calculated seasonal variations in the water demand for each consumer category. The elasticity of the water demand was estimated in relation to the price. They found that the highest water consumption concerned the domestic sector (80% of the studied sample), and the highest consumption was in the summer period.

Cape Flats in the Western Cape Province, South Africa (Jansen and Schul, 2006)

Jansen and Schul (2006) focused on factors influencing water consumption. Principally, they estimated the price elasticity of the water demand using data obtained from households living on the Cape Flats in the Western Cape Province, South Africa. They found that the price elasticity differs significantly between the High-income groups and the low ones. While consumption is insensitive to price changes among the poor, the richest group of households reacts to price changes much more. In addition, they concluded that a social manager of water must have a good knowledge of the water demand structure to propose a socially efficient water pricing structure.

Colgate Campus (Coates, et al. 2011)

The topic of water consumption is considered as a major issue in the sustainable management strategy of the Colgate Campus. The university conducted works to investigate the water consumption and the measurements to be taken to reduce this consumption. The campus buildings were ranged into five categories: Residential, Academic/Administrative, Service Facilities, Athletic Facilities, and Dining Facilities. By studying each category, the university determined the highest consuming sectors and formulated several recommendations, such as: improvement of the Athletic Field irrigation methods and the re-evaluation of the current metering systems.

South Kensington Campus - imperial college – London (Ward et al. 2010).

The research work on the water consumption of the *South Kensington campus included* buildings ranking according to their overall water consumption as well as the identification of patterns of water consumption based on telemetry data. The work resulted in some recommendations for the reduction of water consumption on the campus; mainly frequent examination of the telemetry data to identify unexpected consumption rates, in particular for periods of low consumption such as at night or in vacation period. This survey allows an efficient localization of water losses.

University of KANSAS: (Gleeson and Klenow, 2009)

The research work at the Kansas Campus aimed to analyse the water use in this old campus. The work included an analysis of the water flow in the water network as well as the water use in the campus and its variation at different times scale. The study resulted in some recommendations for the reduction of the water consumption, mainly public education and awareness of students as well as faculty members concerning the water conservation. Examples of good practices were proposed on the basis of other universities experiences.

Yale University (Iversen, 2010)

The campuses of Yale University include over four hundred buildings. Almost every building uses water for various types of activity. The research work resulted in detailed data about each building, mainly dates of completion and renovation, size, available stations, capacity and type of use (academic, administration, athletic, laboratories). The study suggested some recommendations concerning water-monitoring program and users' awareness concerning the reduction of the water consumption.

California institute of technology (Kuo, 2008)

In response to rising water costs and increasing water shortages in the Los Angeles area, the California Institute of Technology developed a water efficiency program within its sustainable strategy. The program included analysis of the water efficiencies in different sector of the campus. Water consumption was analyzed for each building. The buildings were organized in 6 subcategories according to the water use: research, student life, gyms, irrigation, and utility plants. Analysis showed that the largest water use concerned two utility plants on campus: the central and satellite plants, which were responsible for providing tye campus with chilled water and electricity. These two plants were responsible for 45% of the campus' water consumption. Improvement of the water system management for these utilities was proposed as the main measurement for the reduction of the campus water consumption.

1.3 Leakage in water Networks

As discussed previously the water loss constitutes a major concern in the sustainable management of water ressources ***(Gertler et al. 2010).***

This section presents a literature review of this issue, with a particular concern for the following:

- Leakage definition
- Causes of leakage
- Leakage detection
- Water losses
- Cases studies

1.3.1 Leakage definition

Water losses are the difference between the input water volume and the authorized consumption. Table 1.1 summarizes the main water losses in the water distribution system according the international Water Association (IWA). They include tow categories:

- Apparent losses, which consist in unauthorized consumption and all types of metering inaccuracies.
- Real losses, which concern all types of leaks, bursts and overflows on mains, service reservoirs and service connections, up to the point of customer metering.

Table 1.1 : Water losses definition according to the International Water Association (IWA)

Apparent loss	Unauthorised consumption
	Customer meter inaccuracies
Real loss	Leakage on transmission and distribution mains
	Leakage and overflows at storage tanks
	Leakage on service connections up to point of customer meter

1.3.2 Causes of leakage

Leakage results generally from the deterioration of the water distribution system, which could be caused 3 categories of factors (Table 1.2):

- Physical factors, which are related to the pipe (material, age, diameter, thickness, ..) and the type of joint.
- Environmental factors, which concern trench backfill, soil type, climate condition and pipe location
- Operational factors such as water pressure, water flow velocity, water quality and internal corrosion

Table 1.2: Factors of deterioration of the water distribution systems

Physical factors	**Environmental factors**	**Operational factors**
Pipe material	Pipe bedding	Water pressure
Pipe wall thickness	Trench backfill	Flow velocity
Pipe age	Soil type	Water quality
Pipe diameter	Climate condition	Internal corrosion
Type of joints	Pipe location	…

Figure 1.2 shows the main modes of failure in water mains and their origins. We can distinguish:

- Circumferential break, which is due to frost, soils swelling and thermal contraction.
- Longitudinal break, which results from internal water pressure, soil pressure, freezing water and traffic load.
- Spilt Bell, which is due to the expansion of joints.
- Bell Shear, which is due to over homing and bending stresses.
- Spiral break, which results from bending and hooping stress induced by water pressure.
- Blow out, which could be caused by internal water pressure and pipe corrosion
- Through hole, which is due to corrosion or casting flaws.

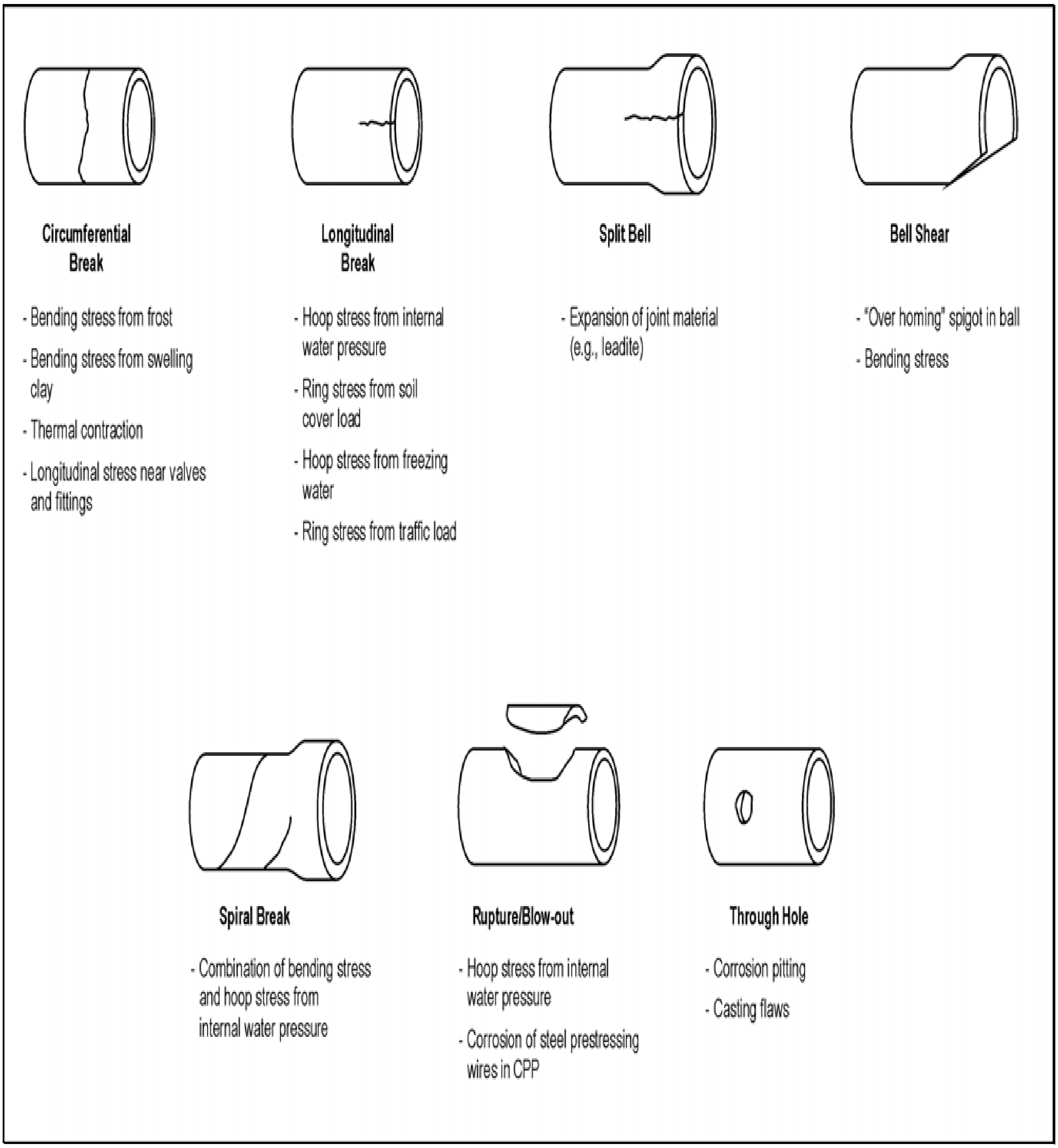

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Figure 1.2 Modes of failure in water mains

1.3.3 Leak detection

The Loss Task Force of the International Water Association (IWA) presented the state of the art in water leak detection. It includes both leak localizing and leak location.
The leak localizing aims at identifying the areas of leakage. The water distribution system is subdivided by a system of valves into temporary zones. The measurement of flow, during the period of minimum night flow, allows determining the areas of suspected leakage. Many utilities use the District Meter Area (DMA), which includes between 500 to 3000 connections into which water can be measured in order to determine the level of leakage.

Acoustic loggers are used to define the general area in which leaks are located. By recording and analyzing the intensity and consistency of the noise, loggers indicate the likely presence of a leak. During the late 1970s the leak location activity significantly improved with the

development of the leak noise correlator. Sensors were deployed at two locations, e.g. two valves on the pipeline either side of a suspected leak position. The difference in the arrival time of the leak noise at each sensor, coupled with the knowledge of the pipe material, diameter and length, enables the leak to be pinpointed.
In the beginning of the 21^{st} Century, a combined acoustic logger and leak noise correlator was developed. This system has the advantage of reducing the time between identification of a leak noise and pinpointing of the leak.

The ground radar has been developed in recent years for the location and surveying of pipes, cables and other buried objects. Water leaks can be identified through the observation of the disturbed ground or cavities around the pipe.

Gas injection and tracing techniques are also used for the detection of water leaks in house connections and other small diameter pipes, especially in non-metallic pipes. The leak is located by filling the pipe with tracer gas (mainly industrial hydrogen) that escapes at the point of the leak and then detected accurately with a 'sniffing' probe on the surface.

An advanced system form of leak localization has been recently developed using a surface sensor array. The system sends a radio frequency signal into the ground and detects the reflection. Flowing water from a leak causes phase and amplitude modulation of the reflected signal, which is detected by an interferometer.

1.3.4 Water loss management

Figure 1.3 shows the leakage management strategy ***(Lambert and Taylor 2010)***, which aims to reduce the water loss. It is based on:

- Pressure management.
- Active leakage control.
- Speed and quality repairs of pipes.
- Installation, management and renewal of pipes.

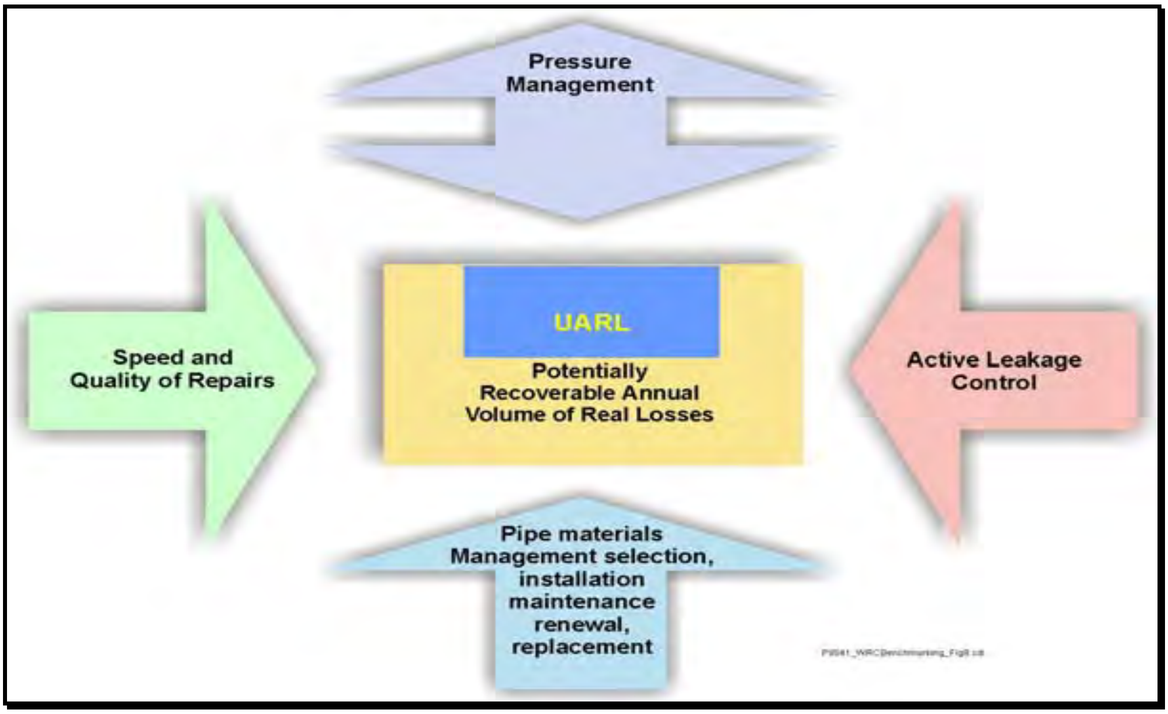


Figure 1.3 Strategy for the management of water loss. (Lambert and Taylor 2010),

1.3.5 Cases studies

City Addis Ababa-Ethiopia (Desalegn 2005)

Desalegn (2005) analyzed the water losses the city Addis Ababa, which faces a high rate of water losses. He found a loss of about 41%. The principal cause of water losses in this city was attributed to leakage and customers meter errors. He proposed a methodology to evaluate and reduce losses in the water system.

Thailand (Pornprommin et al. 2007)

A project was launched in Thailand for the reduction of the high leakage in the water networks of Thailand (about 40%). The project is based on the use of the district meter area (DMA) method. The hydraulic characteristics of the water network were investigated. The analysis of the pressure and the flow records permitted to localize the expected areas of low water pressure and water leakage.

Mutare, Zimbabwe (Marunga et al, 2006)

Marunga et al. (2006) analyzed the high water losses in Mutare. They found that the value of the unaccounted water attained 57%. Epanet was used for modeling the pressure distribution. They recommended (i) investigating the leakage control by a pressure management in the city; and (ii) the necessity of replacing the very old pipes.

City of Vidin-Bulgaria (Kalinkov et al. 2011)

Kalinkov et al. (2011) evaluated the water losses in the water supply system of the city of Vidin-Bulgaria. They calculated the water balance for the entire city, and the monthly water balance for pilot areas. Analysis of the night flow records in the (DMA) allowed the determination of the unreported leaks.

Enia (Italy) (Fantozzi et al. 2009)

The strategy selected by Enia utility (Italy) in order to reduce water leakage in the water distribution systems was based on the use of both the District Metered Areas (DMA) and the Pressure Management Areas (PMA). A leakage reduction program was implemented in 93% of the network (4850 km), where the distribution systems were divided into more than 260 DMAs. The project allowed more than 16% reduction in the per capita daily inflow and more than 20% reduction in the number of repairs, mainly by (i) a pressure reduction and (ii) a focused network renewal.

Wattrelos City, France (Jafar et el., 2010)

Jafar et al. (2010) used the artificial neural networks (ANN) method for the prediction of failures in the water supply systems and for the determination of the optimal time for the renovation of pipes in the water supply system. For the calibration of the ANN model, they used a data set collected during 14 years. They found that the ANN method could be used effectively for the prediction of failures in the water networks, and for establishing a rehabilitation strategy for of the water supply systems.

Trondheim, Norway (Røstum, 2000)

Røstum (2000) used the statistics approach for the prediction of the pipe failures in the water distribution network in Trondheim, Norway. He analyzed the influence of factors that may affect the water network. He showed that the grey cast iron and the unprotected ductile iron pipes were highly concerned by the deterioration of the water network.

1.4 Smart grid for water management

1.4.1 Presentation

The implementation of the smart water networks technology enables companies to monitor water pressure, flow, consumption and quality (pH, dissolved oxygen, conductivity, residual chlorine, various chemical and biological contaminants). Consequently, the smart technology will help in a rapid detection of water leakage and water contamination in the water distribution system. In addition, it helps in the reduction of the energy used in the water supply and in improvement of the information of end-users.

Smart water technology constitutes a good opportunity for the water utilities to improve their productivity and efficiency and for enhancing the customer service. And consequently to improve the water networks management.

The smart water networks technology included five interconnected layers as illustrated in figure 1.4:

- Measurement and sensing instrumentation
- Communication service
- Data management
- Real time data analytics and modeling
- Automation and control

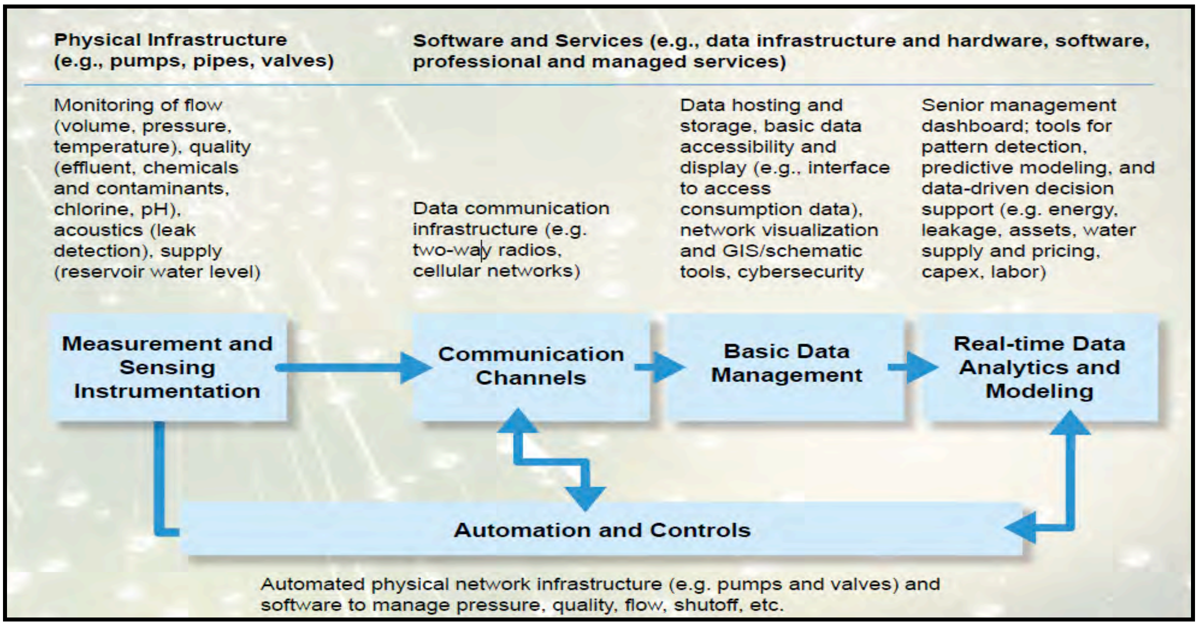


Figure 1.4 Layers of smart water network

1.4.2 Cases studies:

Boston (Stoianov et al. 2007, 2008)

Stoianov et al. (2007, 2008) developed a prototype system for a real-time monitoring of the water system, which included monitoring of hydraulic, water quality, and water level in sewer collector and sewer outflows. The monitoring system was deployed in collaboration with Boston water and sewer Commission (BWSC). The project included three stages:

- Stage 1 concerned the development and the field validation of the prototype system.
- Stage 2 concerned testing and validation of data analysis techniques such time synchronized data collection and acoustic leak detection.
- Stage 3 concerned the complete real-time monitoring method.

Figure 1.5 shows the smart water monitoring system. It includes 3 tires:

- Sensors and sensors nods
- Cluster head & gateway
- Middleware & Bach-end

Figure 1.6 illustrates the field deployment of the prototype monitoring system, which includes

- A pH sensor in a Cast-iron pipe (12’’) which supplies potable water.
- A pressure sensor in a cast iron pipe of (8”).
- A water level monitoring in the combined sewer outflow collector, which is composed of two pressure transducers at the bottom of the collector and an ultrasonic sensor on the top.

In the second stage of the project, a laboratory pipe was installed to validate the monitoring method for leakage detection and localization. Leaks were created or simulated in two places by installing valves (orifice leaks) along the pipe, as illustrated in figure 1.7.

The project included a high concern in the reliability of data transfer and in the influence of the weather on data communication.

Tests showed a good efficiency of the pressure sensors, while the pH sensor needed maintenance or replacement. Figure 1.8 illustrates an example of the pH sensor data for a week.

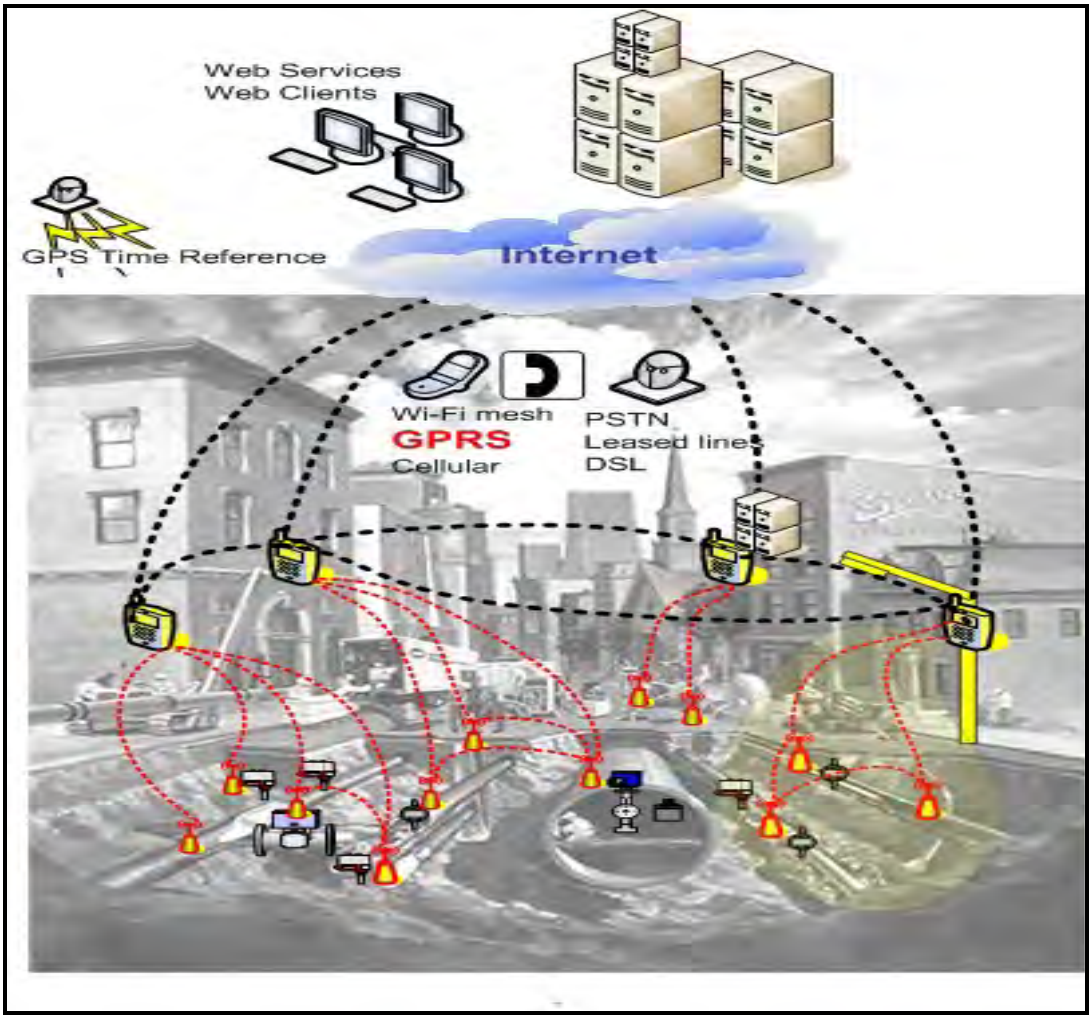
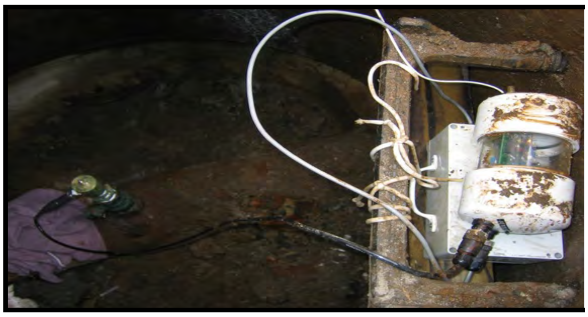
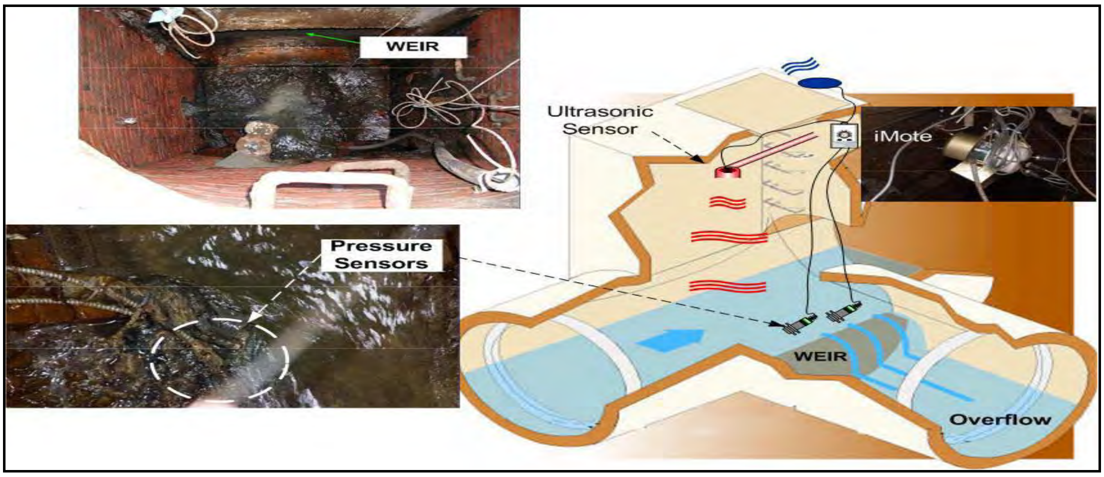


Fig 1.5 Smart water monitoring system used in Boston (Stoianov et al. 2007, 2008)

Installation of pH probe



Installation of pressure sensor



Water level Monitoring in the sewer outflow collector

Figure 1.6 Examples of sensors used in Boston Smart Water System

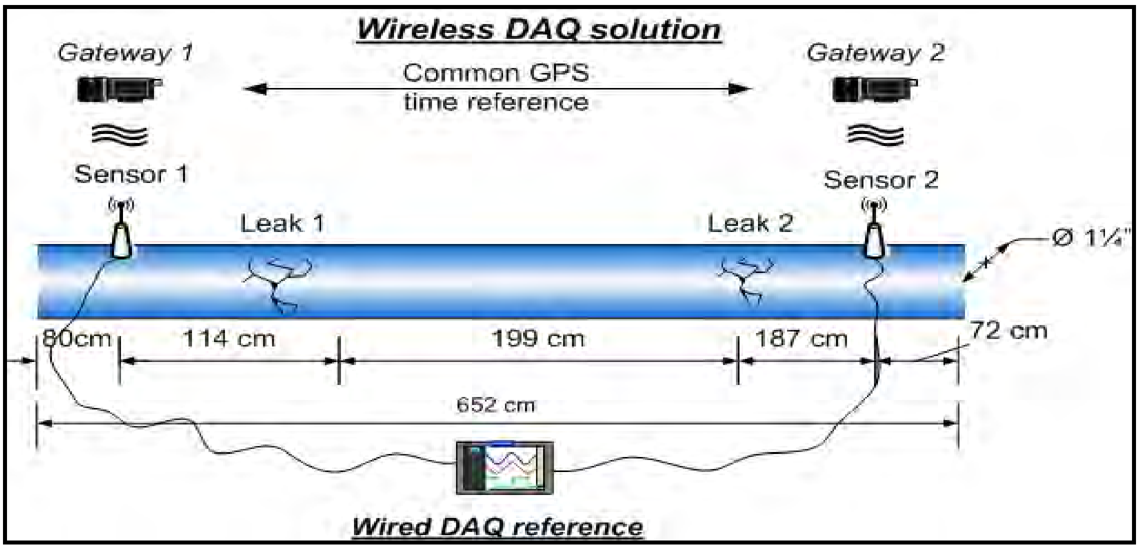


Fig 1.7 Laboratory pipe rig for the water leakage detection in Boston

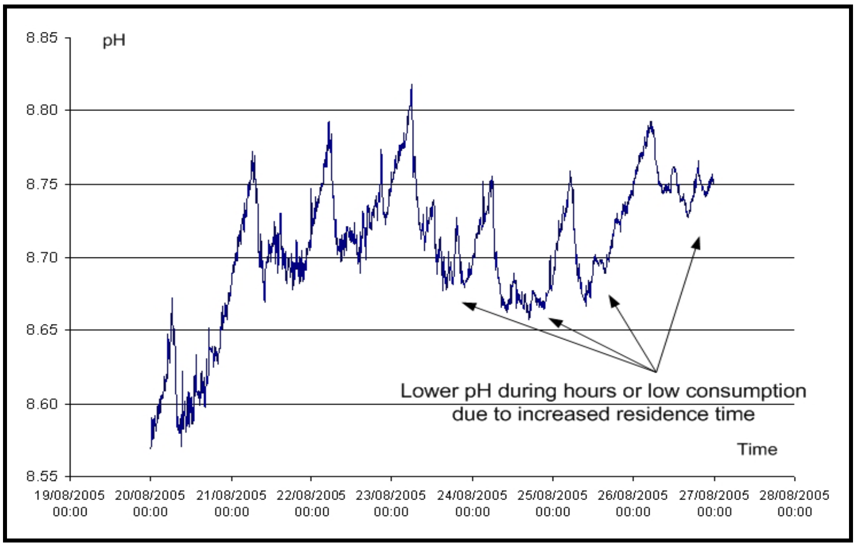


Fig 1.8 pH record (Boston Smart Water Sysem)

Lemesos water system (Cyprus) (Christodoulou and Milis 2010)

The lemesos water system is over 50 years of age and serves about 170 000 residents through approximately 64 000 consumer meters. The water network is divided into pressure zones; each is then subdivided in District metered areas (DMAs). The DMAs vary in size between 50 properties to 7000 with an average size of 3000 properties. The DMAs have been defined to minimize the water loss at peak demands. Meter readings are connected via a SCADA system to a control room. Figure 1.9 shows the deployment of the pilot project.

Figure 1.9 Deployment of the water smart pilot – Lemesos (Christodoulou and Milis 2010)

Singapore (Whittle et al. 2009, 2011)

The project "WaterWiSe@SG" aimed at developing a real time monitoring system of the water distribution network in Singapore downtown. It included real time monitoring of both hydraulic and quality parameters: pressure, flow, pH, chlorine residual, turbidity, conductivity and dissolved oxygen. The system is intended for the localization of leakage and the prevision of pipe bursts.

The project included 3 phases:

- Phase 1: deployment of a basic system with 8 sensor nodes for the monitoring and data collection (pressure, flow and acoustic).
- Phase 2: Extension of the network to contain 25 of sensor nodes.
- Phase 3: full-scale deployment of the system, with more than 100 sensor nodes.

Figure 1.10 illustrates the sensor node deployment, which includes pH, flow probes, pressure sensor, hydrophone and GPS antennas.

A 3G network is used for data transfer from sensors to servers (Figure 1.11). Real time and historical data graphs can be visualized on the project web-portal.

Figure 1.12 illustrates a week records concerning pressure, pH and water flow. It shows a variation of the water pressure around 55 psi, a high variation of the water flow according to the water consumption and a high local variation of pH.

Figure 1.13 shows two records of the water pressure with leakage events. It can be seen that leakage induces a sharp drop in the pressure. Consequently, the drop in the pore pressure could be used as an indicator for the water leakage.

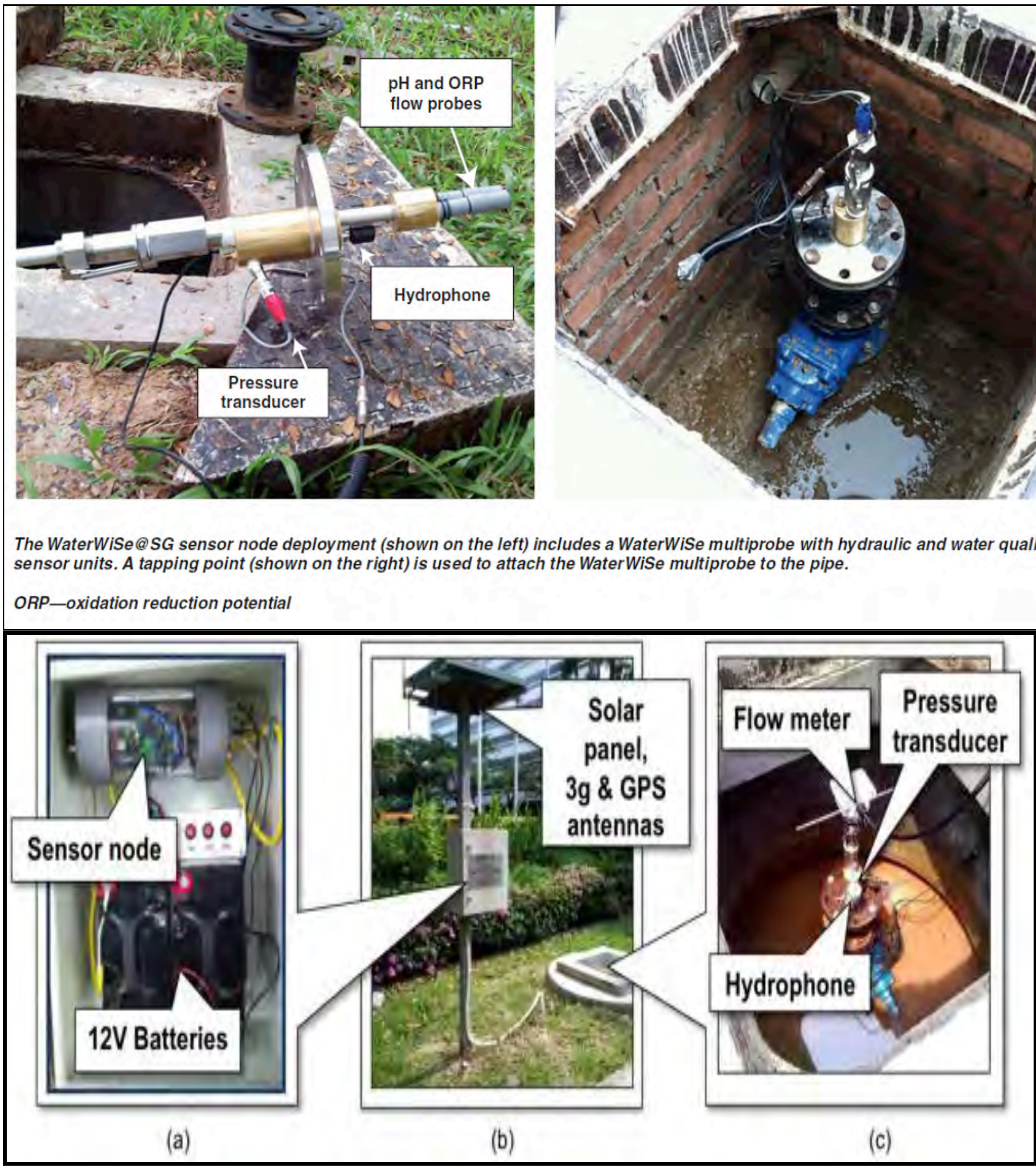


Figure 1.10 Sensor node deployment (Singapore) (Whittle et al. 2009, 2011)

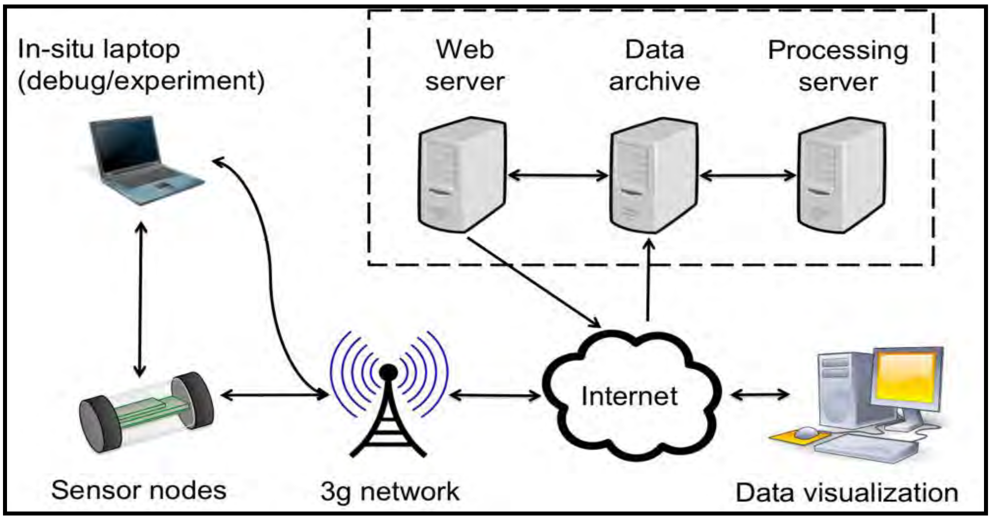


Figure 1.11 Communication system used in Singapore Project

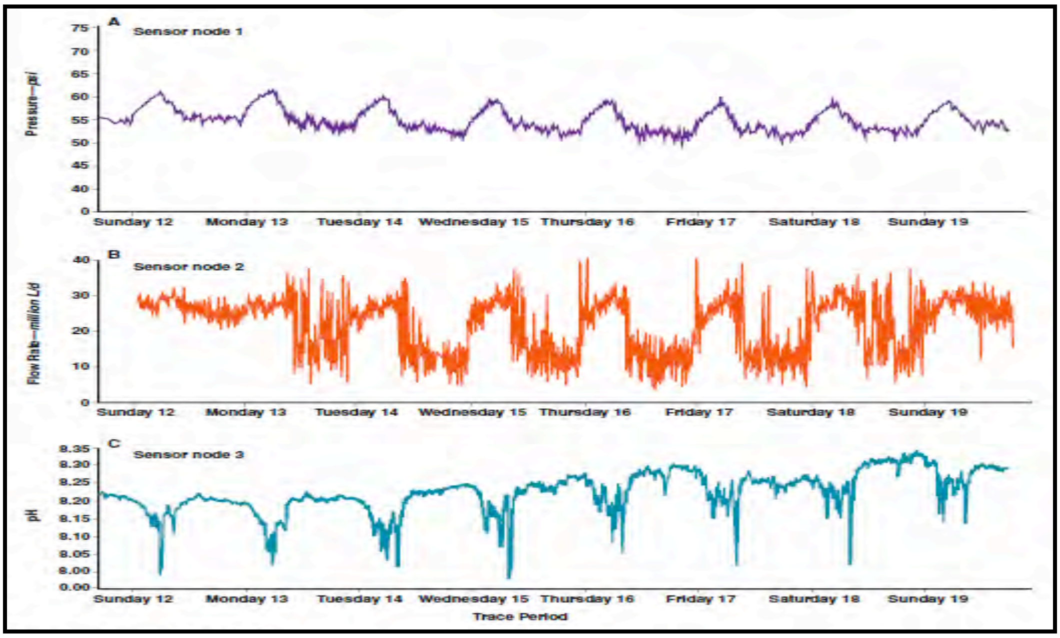


Figure 1.12 Examples of a week records (Singapore)

a) Pressure trace, b) flow trace, c) pH trace

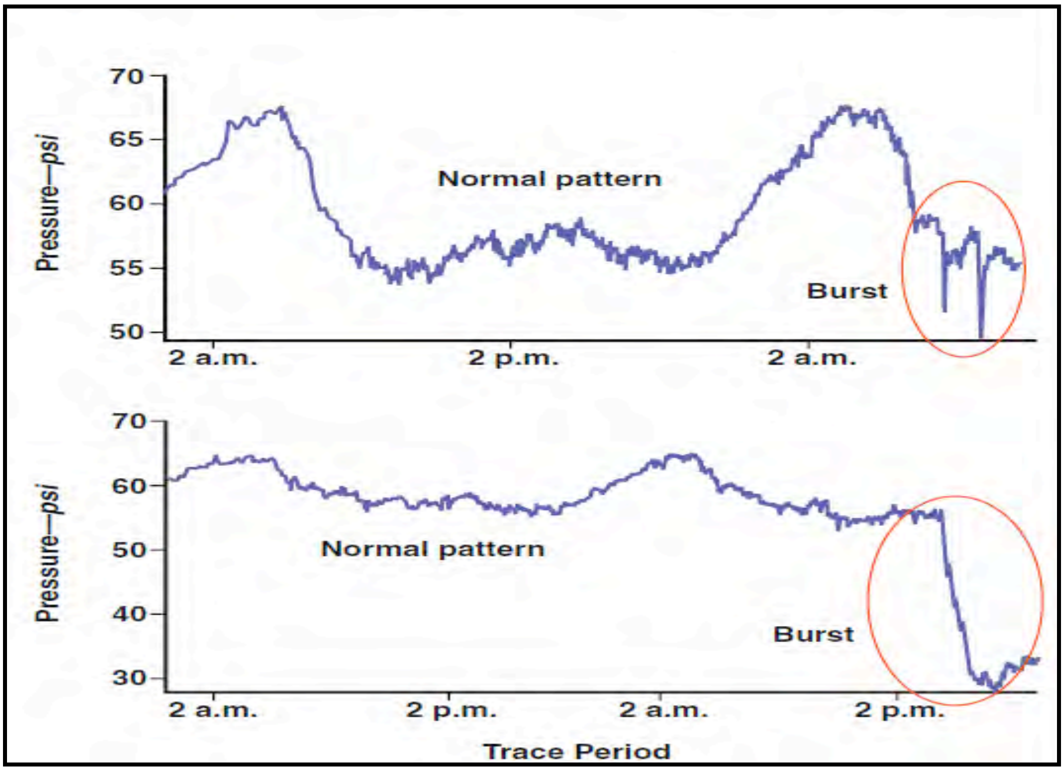


Figure 1.13 Illustration of records with water leakage events (Singapore Project)

1.5 Conclusion

This chapter presented a literature review of major water distribution challenges, with a particular focus on the water demand management, water leakage detection and control and the use of smart systems in water management.

Water demand management is a management approach that aims to conserve water by controlling demand through the application of measures such as regulatory, technological, economical and social at spatial and institutional levels. It aims at minimizing the water losses in transport and storage systems and the reuse of water. Analysis shows that the pressure management is of great importance, in particular in reducing leakage. The water demand management is also crucial in determining the water prices and evaluating investment projects. Selected case studies showed different approaches used in the water demand management. Monitoring is largely used for the determination of the water demand. Analysis of recorded data allowed recommendations for the reduction of the water demand.

Water leakage constitutes a major concern in the sustainable management of water resources. It results from the deterioration of the water distribution system, which could be caused by (i) Physical factors related to pipes(material, age, diameter, thickness, ..) and joints, (ii) Environmental factors, which concern trench backfill, soil type, climate condition and pipe location and (iii) Operational factors such as water pressure, water flow velocity, water quality and internal corrosion

Leak detection is also of major importance. It includes leak localizing and leak location.

The former aims at identifying the areas of leakage using mainly the District Meter Area (DMA). The latter is conducted using different technologies, mainly acoustic loggers, leak noise correlator, the ground radar, the gas injection and tracing techniques and the surface sensor array. Case studies showed methods used for the identification of the water losses. The DMA technology is largely used in these case studies.

The implementation of the smart water networks technology aims at conducting a real-time monitoring of the water distribution system (pressure, flow, water consumption, and water quality). It constitutes an efficient emerging technology for a rapid detection of the water leakage and contamination as well as the reduction of the energy used in the water supply and for the improvement of the communication with end-users. Smart water systems include 5 interconnected layers (i) Measurement and sensing instrumentation, (ii) Communication service, (iii) Data management, (iv) Real-time data analytics and modeling and (v) Automation and control.

Case studies showed mainly the monitoring and communication phases of the deployment of the smart water network. The use of this technology in the control of water network is still in the starting phase.

In the following chapters, the work will focus on the analysis of the water consumption in the Campus of the University of Lille1, which presents a small town. Analysis will be based on a large monitoring program of the flow in the water network. This analysis aims at understanding the water consumption in the Campus and to develop consumption profiles of high consuming buildings, which will be used for the water detection in the smart water management system of the Campus.

1
2 Presentation of the site study (Scientific Campus – Lille1 University)

2.1 Introduction

The construction of the Scientific Campus – Lille 1 University started in 1964; it was inaugurated in 1967. It covers an area of about 110 hectares, which is located in the City of Villeneuve d'Ascq near the City of Lille in the North of France. The campus has experienced other periods of construction, mainly after 1980. Today, the campus includes 145 buildings with a total construction area of about 325 000 m^2. It is organized in (Figure 2.1):

- Scientific Poles: Mathematics, Physics, Chemistry, Biology, Social Sciences,
- Engineering schools (Polytech'Lille and Ecole Centrale de Lille)
- Institute of Technology (IUT)
- Administrative Buildings
- Central Library and cultural space.
- Students Residences
- Sports Facilities
- Restaurants

Figure 2.1: Scientific Campus – University Lille1 (Villeneuve d’Ascq)

The buildings of the campus are characterized by a wide diversity in terms of age of construction (between 5 and 50 years), quality of construction and main use (teaching, research, administration, residence, sport, catering, ..). This diversity of use gives the campus a high originality for field studies.

In the following, we present in a more detailed way, the buildings of the campus, the water distribution network, the annual water consumption of the principle sectors and buildings. This analysis allows determining the consumption patterns of buildings and choosing some of these buildings for a more detailed analysis, which will be presented in the third chapter.

2.2 Presentation of the Campus buildings

The presentation will focus on 67 buildings of the campus, which presents a total surface area of about 323 000 m^2. Small buildings will not be considered in this analysis. Figure 2.2 shows the distribution of these buildings according to their surface area. It can be observed that 12 buildings cover about 51% of the total surface, and that about 80% of the total surface concerns 28 buildings.

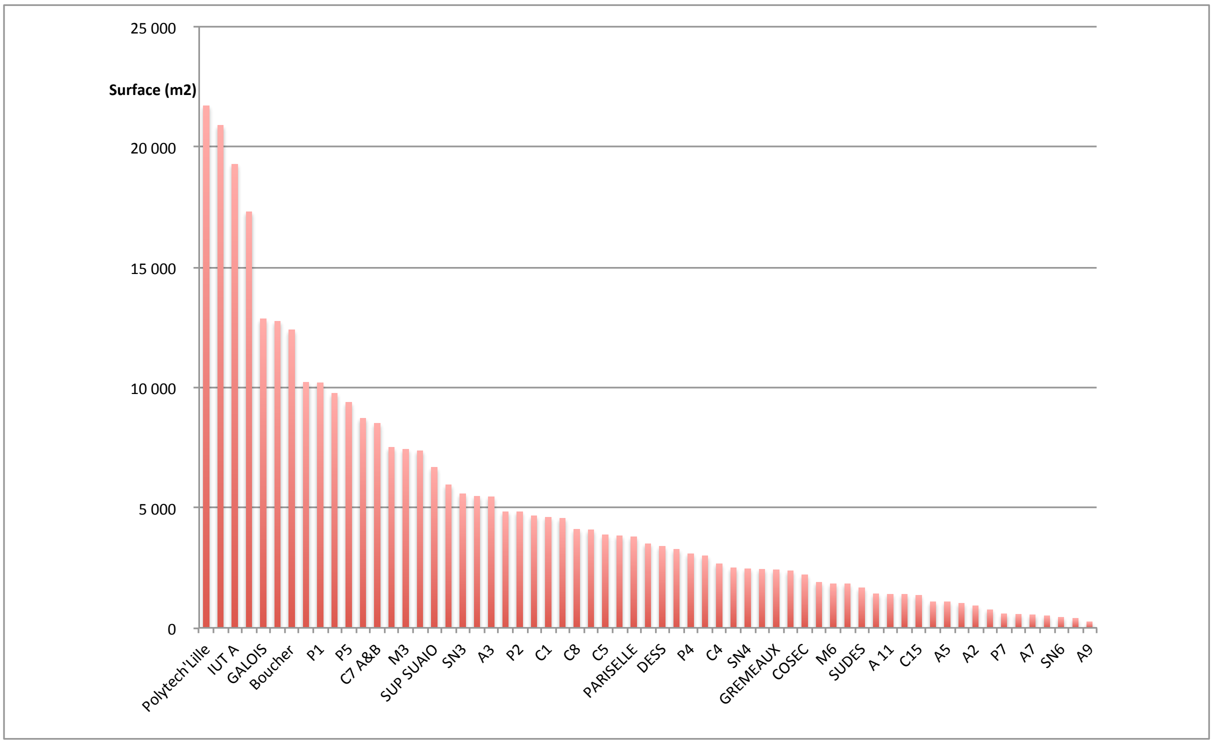


Figure 2.2: Ranking of the Campus buildings according to their surface area.

The buildings of the campus are clustered in 11 sectors according to their usage and location:

- Administration & services
- Chemistry
- Engineering schools
- Institute of technology (IUT)
- Mathematics and Computer Science
- Natural Sciences
- Physics
- Social Science
- Students Residence
- Restaurants
- Sports

Figure 2.3 shows the surface construction area by sector. It can be observed that the sector of the students residence presents about 18% of the total surface, followed by the sectors of engineering (14%), chemistry (13%), physics (11%) and administration & services (11%).

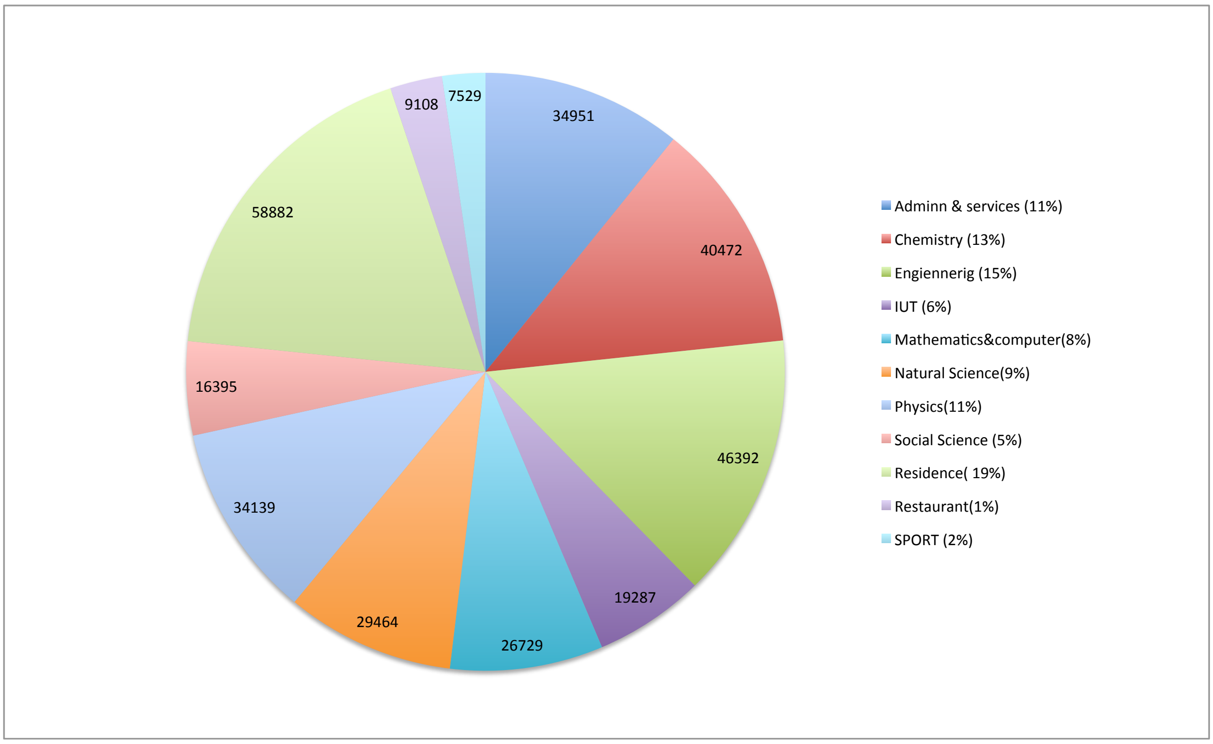


Figure 2.3: Distribution of the buildings surface area by sector

2.2.1 Administration & services sector

The administration & service sector is composed of 14 buildings, which concern the administration of the university, the library, the cultural space, the heating center and two teaching buildings which are not affected to faculties (SUP and DESS). Table 2.1 summarizes the use of these buildings as well as their year of construction and surface area. Some of them (A1, A2, A3, A10, library) were constructed in 1966 (during the campus construction), while others were constructed after 1988. The total surface area of this sector is equal to 34 716 m^2. The library is the biggest building (about 9 700 m^2).

Table 2.1 Buildings of Administration & services sector

Building	Main Use	Construction year	Surface Area (m^2)
A1	Heating center	1966	1 401
A3	Administration	1966/1992	5 450
A7	Administration	1996	538
SUDES	Administration	1996	1 660
SUP/SUAIO	Administration & Teaching	2004	6 680
A2	Technical Service	1966	923
A6	Technical Service	1995	497
A9	Sport	1988	254
A 11	Culture	2001/2003	1 408
Librarat	Library	1966	9 747
A 10	Health centre	1966/1998	570
A4	Administration	1988	1 095
A5	Administration	1988	1 095
DESS	Teaching	1995	3 398
	Total Surface area		34 716

2.2.2 Chemistry Sector

The chemistry sector is composed of 11 buildings, which concern mainly research and teaching. Table 2.2 summarizes the use of these buildings as well as their year of construction and surface area. The majority of theses buildings were constructed in 1966 (C1, C3, C4, C5, C6, C7, C8, C9, C11). Rehabilitation and extension works were conducted later in some of these buildings, mainly for the security measurement (C4, C7, C9, C11). Two buildings were constructed in 1992 and 1996 (C15 and C16). The total surface area of this sector is equal to 34 716 m^2.

Table 2.2 Buildings of the chemistry sector

Building	Main Use	Construction year	Surface Area (m^2)
C1	Teaching	1966	4 602
C15	Teaching	1992	1 348
C16	Teaching	1996	761
C7	Teaching and research	1964, 2002	8 500
C5	Research and teaching	1966	3 862
C6	Research and teaching	1966	5 481
C8	Research and teaching	1966	4 107
C11	Research	1966/2000	1 027
C3	Research	1966	3 259
C4	Research	1966/2003	2 675
C9	Research	1966/1995	4 561
	Total Surface area (m^2)		40 183

2.2.3 Sector of Engineering Schools

The sector engineering schools includes three buildings of Polytech'Lille and Ecole Centrale de Lille, which concern mainly teaching and research. Table 2.3 summarizes the use of these buildings as well as their year of construction and surface area. Two buildings were constructed in 1966 and 1970 (Ecole Centrale de Lille and Polytech'Lile-D). The main building of Polytech'Lille was constructed in 1997. The total surface area of this sector is equal to 46 392 m^2.

Table 2.3 Buildings of the sector of engineering schools

Building	Main Use	Construction year	Surface Area (m^2)
Polytech'Lille - D	Research and teaching	1970	7 366
Polytech'Lille	Teaching	1997	21 720
Ecole Centrale de Lille	Teaching and Research	1966	17 306
	Total Surface area (m^2)		46 392

2.2.4 Institute of technology (IUT)

This sector is composed of one big building (19 287 m^2), which was constructed recently (2006). This building concerns mainly teaching with pedagogic laboratories.

2.2.5 Sector of Mathematics and Computer Science

The sector of Mathematics and Computer Science includes 6 buildings, which concern mainly both research and teaching. Table 2.4 summarizes the use of these buildings as well as their year of construction and surface area. Four buildings were constructed in 1966 (M1, M2, M3, M4). Two buildings were constructed in 1993 and 1994 (M5 and M6). Rehabilitation and extension works were conducted later in buildings (M2 and M3.). The total surface area of this sector is equal to 26 729 m^2.

Table 2.4 Buildings of the sector of Mathematics and Computer Science

Building	Main use	Construction date	Area (m^2)
M1	Teaching	1966	8 723
M2	Research	1966/1994	3 838
M3	Research and teaching	1966/2002	7 437
M4	Computer Centre	1966	1 898
M5	Teaching	1993	3 001
M6	Research	1994	1 832
	Total Surface area		26 729

2.2.6 Sector of Natural Science

The sector of Natural Science includes 5 buildings, which concern mainly research and teaching. Table 2.5 summarizes the use of these buildings as well as their year of construction and surface area. All of these buildings were constructed in 1966. Minor rehabilitation works were conducted later. The total surface area of this sector is equal to 29 023 m^2.

Table 2.5 Buildings of the sector of Sector of Natural Science

Building	Main Use	Construction year	Surface Area (m^2)
SN1	Teaching	1966	10 205
SN2	Research	1966	4 829
SN3	Research	1966	5 584
SN4	Research	1966	2 459
SN5	Teaching Research	1966	5 945
	Total Surface area		29 023

2.2.7 Sector of Physics

The Physics sector is composed of 5 buildings, which concern mainly research and teaching. Table 2.6 summarizes the use of these buildings as well as their year of construction and surface area. Three major buildings (P1, P4, P3) were constructed in 1966. Rehabilitation and extension works were conducted later in 1999 in the building P5. The research building CERLA was constructed in 1998. The total surface area of this sector is equal to 34 139 m^2.

Table 2.6 Buildings of the sector of Physics

Building	Main Use	Construction year	Surface Area (m²)
P7	Administration & Teaching	1992	584
P1	Teaching	1966	10 197
P4	Research and teaching	1966	3 090
CERLA	Research	1998	1 411
P3	Research	1966	4 655
P5	Research	1966/1999	9 373
P2	Research and teaching	1966	4 829
	Total Surface area		34 139

2.2.8 Sector of Social Science

The sector of social science is composed of 4 buildings, which concern mainly teaching and research. Table 2.7 summarizes the use of these buildings as well as their year of construction and surface area. Thee teaching building SH1 was constructed in 1988. The buildings Geography and SH2 were constructed in 1996, while the teaching building SH3 was constructed more recently (2003). The total surface area of this sector is equal to 16 395 m^2.

Table 2.7 Buildings of the sector of social science

Building	Main Use	Construction year	Surface Area (m²)
SH1	Teaching	1988	2 437
SH3	Teaching	2003	7 508
Géographie	Teaching and teaching	1996	2 373
SH2	Teaching and teaching	1996	4 077
	Total Surface area		16 395

2.2.9 Sector of Students' Residence

The sector of students' residence is the largest sector (total surface area = 58 882 m^2). It is composed of 4 big residences, which were constructed in 1966. Some of these residences were refreshed later. Table 2.8 summarizes the information concerning three residences of this sector.

Table 2.8 Buildings of the sector of students' residence

Building	Main Use	Construction year	Surface Area (m²)
Boucher	Residence	1966	12 388
Galois	Residence	1966	12 844
Bachelard	Residence	1966	12 751
	Total Surface area		37 983

2.2.10 Sector of Restaurants

This sector includes three restaurants with a total surface area of 9 108 m^2 (Table 2.9). Restaurants Sully and Pariselle were constructed in 1966. The smallest restaurant (Barrois) was constructed more recently.

Table 2.9 Buildings of the sector of restaurants

Building	Main Use	Construction year	Surface Area (m^2)	Total/sector
Sully	Catering	1966	3 497	
Pariselle	Catering	1966	3 784	
Barrois	Catering	20004	1 827	
	Total Surface area		9 108	9 108

2.2.11 Sector of Sport

The sector of sport includes 2 sport halls, which were constructed in 1994 and 1996, a building facility sport (COSEG), which was constructed in 1975 and a small building for social and entertainment activity, which was constructed in 1994. The total surface area of this sector is equal to 7 529 m^2 (Table 2.10).

Table 2.10 Buildings of the sector of sport

Building	Main Use	Construction year	Surface Area (m^2)
COSEC - sport	SPORT	1975	2 219
Hall Gremeaux	SPORT	1994	2 415
Hall Vallin	SPORT	1996	2 500
Club House		1994	395
	Total Surface area		7 529

2.3 The water supply system

2.3.1 Presentation

The water supply system was constructed during the construction of the Campus between 1964 and 1966. It contains different components and appurtenances, such as fire hydrants, valves, stabilizers, purges and fountains. Figure 2.4 shows the organization and the extension of this complex system. It is connected to the water supply network of the City of Villeneuve d'Ascq at the following locations:

- Cité Scientifique in the North of the Campus
- 4 Cantons in the South of the Campus
- ECL in the South-West of the Campus
- Bachelard in the West of the Campus
- M5 in the West of the Campus.

These several connections induce a high complexity in the prediction of the water flow in the network. The length of the water supply system is equal to 14 km. The pipes have different diameters, which vary between 4 and 30 cm.

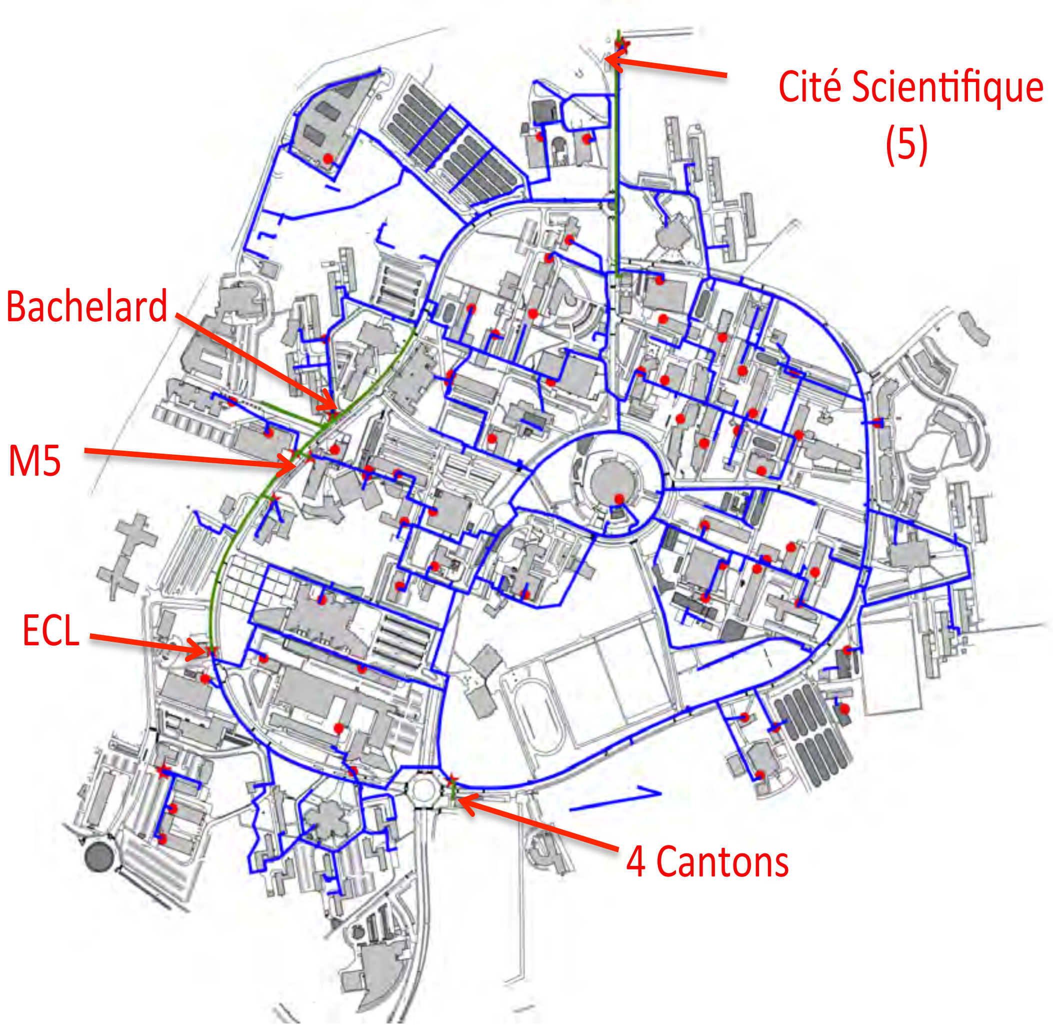


Figure 2.4 Water supply net work of the Scientific Campus

2.3.2 Instrumentation of the water network

A system of Automatic Meter Reading (AMR) was progressively implemented in the water network since 2008 in order to follow the water consumption of the Campus and that of the main buildings. Figure 2.5 shows the architecture of this system. Each AMR communicates the recorded values to a server every 60 minutes through a radio communication system. Authorized users can access to the recorded data trough Internet connection.

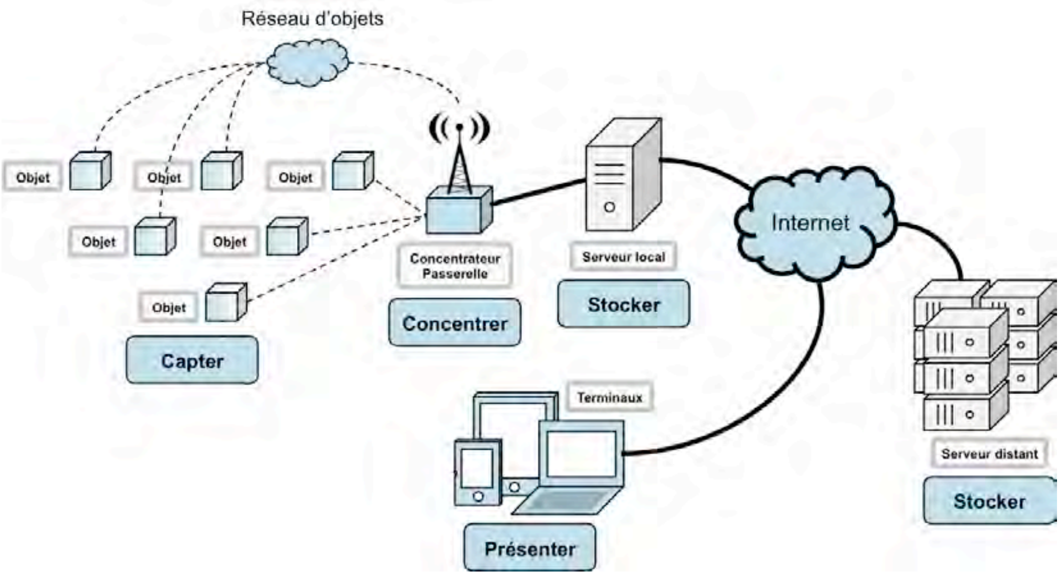


Figure 2. 5 Automatic recording system used in the water supply network of the Scientific Campus

The consumption of the campus is followed through:

- 5 AMR at the Cité Scientific connection,
- 1 AMR at the 4 Cantons connection,
- 1 AMR at Bachelard Connection;
- 1 AMR at ECL connection
- 1 AMR at the M6 connection.

4 AMR are also used for the isolated connections M5, Hall Vallin, ICARE and CUEEP.

The consumption of the main buildings are followed by 55 AMR:

- Administration & services: 5 AMR (A1, A2, A3, Library, SUDES and DESS)
- Chemistry: 10 AMR (C1, C2, C3, C4, C5, C6,C7, C8, C9 and C11)
- Engineering schools: 5 AMR (Polytech, Polytech-D, ECL1, ECL2, ECL3)
- Institute of technology (IUT) : 1 AMR (IUT)
- Mathematics and Computer Science: 6 AMR (M1, to M6)
- Natural Sciences: 5 AMR (SN1 to SN5)
- Physics: 6 AMR (Cerla, P1 to P5)
- Social Sciences: 4 AMR (Geography, SH1 to SH3)
- Students Residence: 7 AMR (Bachelard L, D and Pythagore; Boucher G and J; Galois A and C)
- Restaurants: 3 AMR (Sully, Pariselle and Barrois)
- Sports: 3 AMR (Club House, Cosec, Hall Gremaux).

The AMR data are checked by direct readings of the water consumption counters.

2.3.3 Global analysis of the water consumption

This section presents an analysis pf the water consumption in 2011 in the main buildings of the Campus. Figure 2.6 shows a ranking of buildings according to their consumption. It can be shown that the main consumption concerns about 20 buildings. Figure 2.7 shows a ranking of the highest consumption buildings according to their consumption. The consumption of these buildings is equal to 80% of the total consumption. It can be observed that:

- About 80% of the consumption concerns 15 buildings
- The highest consumption concerns the students residences, whose consumption is equal to 52 % of the total consumption.
- This group includes 5 research buildings (C6, C7, P5, CERLA, SN3), 3 teaching buildings (Polytech'Lille, IUT A, SN1), 3 restaurants (Parielle, Sully, Barrois) and one administration building (A1).

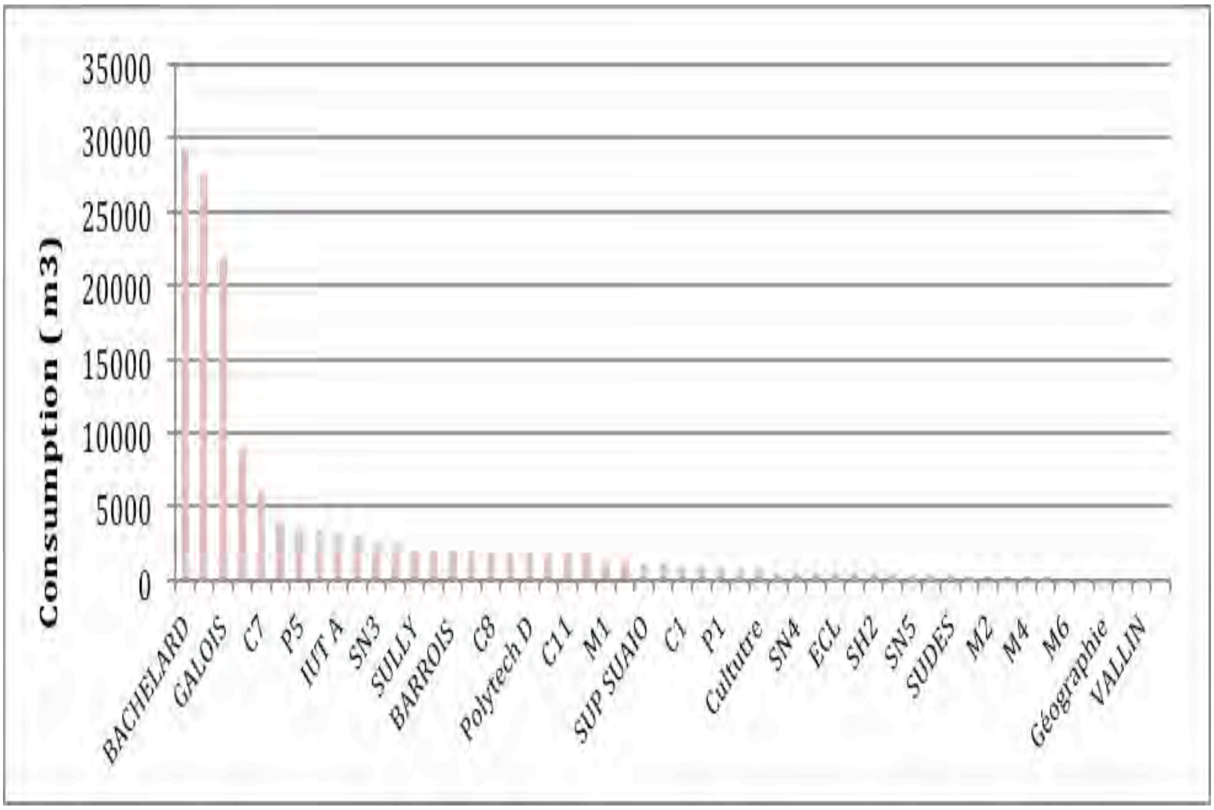


Figure 2.6 : Ranking of buildings according to their water conumption

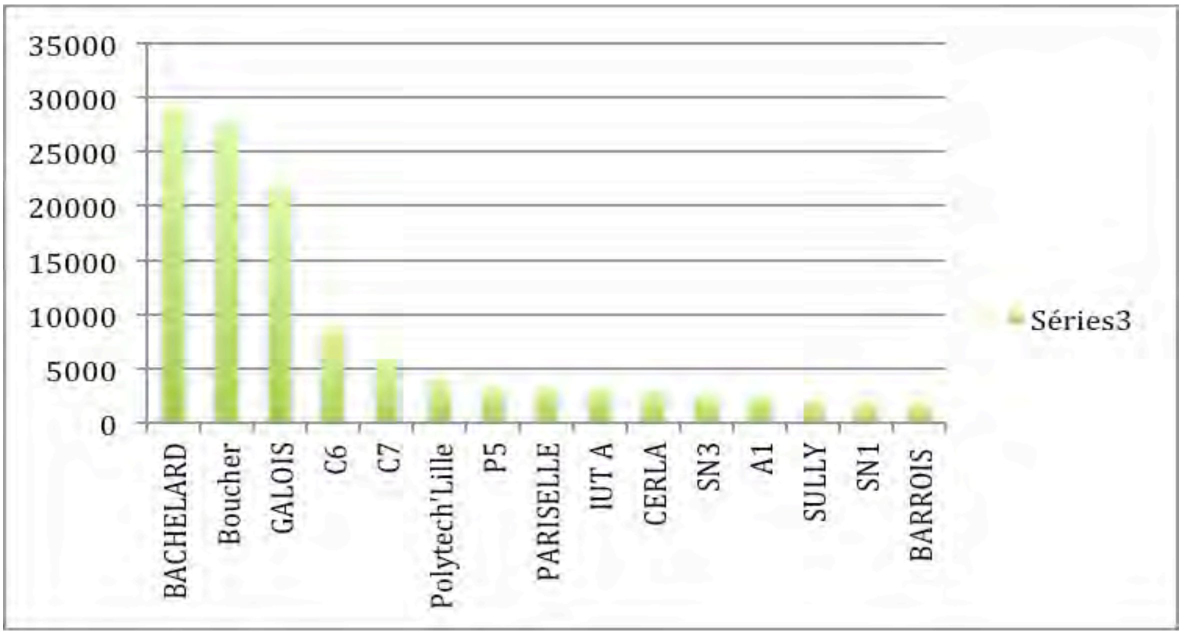


Figure 2.7 : Ranking of the buildings according to their water conumption (80% of the total consuuption)

Figure 2.8 shows the ratio of the water consumption of the campus sectors. It can be seen that the sector of residence presents 52% of the total consumption followed by the sector of chemistry (17%), the sector of physics (6%) and that of natural science (5%). The lowest consumption concerns the sectors of Sports (1%), Social science (2%), Mathematics (2%) and IUT (2%).

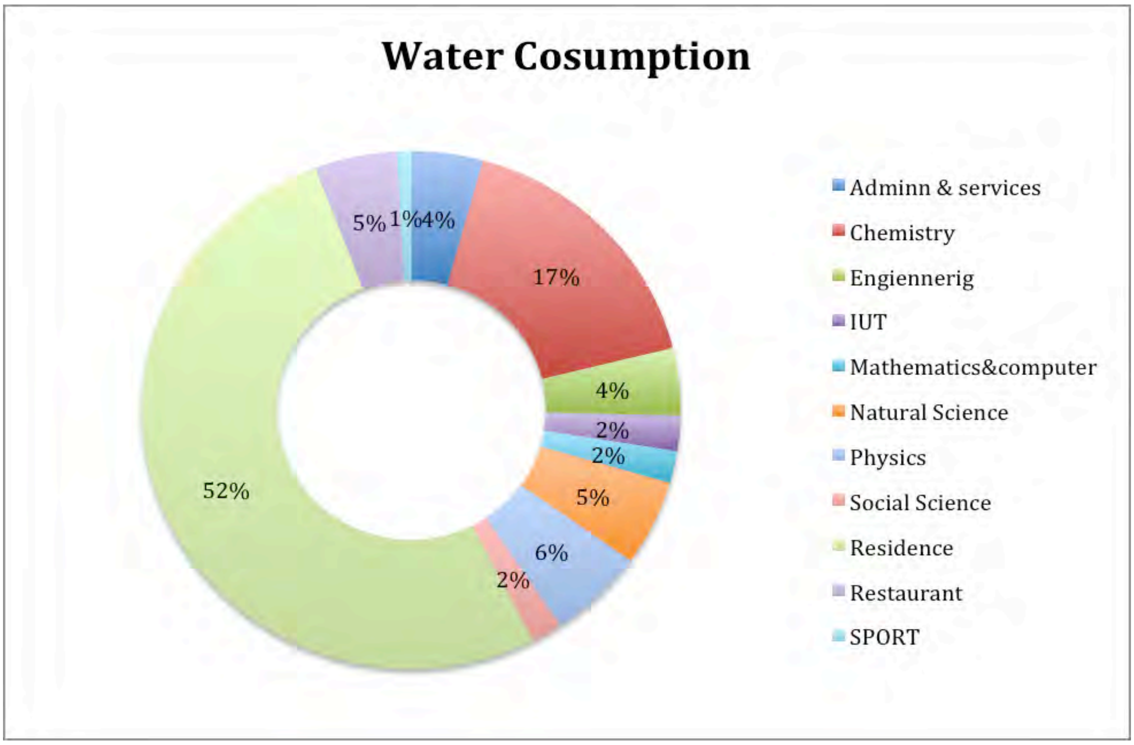


Figure 2.8 Ratio of of the water consmption of the Campus sectors

Figure 2.9 shows the ratio betwen the water consumption and the surace area for all the sectors. It can be observed that the sector of residences presents the highesr ratio (2.07 m^3/m^2) to be cmpared with the mean ratio (0.5 m^3/m^2). This sector is folowed by the sector of restaurants (0.83 m^3/m^2), the sector of chemistry (0.64 m^3/m^2), natural science (0.27 m^3/m^2), and physics (0.25 m^3/m^2). The sector of mathematics and computer sciences presents the lowest ratio (0.11 m^3/m^2).

Figure 2.10 illustrat the radar shart for both the surace area and water consumption for all sectors. It clearly shows the particular situation of the sectors of residences, chemistry and restaurants.

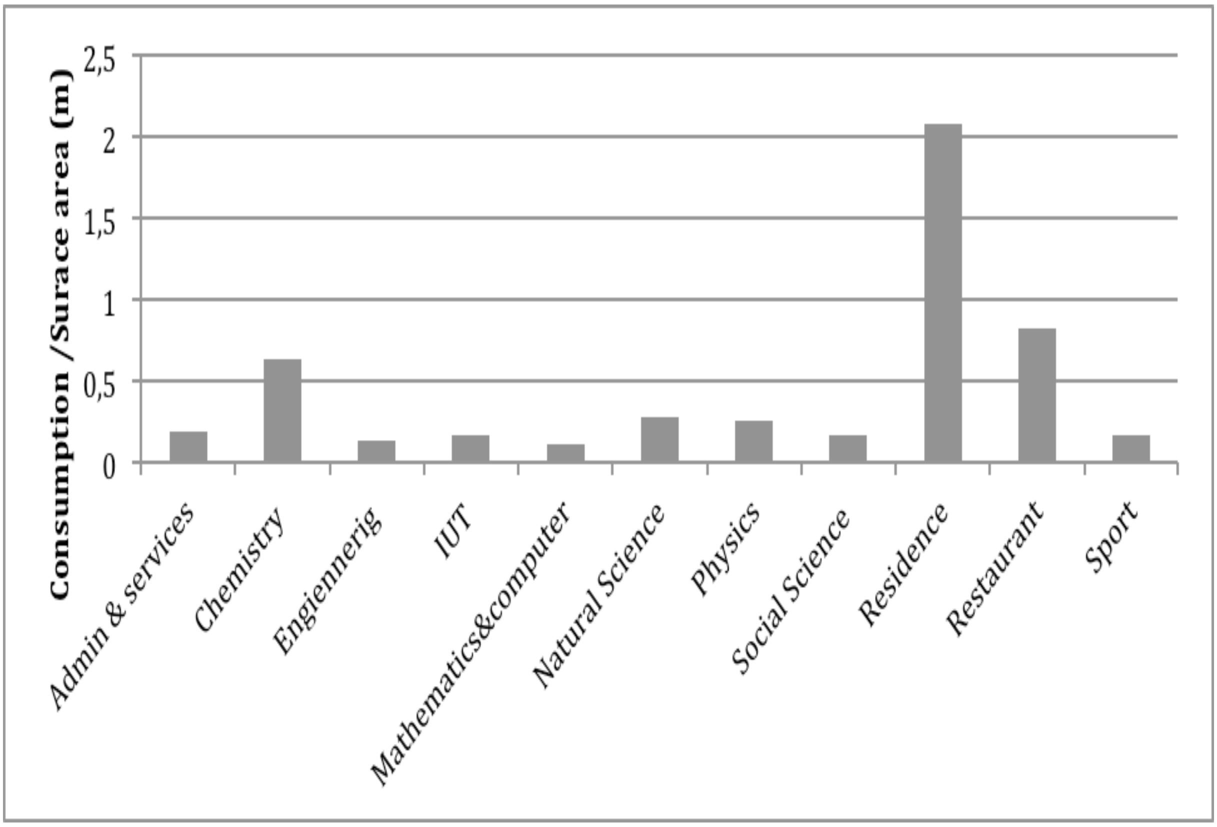


Figure 2.9 Ratio the water consumption and the surace area for all the sectors

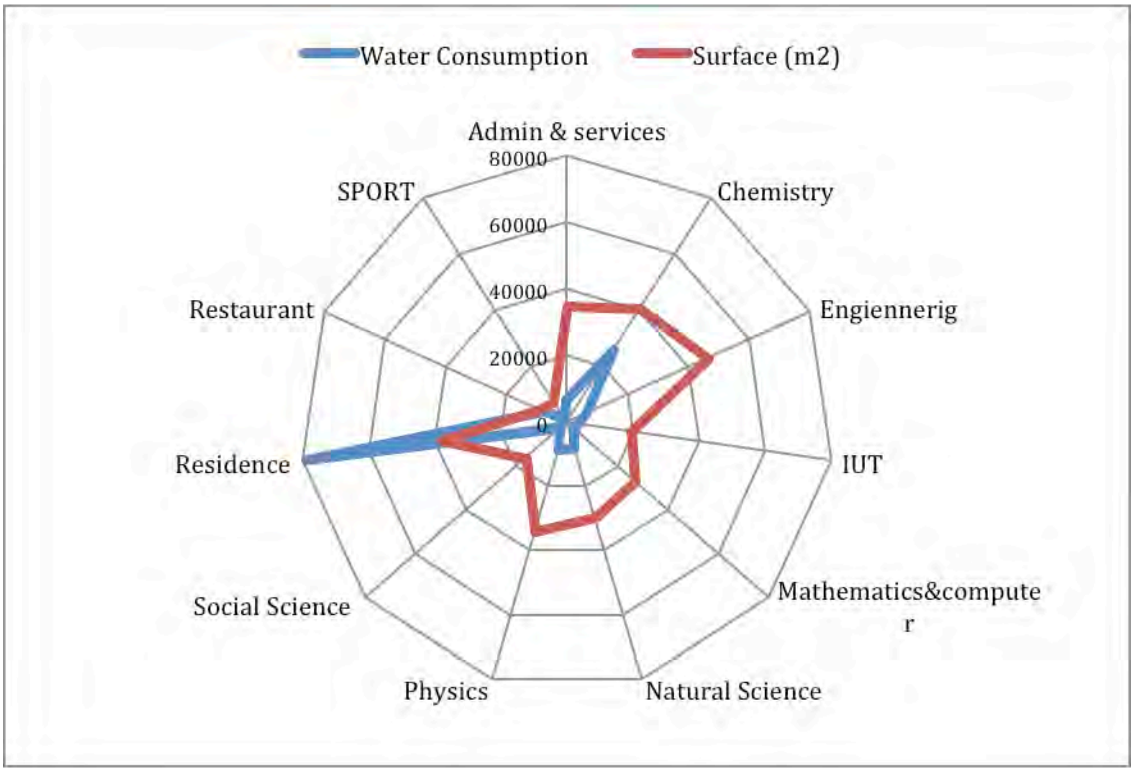


Figure 2.10 Radar chart for the water consumption and the surface area for all the sectors.

Figures 2.11 illustrates the repartition of the data of all buildings of the Campus in the plan (surface area, consumption). This figure clearly shows the particular high consumption of the sectors of residence and chemistry with regard to other sectors.

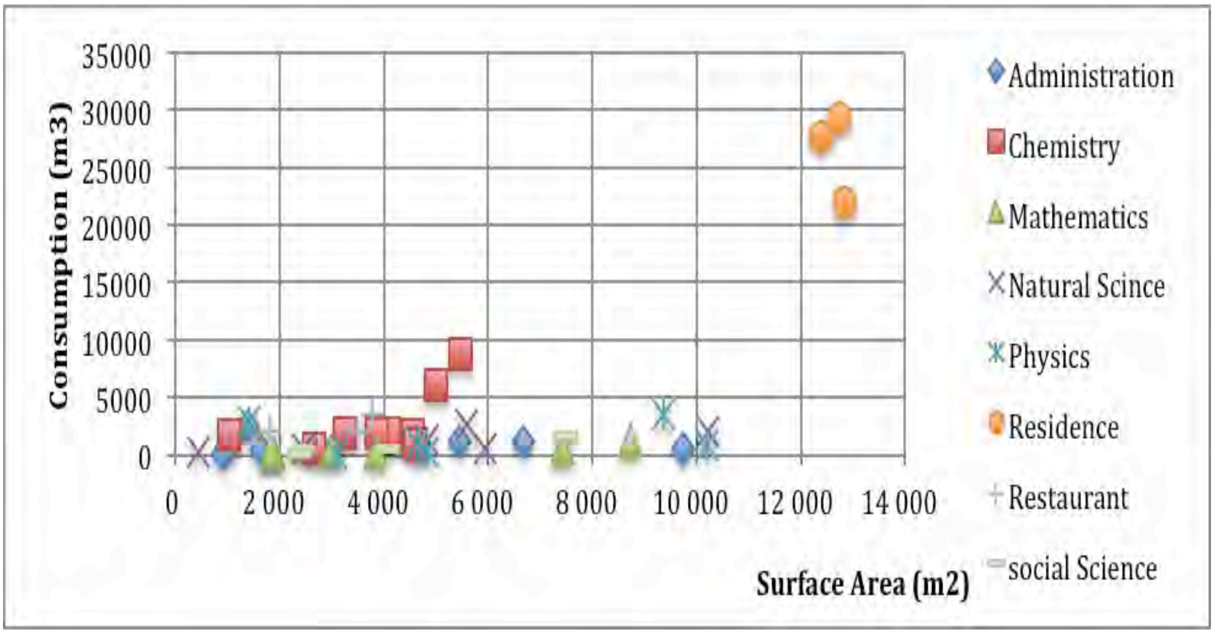


Figure 2.11 Consumption versus surface area for all the buildings of the campus

2.3.4 Selection of buildings for detailed analysis

The consumption of the students residences is summarizd in table 2.11. It can be observed that the consumption of residence Bachelard is the higgest (37%), follwed by the residence Boucher. In the next chapter we will focus our analysis on the residence Bachelard

Table 2.11 : Water consumption in the sector of restaurants

Building	Area (m²)	Consumption	% Consumption
Bachelard	12 751	29297	37
Boucher	12 388	27610	35
Galois	12 844	21940	28

Table 2.12 gives the repartition of consumption of the three restaurants of the Campus. It can be observed that the consumption of Pariselle is equal to 46% of the restaurants total consumption. In the next chapter we will focus our analysis on this restaurant.

Table 2.12 :Water consumption in the sector of restaurants

Building	Main use	Area (m²)	2011	% Consumption
Pariselle	Catering	3 784	3479	46
Sully	Catering	3 497	2068	27
Barrois	Catering	1 827	1982	26

Table 2.13 summarizes the consumption of the buildings of the Chemistry sector. It can be observed that the consumption of buidings C6, C7 and C3 is equal to 66 % of the total consumption of this sector. In the next chapter we will focus our analysis on buildings C6 and C7. The first building is used for research, while the second is used for both teaching ans research.

Table 2.13 Water consumption of the sector of chemistry.

Building	Main use	Area (m²)	Water Consumption (m3)	% Consumption
C6	Research	5 481	8838	34
C7	Research and Teaching	8 500	6149	24
C3	Research	3 259	1966	8
C8	Teaching and research	4 107	1904	7
C5	Teaching and research	3 862	1887	7
C9	Research	4 561	1755	7
C11	Research	1 027	1713	7
C1	Teaching	4 602	1029	4
C4	Research	2 675	497	2

Table 2.14 summarizes the consumption of the buildings of the sector of Physics. It can be observed that the consumption of buidings P5 and CERLA is equal to 74 % of the consumption of this sector. In the following we will focus our analysis on these two buildings.

Table 2.14 Water consumption in the sector of Physics

Building	Main use	Area (m²)	2011	% Consumption
P5	Research	9 373	3499	40
CERLA	Research	1 411	3010	34
P3	Research	4 655	1000	11
P1	Teaching	10 197	855	10
P2	Teachning and research	4 829	300	3
P4	Teachning and research	3 090	145	2

The consumption of the buildings of the sector of the administration & services is summarizd in table 2.15. It can be observed that the consumption of buidings A1, SUP and A3 is equal to the 73 % of the consumption of this sector. In the following, we will focus our analysis on building A1 which is used for the heating center of the university as well as the building A3 which is used for the administration of the University.

Table 2.15 Water consumption in the sector of administration and services

Building	Main use	Area (m²)	2011	% Consumption
A1	Heating centre	1 401	2499	39
SUP	Administration and teaching	6 680	1124	17
A3	Administration	5 450	1095	17
Culture	Cultural activity	1 000	695	11
BU	Library	9 747	619	10
SUDES	Administration	1 660	393	6

2.4 Conclusion

This chapter included a presentation of the site of the Scientific Campus – Lille1 University, which is used in this research work. This site is representative of a small town of about 25 000 habitants and 145 buildings for a total construction area of 323 000 m^2. It presents several advantages for field study of the water demand and consumption. The buildings have varied usages: students' residence, restaurant, sport, administration, research, teaching, teaching and research. This variety of usage is particularly interesting for the analysis of the consumption profile. In addition the site is organized in 11 main sectors, which allows conducting analysis of water consumption by zone (sector). The site is equipped by an automatic metering reading (AMR). The consumption data is available for the main buildings at different time intervals. For the majority of buildings the data is available since 2008 at a time interval recoding of one hour.

Consumption analysis conducted in the chapter allowed the selection of sectors and buildings, which will be analyzed in more details in the next chapter. This selection was based on the water consumption and the buildings usage, in order to well cover the most significant water consumption profiles.

3 Analysis of the water consumption of the Scientific Campus

3.1 Introduction

This chapter presents analysis of the water consumption of the main sectors of the Scientific Campus. Analysis will focus on the 5 following relevant sectors (Figure 3.1) (i) Students' residence, (ii) Restaurants, (iii) Administration & services, (iv) Chemistry and (v) Physics. These sectors cover the main buildings use: research, teaching, administration, residence and catering.

Analysis will be conducted at different times scales (monthly, weekly, daily and hourly). It aims establishing the consumption profile of the main campus buildings at the different time scales.

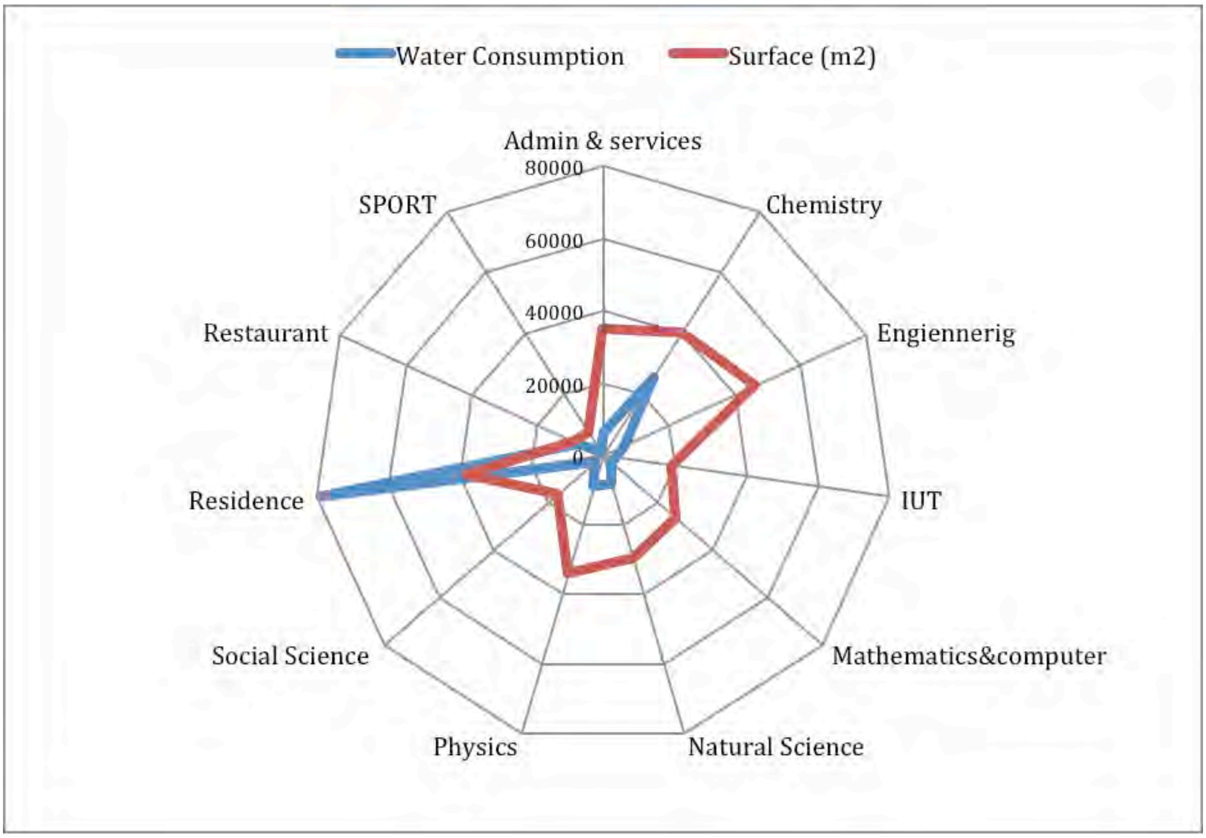


Figure 3.1 Radar chart for the water consumption and the surface area of the sectors of the Scientific Campus

3.2 Monthly Consumption

3.2.1 Sector of Students Residence

Consumption Analysis

This sector is the first consumer of water in the Campus (52% of the total consumption).

Figure 3.2a shows the monthly consumption of this sector in 2011and 2012. It can be seen that the consumptions in these tow years have similar trends, but with higher values in 2012 (10 285 m^3) than en 2011 (9 790 m^3). The maximum of the water consumption occurs in March and November. It is close to 1000 m^3 /month to be compared with the mean value of the water consumption, which is equal to 857 m^3/month in 2012 and to 815 m^3 /month in 2011.

Generally, form January to August, we observe a decrease in the water consumption, which is followed by an increase from September to November. The decrease in February and December results from the winter vacation and the year-end vacation, respectively. The high decrease in July and August is due to the summer vacation. However, the water consumption in August (4160 m^3 in 2011 and 5 930 m^3 in 2012) is too high with regard to the very low number of students who stay in the Campus during the summer vacation. This high consumption requires more investigation in order to understand the water use in this period.

Figure 3.2b shows the monthly consumption of the residence Bachelard in 2011and 2012. This consumption has similar rends with that of the sector of residences: Consumption decrease between January and August, followed by an increase from September to November. The decrease in February, December and August is also similar to that of the sector of residences.

Consumption Modeling

The consumption modeling is based upon discrete modeling according to the following discrete function for the consumption of the month k of the year N:

$$F_N(k) = C_N f_k \qquad \sum_{k=1}^{12} f_k = 1 \qquad \text{(Eq. 3.1)}$$

C_N and f_k denote the total consumption of the year N and the ratio of the consumption of the month k to the total consumption of the year.

The determination of the value of the values of f_k is conducted using the mean value of the consumptions in 2011 and 2012. Tables 3.1 gives the values of the functions C_N and f_k for both the sector of residences and the residence Bachelard. Figures 3.3a-b show a comparison between the consumptions in 2011 and 2012 and the simulations using equation (Eq. 3.1). We observe a good agreement between these values for both the sector of residences and the residence Bachelard.

Table 3.1a Values of the annual consumption (C_N) – Sector of residences

Year	2011	2012
Sector of Residences	97 890	102 287
Bachelard	29 297	31 713

Table 3.1b Values of the discrete monthly function (f_k) – Sector of residences

k =	1	2	3	4	5	6	7	8	9	10	11	12
Sector of Residences	0.092	0.083	0.097	0.086	0.090	0.080	0.057	0.050	0.084	0.096	0.098	0.087
Bachelard	0.092	0.081	0.092	0.088	0.090	0.077	0.061	0.059	0.080	0.091	0.099	0.090

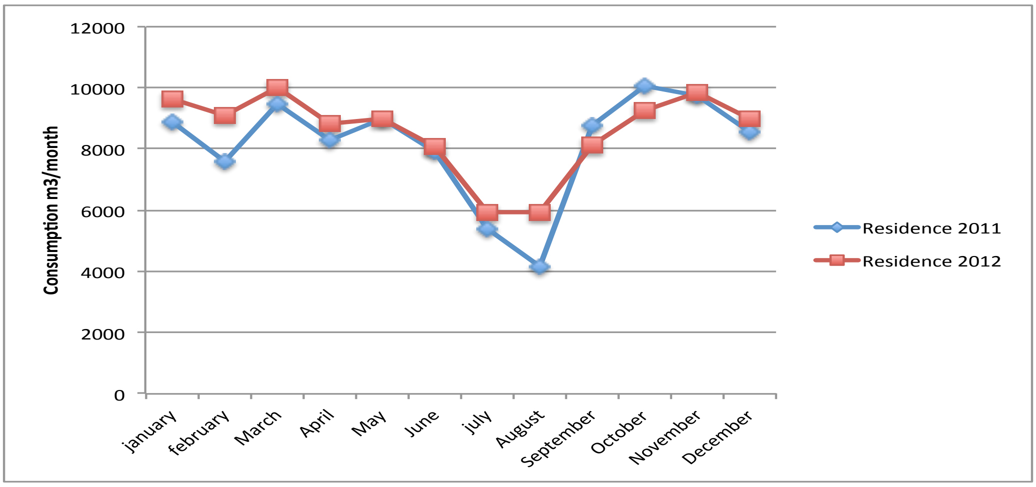


Figure 3.2a : Monthly water consumption - Sector of residences

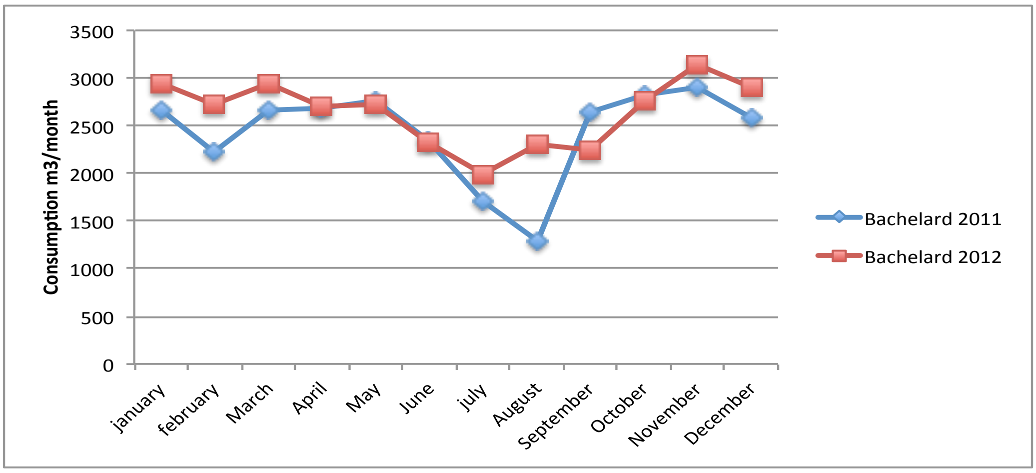


Figure 3.2b: Monthly water consumption - Bachelard Residence

Figure 3.3a Calibration of the function (Eq. 3.1) on the sector of residences consumption

Figure 3.3b Calibration of the function (Eq. 3.1) on Bachelard water consumption

3.2.2 Sector of restaurants

Consumption Analysis

This sector concerns three restaurants of the Campus whose consumption is equal to 5% of the total consumption of the Campus.

Figure 3.4a shows the monthly consumption of this sector in 2011and 2012. The consumption in December 2012 shows an abnormal increase (about 2 250 m^3/month), it could result from a water leakage; because in this period we expect water consumption lower than 1000 m^3 (water consumption in November). This abnormal increase leads to an important annual consumption in 2012 (9 565 m^3) to be compared with that of 2011 (7 530 m^3). Between January and November, we observe similar consumption trends in 2011 and 2012: a decrease between January and August followed by an increase from September to November with a small consumption drop in February. In August 2011, we observe a very low water consumption (close to zero), while in August 2012; we observe a significant consumption (450 m^3/month). Generally, the restaurants are close in August.

Figure 3.4b shows the monthly consumption of the restaurant Pariselle in 2011and 2012. The consumption in 2012 shows an abnormal increase (about 2 000 m^3/month) in December, which is responsible of the increase in the sector water consumption in December 2012. This abnormal increase could be attributed to a water leakage; because the water consumption in December is expected to be lower than that in November (500 m^3). This abnormal increase leads to an important increase in the annual consumption in 2012 (5 228 m^3) to be compared with that of 2011 (3 370 m^3). Between January and November, we observe similar trends in the water consumption in 2011 and 2012: a general decrease between January and August, followed by an increase from September to November. A very low water-consumption (close to zero) is observed in August, which is coherent with the restaurant closing in the summer vacation.

Consumption Modeling

The determination of the values of f_k is conducted using the mean value of the consumption in 2011 and 2012 (the abnormal consumption in December 2012 was changed assuming that the ratio of this consumption to that in November is equal to the ratio in 2011).

Tables 3.2a-b give the values of the function C_N and f_k for both the sector of restaurants and the restaurant Pariselle. Figures 3.5a-b show a good calibration of equation Eq.1 on the consumption of both the sector of restaurants and Pariselle restaurant.

Table 3.2a Values of the annual consumption (C_N) – Sector of restaurants

Year	2011	2012
Sector of Restaurant	7 531	8 138
Pariselle	3 479	3 640

Table 3.2b Values of the discrete monthly function (f_k) – Sector of restaurants

k =	1	2	3	4	5	6	7	8	9	10	11	12
Sector of Restaurant	0.113	0.090	0.103	0.069	0.076	0.068	0.043	0.031	0.095	0.100	0.116	0.097
Pariselle	0.117	0.094	0.106	0.067	0.067	0.047	0.007	0.022	0.116	0.115	0.113	0.131

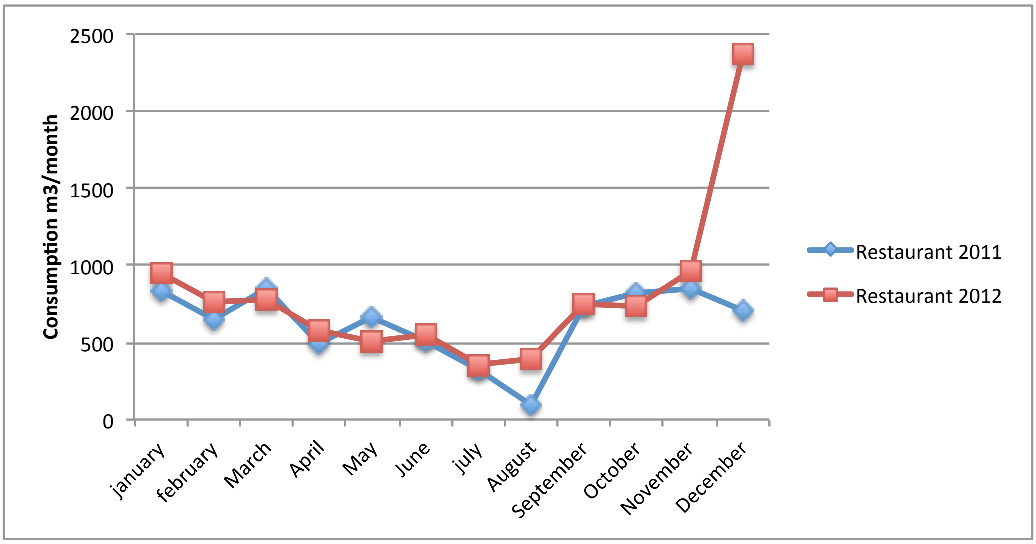


Figure 3.4a: Monthly water consumption of the sector of restaurants

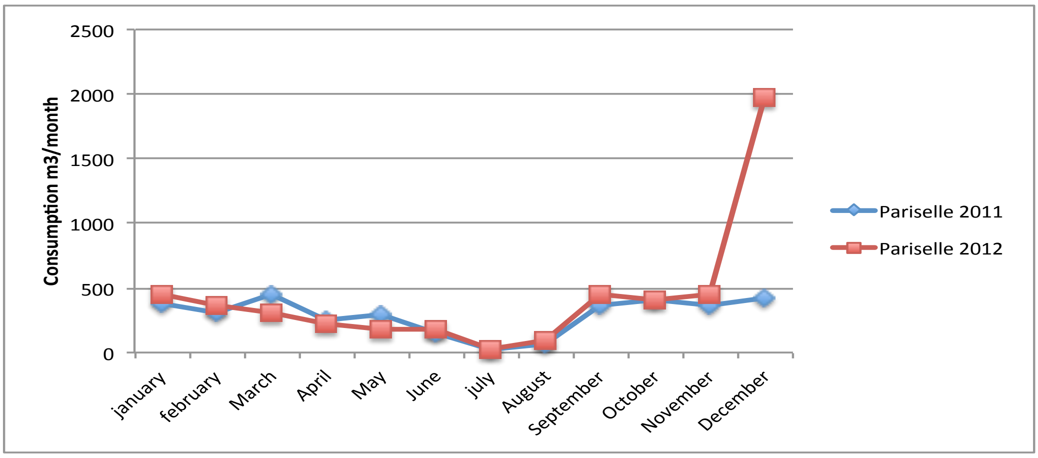


Figure 3.4b: Monthly water consumption of Pariselle

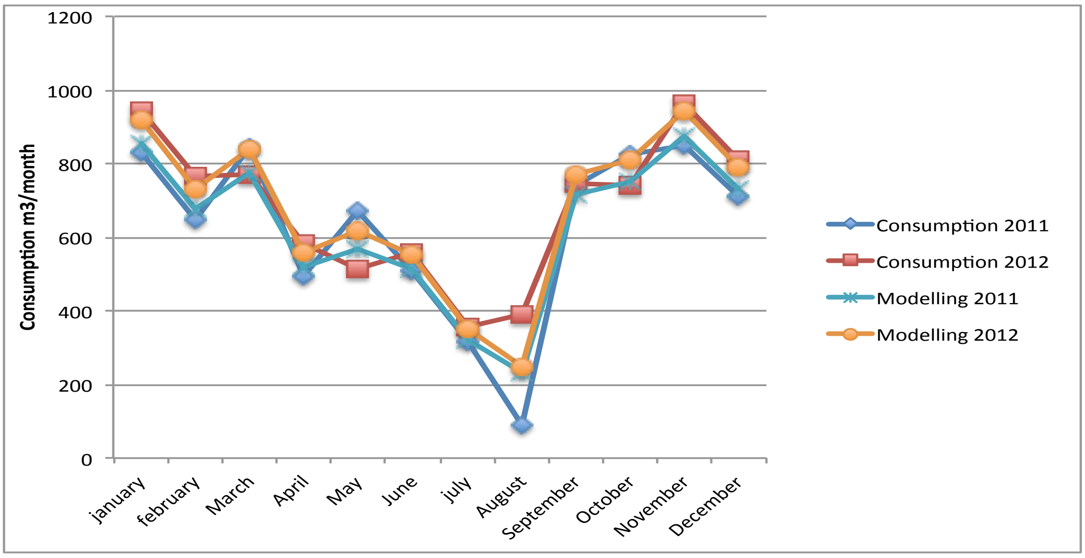


Figure 3.5a Calibration of the function (Eq. 3.1) on the consumption of sector of restaurants (After rectification of the consumption in December 2012)

Figure 3.5b Calibration of the function (Eq. 3.1) on Pariselle consumption (After rectification of the consumption in December 2012)

3.2.3 Sector of Chemistry

Consumption Analysis

The sector of chemistry is composed of 11 buildings whose consumption is equal to 17% of the total consumption of the Campus. Figure 3.6a shows the monthly consumption of this sector in 2011and 2012. The consumption in 2011 shows an abnormal increase in March (about 3 320 m^3), which could result from a water leakage or an intensive use of a high water-consuming apparatus. The water consumption in 2011 (26 170 m^3) is higher than that in 2012 (23 010 m^3).

The consumption trends of this sector are different from that of the sector of residences. We observe an increase in the consumption between January and April, followed by a decrease from April to August, which is then followed by an increase up to November. In 2011 the maximum of consumption occurs in March (3 330 m^3), while it occurs in April in 2012 (2530 m^3). A significant consumption is observed in August (about 720 m^3 in 2012 and 900 m^3 in 2012). This consumption seems abnormal, because of the summer vacation.

Figure 3.6b and 3.6c show the monthly consumption of the buildings C6 and C7. The former is a research building, while the latter is used for both teaching and research. The consumption of the building C6 in 2011 and 2012 shows irregular trends, which could be related to an irregular use of a high water-consuming research device. However the maximum of consumption in 2011 (1 200 m^3/month) occurs in March, while the minimum (400 m^3/month) is observed in August. In 2012, the maximum water consumption (850 m^3/month) occurs in February and April, while the minimum is observed in September (200 m^3/month).

The consumption of the building C7 is more regular. We observe a good agreement between the variation of the consumption in 2011 and 2012. The consumption in the period January - June and in October is close to 600 m^3/month. The consumption in July, September and December is close to 500 m^3/month; while the minimum consumption occurs in August (200 m^3/month).

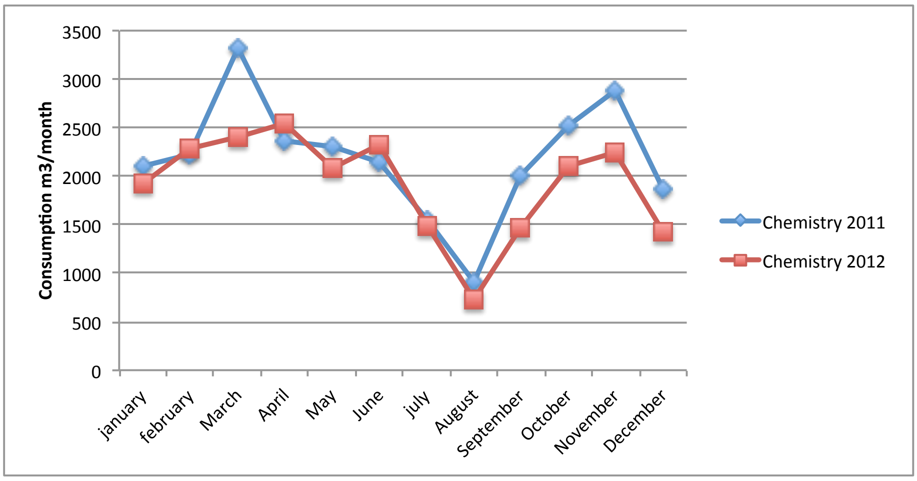


Figure 3.6a: Monthly water consumption in the sector of chemistry

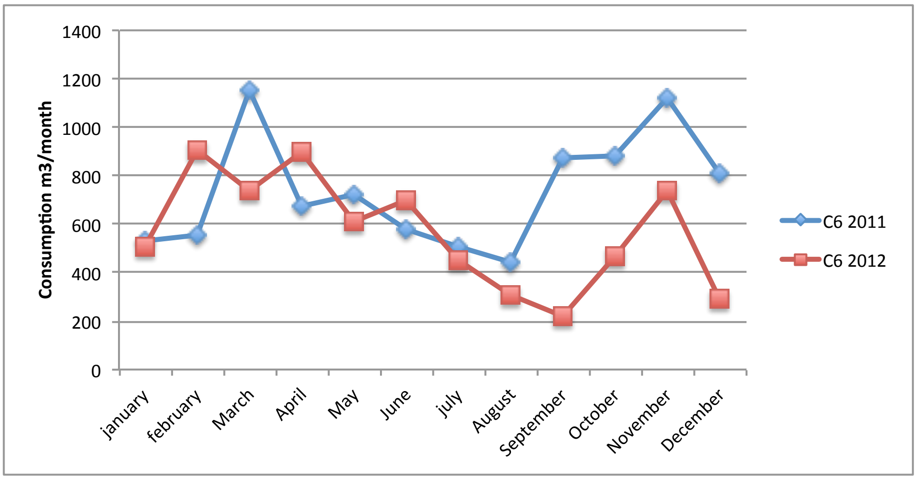


Figure 3.6b: Monthly water consumption of the building C6

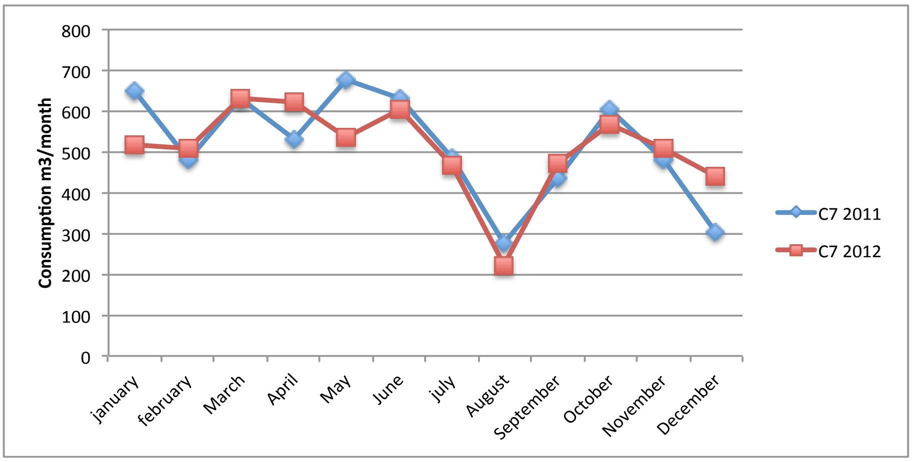


Figure 3.6c: Monthly water consumption of the building C7

Consumption Modeling

The determination of the values of f_k is conducted using the mean value of the consumption in 2011 and 2012. Tables 3.3a-b summarize the values of the function C_N and f_k for the sector of Chemistry and the buildings C6 and C7. Figures 3.5a-7 show a good calibration of equation Eq.1 on the consumption of the building C7, but a poor calibration for the building C6 and the sector of Chemistry.

This result shows that the prediction of the water consumption for a research building with a high-consuming device, should be determined from the schedule of the use of this apparatus.

Table 3.3a Values of the annual consumption (C_N) – Sector of Chemistry

Year	2011	2012
Sector of Chemistry	26 170	23 012
C6	8 839	6 839
C7	6 194	6 099

Table 3.3b Values of the discrete monthly function (fk) – Sector of Chemistry

k =	1	2	3	4	5	6	7	8	9	10	11	12
Sector of Chemistry	0.082	0.091	0.116	0.100	0.089	0.091	0.062	0.033	0.071	0.094	0.104	0.067
C6	0.066	0.093	0.121	0.100	0.085	0.082	0.061	0.048	0.069	0.086	0.119	0.070
C7	0.095	0.081	0.103	0.094	0.099	0.101	0.077	0.041	0.074	0.095	0.080	0.060

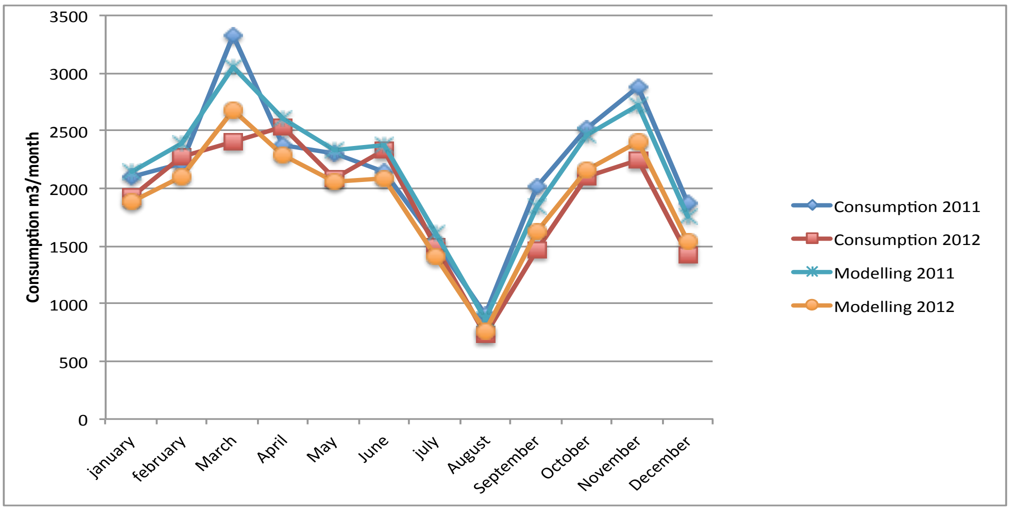


Figure 3.7a Calibration of the consumption function (Eq. 3.1) on the sector of Chemistry

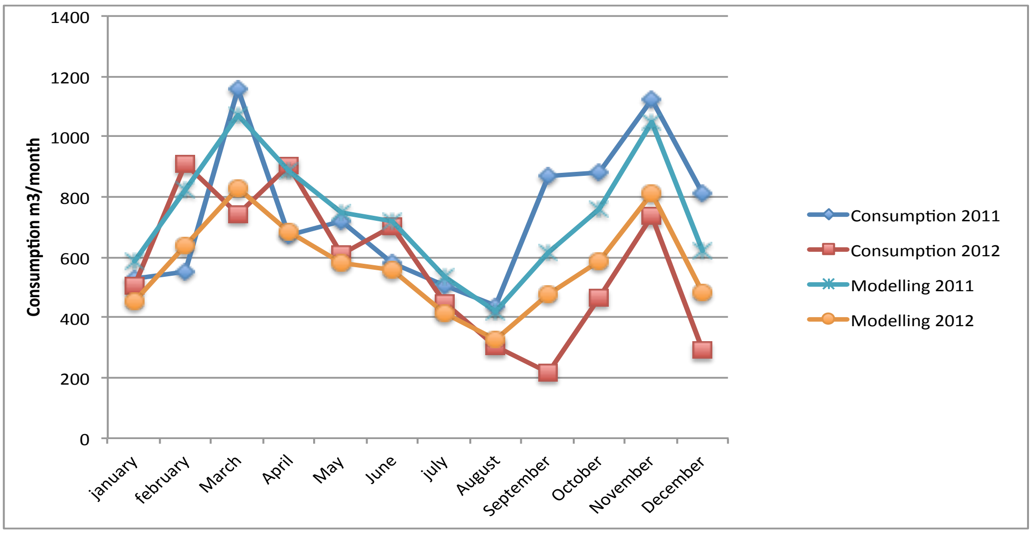


Figure 3.7b Calibration of the function (Eq. 3.1) on the C6 consumption

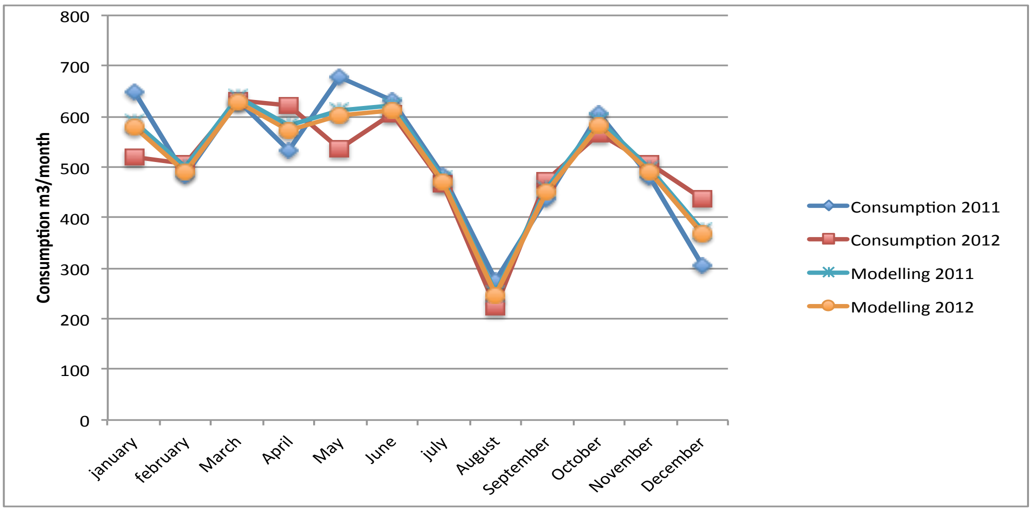


Figure 3.7b Calibration of the function (Eq. 3.1) on the C7 consumption

3.2.4 Sector of Physics

Consumption Analysis

The sector of Physics is composed of 8 buildings whose consumption is equal to 6% of the Campus consumption. Figures 3.8a-c show the monthly consumption of this sector as well as that of the buildings P5 and CERLA (research buildings). The consumption of this sector in 2012 shows regular trends, with a maximum in November (1100 m^3/month) and a minimum in August/September (600 m^3/month). In 2011, the maximum of consumption (1 250 m^3/month) occurs in January, while the consumption in February, March, October and November varies between 1000 and 1 150 m^3/month. The consumption between April and July is close to 400 m^3/month, which seems to be abnormal.

The consumption of the building P5 in 2011 (Figure 3.8b) is equal to zero in the period April-June and in August. This result in not realistic, it could result form a deficiency of the AMR of this building. This deficiency is responsible of the abnormal consumption of the sector of Physics in 2011. The consumption in 2012 is more regular with a maximum in June (600 m^3/month), a minimum in August, September and December (200 m^3/month), and a quasi-constant value (400 m^3/month) for the other months.

The consumption of the CERLA in 2011 (Figure 3.8c) shows peaks in January (387 m^3/month), March (359 m^3/month) and November (297 m^3/month). The minimum of consumption occurs in August (130 m^3/month). The consumption in 2012 shows peaks in February (366 m^3/month) and November (412 m^3/month). The consumption for the other months is close to 250 m^3/month.

Consumption Modeling

Because of the deficiency of the AMR in 2011, we did not calibrate the equation 1 on the data of this sector.

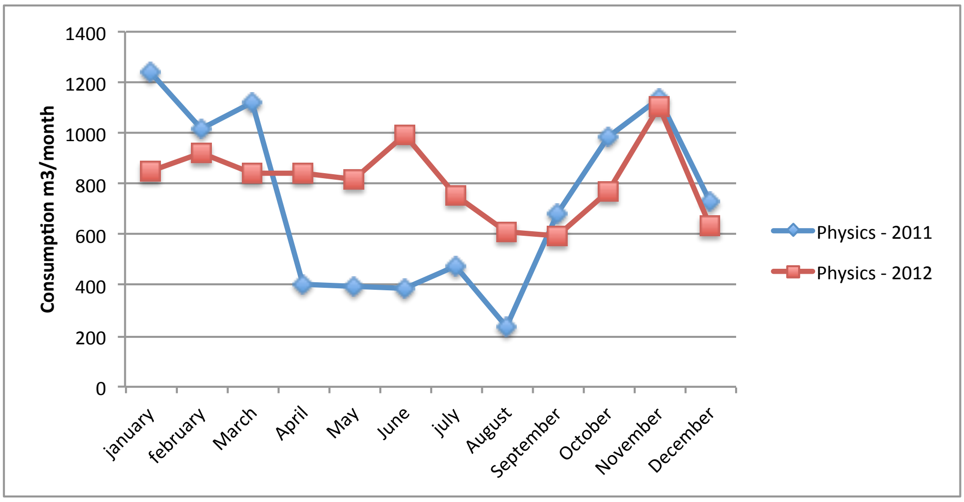


Figure 3.8a: Monthly water consumption in the sector of Physics

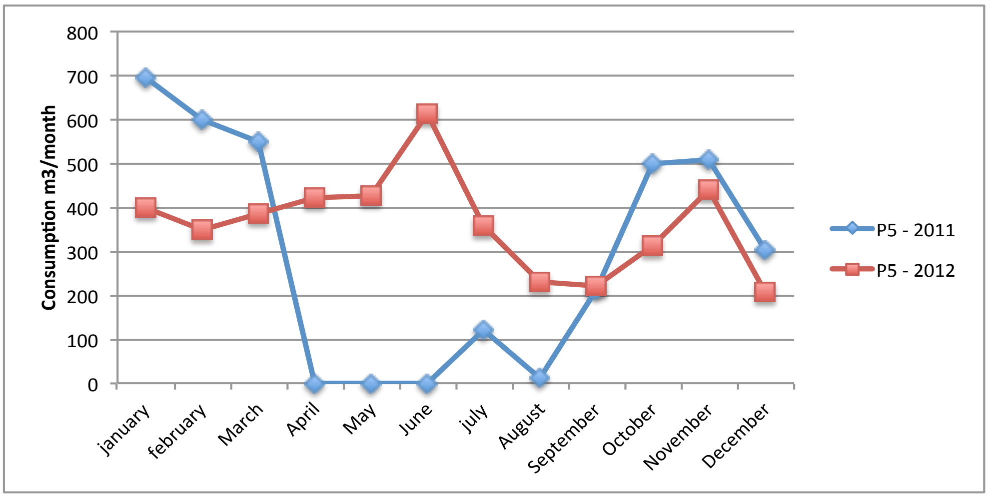


Figure 3.8b: Monthly water consumption of the building P5

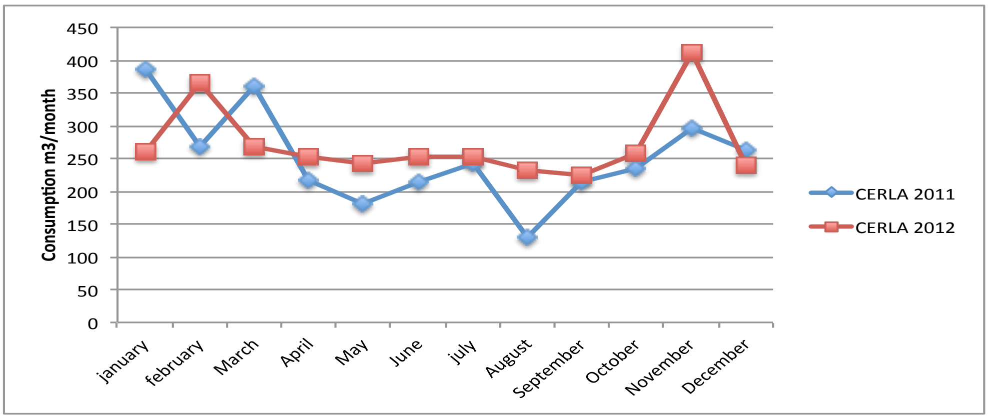


Figure 3.8c: Monthly water consumption of the building CERLA

3.2.5 Sector of the administration & services

Consumption Analysis

The sector of the administration & service includes 14 buildings, which concern the administration of the university, the library, the cultural space, the heating center and two teaching buildings, which are not affected to faculties (SUP and DESS). The consumption of this sector is equal to 4.3% of the total consumption of the Campus.

Figures 3.9a-c show the monthly consumption of this sector as well as that of the building A1 (heating Center) and A3 (Administration).

The consumption of the building A1 (Figure 3.9b) shows high irregularities:

- In 2011, the maximum consumption (607 m^3/month) occurs in March, the minimum (44 m^3/month) in February; for the other months, it varies between 100 and 300 m^3/month.
- In 2012, the maximum of consumption (438 m^3/month) occurs in June, the minimum (12 m^3/month) in August; while the consumption of other months varies between 40 and 300 m^3/month.

The high consumption of A1 in March 2011 and June 2012 seems abnormal. It could be related to a water leakage or to a particular operating process in the heating center.

The consumption of the building A3 (Figure 3.9c) shows an abnormal value in August 2012 (220 m^3/month): This consumption is expected to be very low, because of the summer vacation, as shown in August 2011.

The consumption of the sector in 2012 shows regular trends: the maximum (675 m^3/month) occurs in June; the minimum in February (270 m^3/month). In 2011, we observe high irregularities: the maximum occurs in March (908 m^3/month), the minimum in August (170 m^3/month). For the other months the consumption varies between 330 and 560 m^3/month. The high consumption in March 2011 results from the abnormal consumption in this period of the building A1.

Consumption Modeling

Because of the high consumptions scattering between 2011 and 2012, we did not calibrate the equation 1 on the data of this sector.

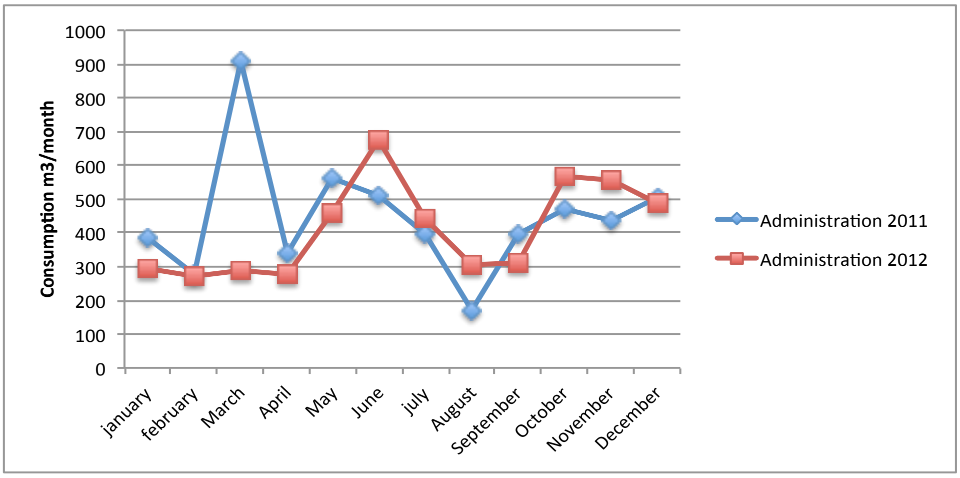


Figure 3.9a Monthly water consumption in the sector of the administration & services

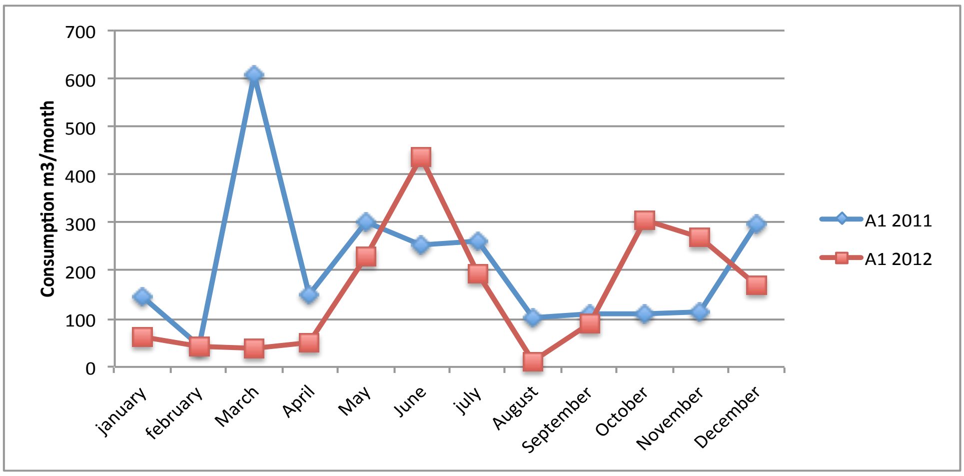


Figure 3.9b Monthly water consumption of the building A1

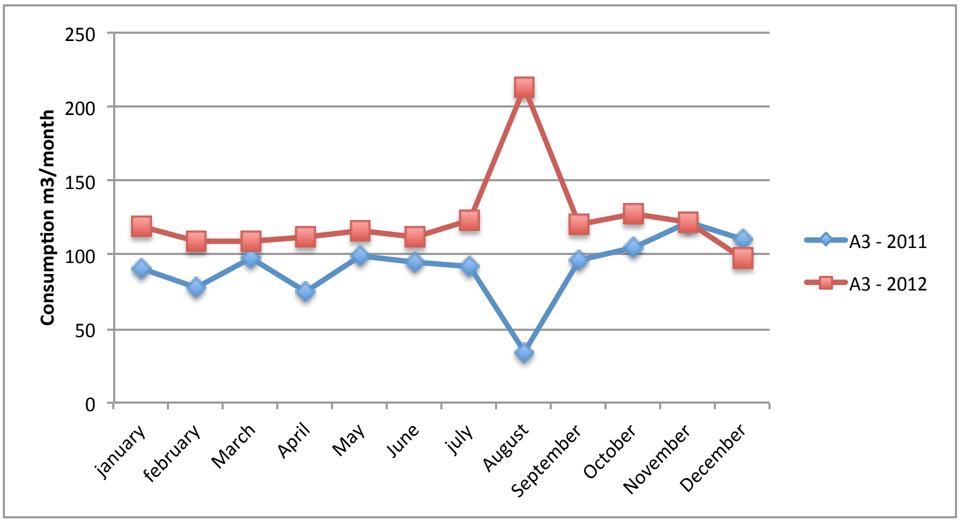


Figure 3.9c Monthly water consumption of the building A3

3.3 Weekly consumption analysis

In this section we present analysis of the weekly consumption of some buildings of the main sectors in order to establish consumption profile of these buildings and (or) to identify abnormal consumptions.

3.3.1 Sector of Students Residence

Figure 3.10 illustrates the weekly consumption of the residence Bachelard in 2011 and 2012. The consumption in 2011 and 2012 shows some scatters:

- The consumption in 2012 (mean value = 604 m^3/week) is higher than that in 2011 (mean value = 558 m^3/week)
- The consumption during the summer vacation in 2011 (around 300 m^3/week) is lower than in 2012 (400 m^3/week).
- The peak of consumption in 2011 oscillates between 600 and 720 m^3/week, while in 2012, it oscillates between 700 and 750 m^3/week.

The consumption profile of this building is characterized by a general high consumption, even during the vacation. This consumption is related to the number of students in the residence. During this work, we did not obtain information about this issue. This work should be pursued in order to establish correlations between the number of students and the water consumption.

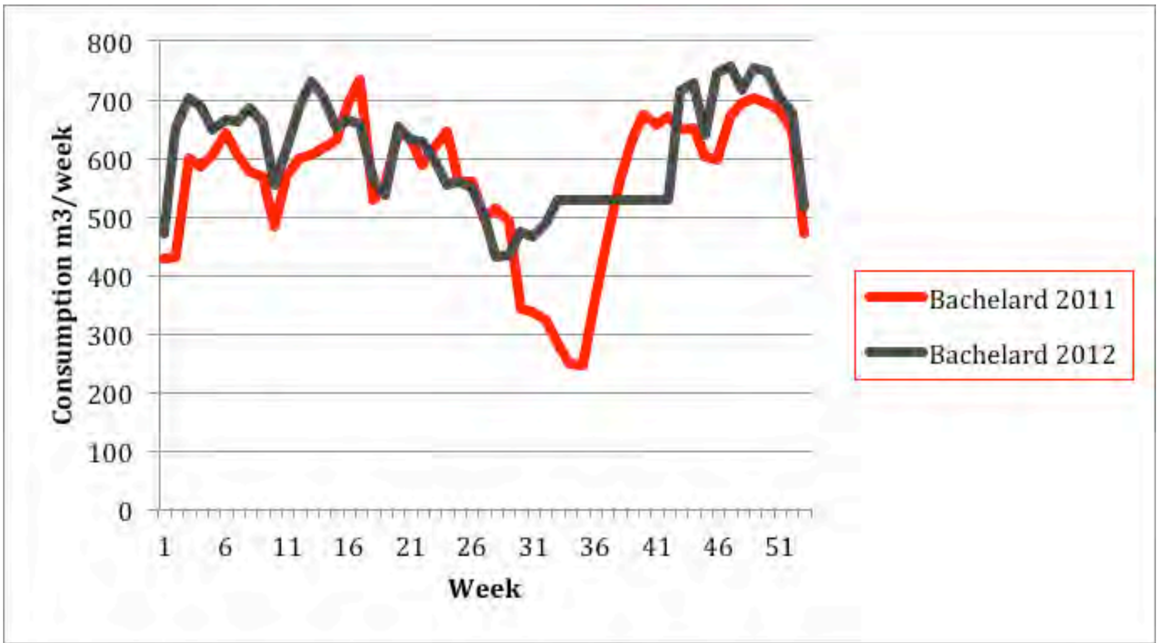


Figure 3.10 Weekly consumption of the residence Bachelard

3.3.2 Sector of Restaurants – Restaurant Pariselle

Figure 3.11a illustrates the weekly consumption of the restaurant Pariselle in 2011 and 2012. It shows a very high consumption in the last three weeks of 2012, which reaches 768 m^3/week in week 51. We observe also a high consumption in the first two weeks of 2012, which reaches 190 m^3/week in the first week of January. This period corresponds to the year-end vacation. This abnormal consumption could result from leakage.

In order to identify the consumption profile of this restaurant, the consumptions in weeks 1, 2, 50, 51 and 52 were modified by assuming that these consumptions are equal to that in 2011. Figure 1.11b shows the consumption in 2011 and in 2012 after rectification of the latter. We observe a good agreement between the consumptions in 2011 and 2012 with a correlation factor of 0.78. We observe very low consumption (close to zero) between the weeks 28 to 35 (summer vacation), and low consumption in weeks 53, 1 and 2 (year-end vacation), week (10) winter vacation and week 19 (spring vacation).

The consumption profile could be characterized as follows:

- Very low consumption during the vacation (close to zero)
- Consumption between 80 and 100 m^3/week for weeks 3 to 21 (January – May)
- Consumption between 40 to 60 m^3/week for weeks 22 to 26 (May, June)
- Consumption between 80 and 120 m^3/week for weeks 38 to 50 (October December).

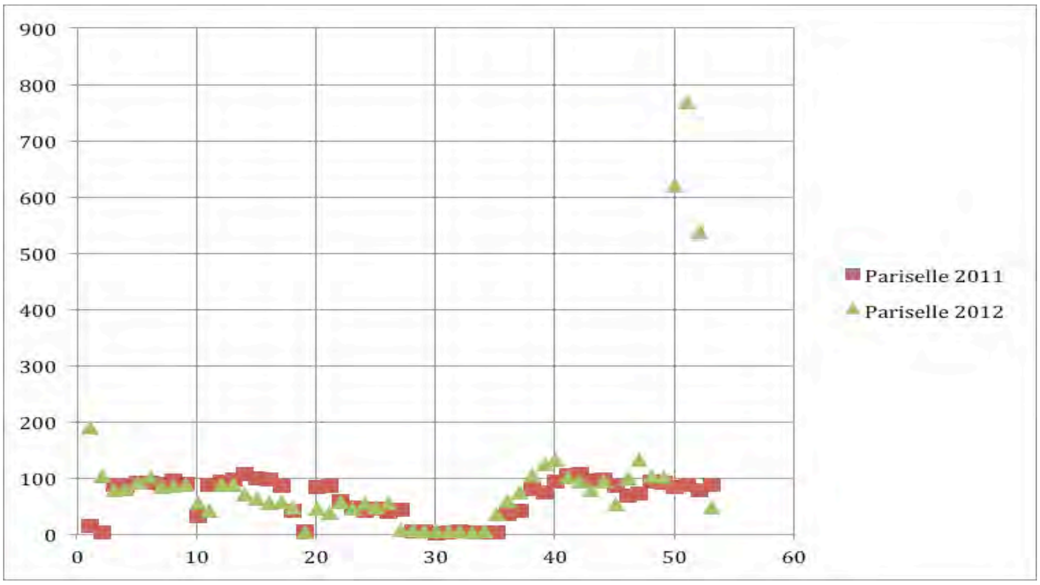


Figure 3.11a Weekly consumption of the restaurant Pariselle

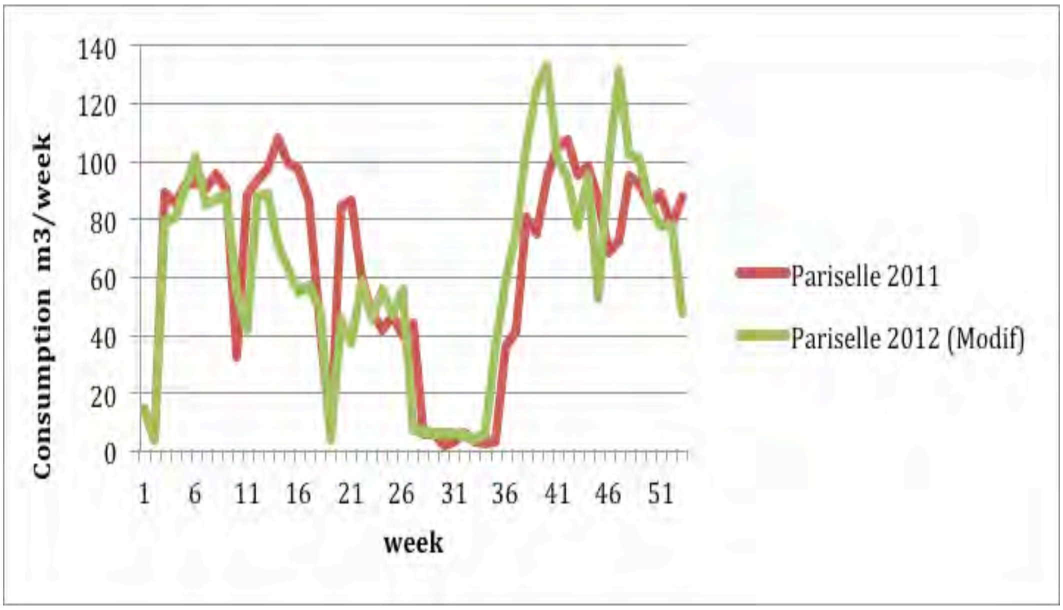


Figure 3.11b Weekly consumption of Pariselle (after rectification of the abnormal consumption in 2012)

3.3.3 Sector of Chemistry

Figure 3.12 illustrates the weekly consumption of the research building C6. It shows a very high scattering between the consumptions in 2011 and 2012: (i) the factor of correlation is equal to 0.18 (ii) the periods of the peaks of consumption do not coincide. The minima of consumption in 2012 occur in the year-end vacation and in weeks 32 to 34 (August), while the peak of consumption (about 350 m^3/week) occurs in weeks 9 (February), 17 (May) and 26 (July). In 2011, the minima of consumption occur in the year-end vacation and in weeks 33 to 35 (August), while the peak of consumption (about 350 m^3/week) occurs in weeks 40, 47, 50 and 51 (between October and December).

The water consumption of this building depends mainly on the use of research apparatus. Consequently, it is difficult to establish profile consumption. The latter should be established according to the use of a research apparatus. In addition, the high consumption related to the research apparatus requires more investigation for the improvement of the operating process of this apparatus in order to reduce the water consumption.

Figure 3.13 illustrates the weekly consumption of the teaching/research building C7. We observe similar consumption trends in 2011 and 2012. The factor of correlation for the consumptions in 2011 and 2012 is equal to 0.64. The consumption is low during the year-end vacation and the summer vacation (less than 50 m^3/week). Otherwise the consumption shows oscillations between 100 and 200 m^3/week with a mean consumption value around 115 m^3/week.

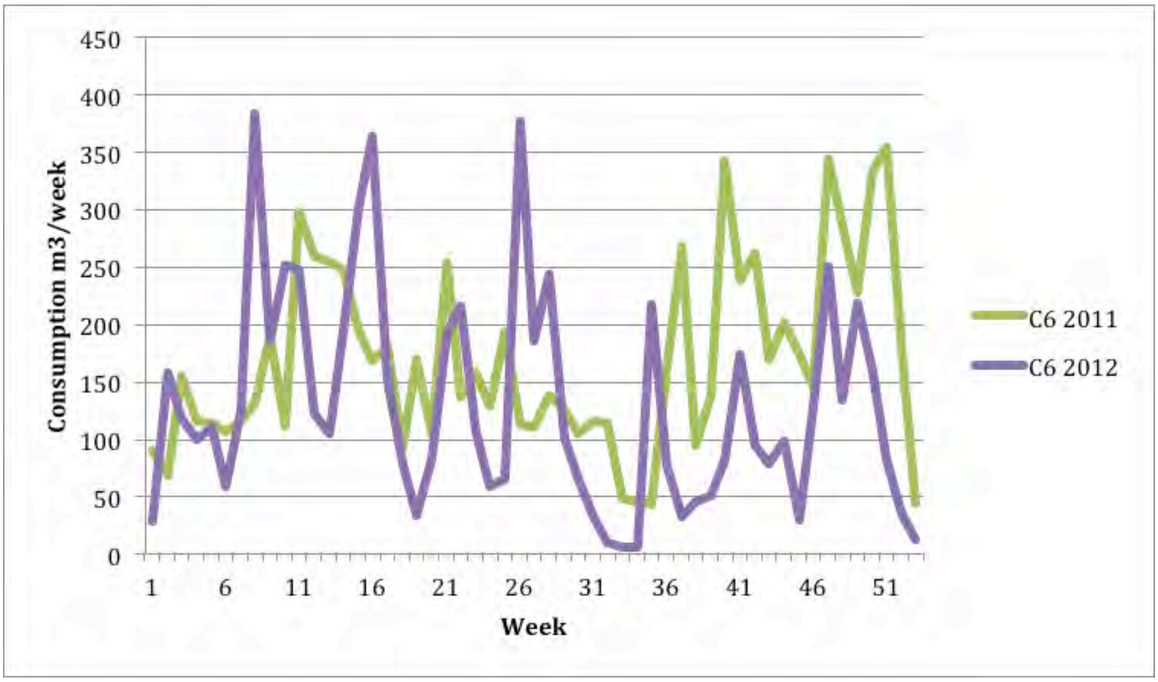


Figure 3.12 Weekly consumption of the building C6

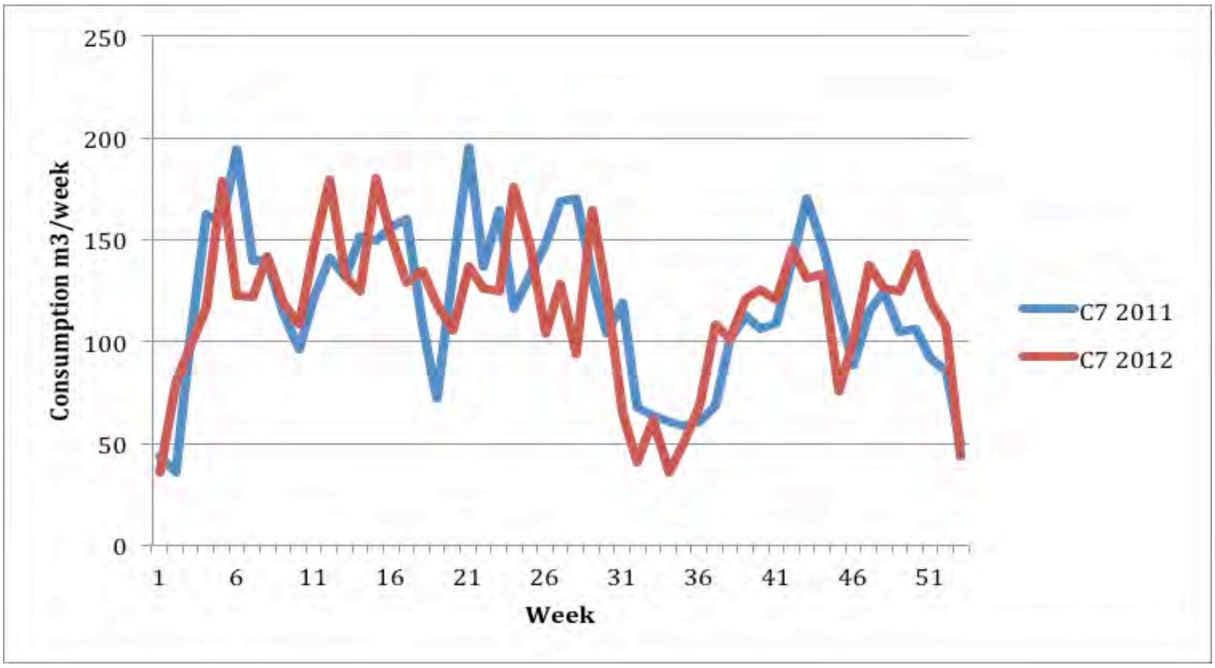


Figure 3.13 Weekly consumption of the building C7

3.3.4 Sector of Physics

Figure 3.14 illustrates the weekly consumption of the research building Cerla. We observe some scatters between the consumptions in 2011 and 2012. The factor of correlation between these consumptions is equal to 0.48.

The building consumption is generally low (around 60 m^3/week), in particular during the vacations (around 30 m^3/week). The consumption peak in 2011 occurs in weeks 5, 6 and 48 ; while in 2012 it occurs in weeks 6, 7, 48 and 49, with a maximum around 160 m^3/week.

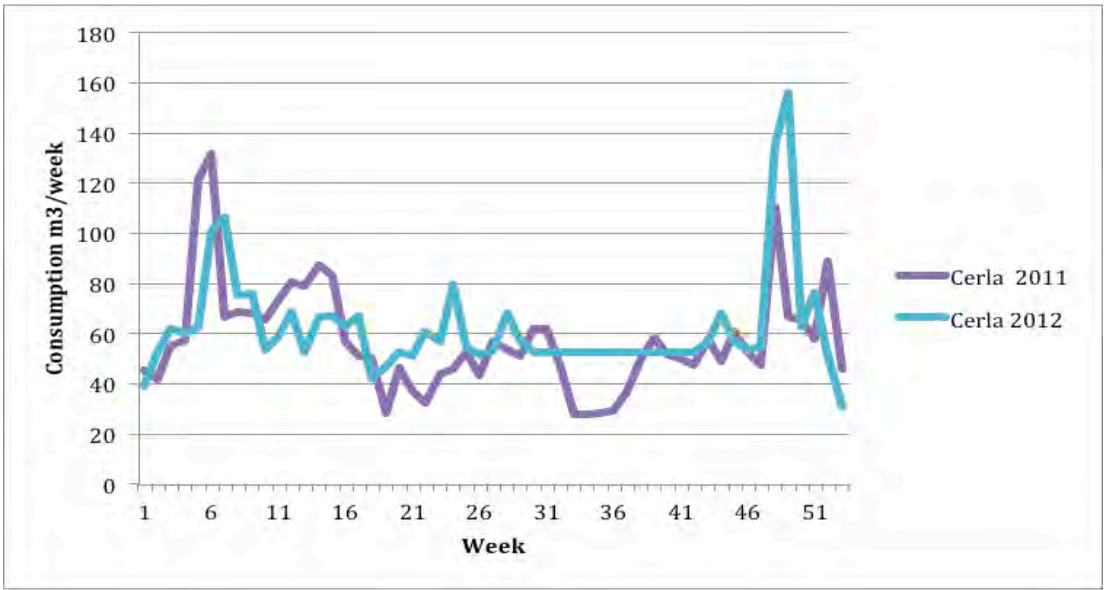


Figure 3.14 Weekly consumption of the building Cerla

3.3.5 Sector of the administration & services, A1 and A3

Figure 3.15 illustrates the weekly consumption of the heating center building A1. It shows a high scattering between the consumptions in 2011 and 2012: (i) the factor of correlation is equal to 0.06 (ii) the periods of the consumption peaks do not coincide. The consumption is characterized by the presence of several peaks:

- in 2011 : weeks 11 (360 m^3/week), 12 (175 m^3/week) and 52 (138 m^3/week).
- in 2012 : weeks 26 (160 m^3/week), 27 (133 m^3/week) and 48 (157 m^3/week)

The water consumption of this building depends mainly on the use of water in the heating center process. It is then difficult to establish a consumption profile. The latter should be established according to the industrial process used in the heating center.

Figure 3.16 illustrates the weekly consumption of the administration building A3. We observe some scattering between the consumptions in 2011 and 2012. The factor of correlation between these consumptions is equal to 0.40. Generally, the building consumption is low (about 2 m^3/week) with very low consumption in the year-end vacation and weeks 34 to 37 (September). The building profile could be characterized by a low consumption all over the year (about 2 m^3/week).

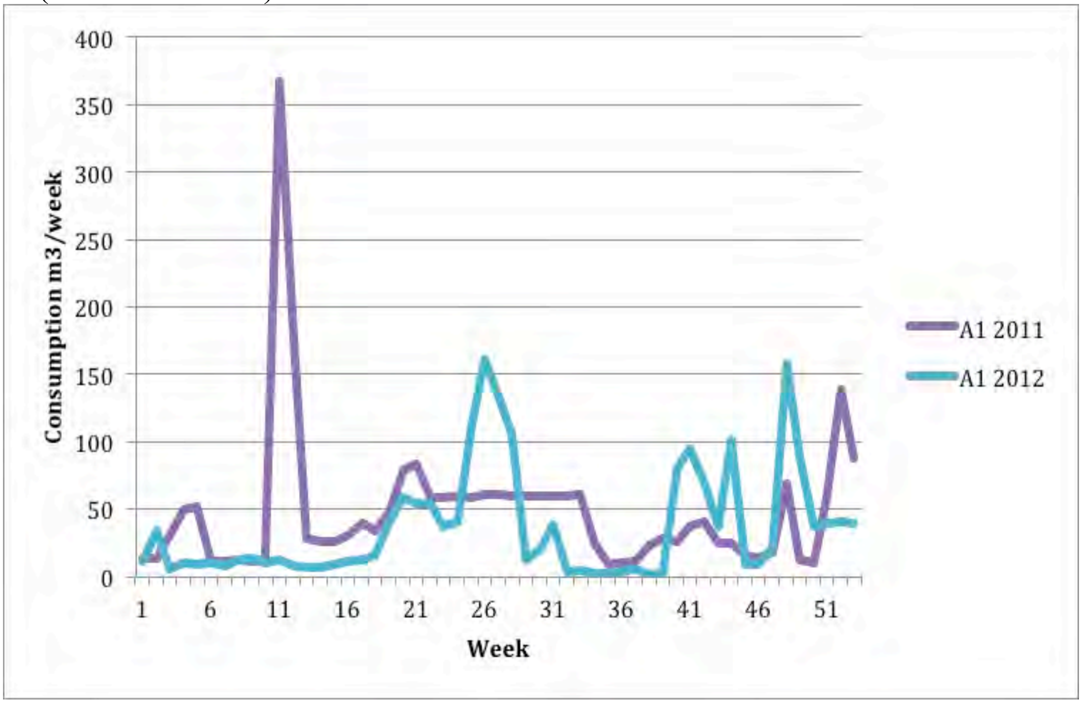


Figure 3. 15 Weekly consumption of the building A1 (administration and services)

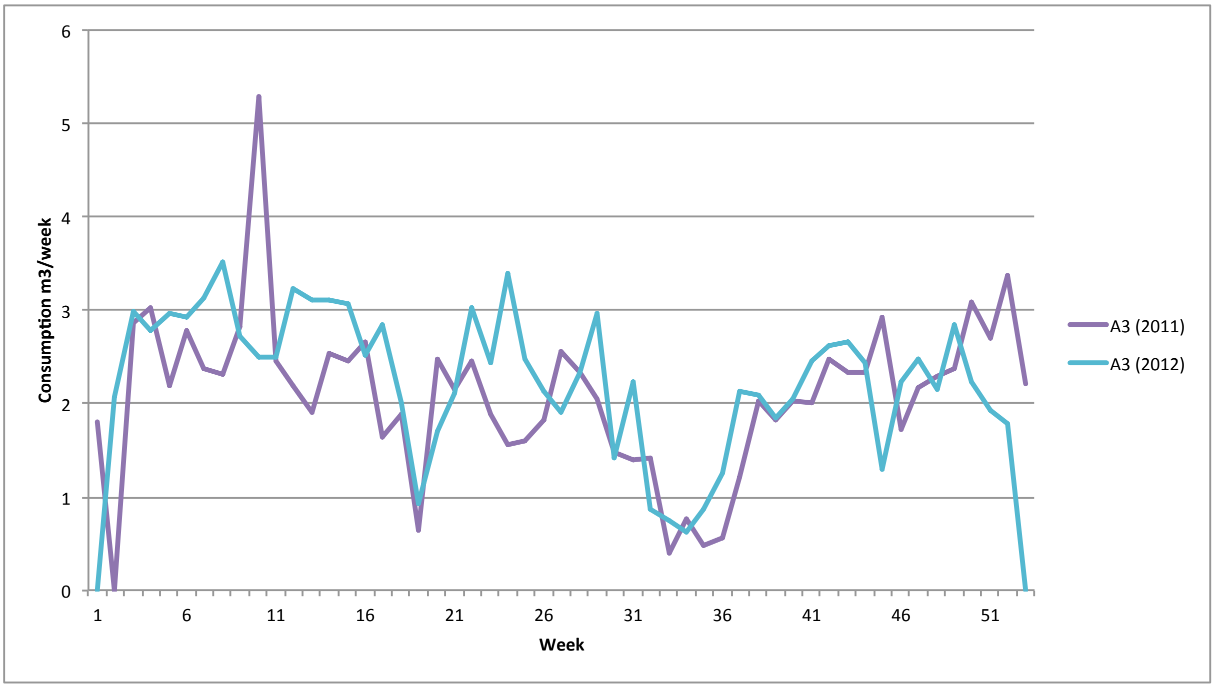


Figure 3. 16 Weekly consumption of the building A3 (administration and services)

3.4 Daily consumption

In this section we present analysis of the daily consumption of two buildings: the teaching/research building C7 of the sector of Chemistry and the administrative building A3.

Building C7

Figure 3.17 shows the daily consumption of the building C7 in 20012. It can be seen that this consumption varies between 4.7 m^3/day and 46 m^3/day with a mean value Mv= 16.66 m^3/day and a standard deviation $\sigma = 7.87$. The figure shows minima of consumption (around 6 m^3/day) in days winch correspond to the weekend and to the vacation period.

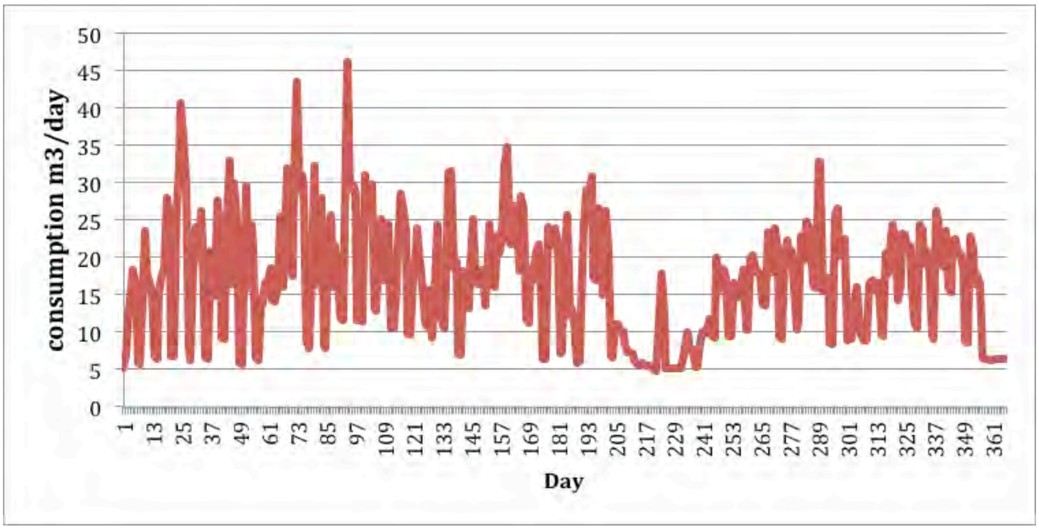


Figure 3.17: Daily consumption of the building C7 (2012)

In order establish the consumption profile of this building; the consumption period is split into two periods:

- Vacation days (Vd), which includes the period of vacation and the weekends.
- Working days (Wd), which includes the period of working days of the year.

Figure 3.18a shows the variation of the consumption for the working days. It can be seen that this consumption varies between 9.1 m^3/day and 46.1 m^3/day with a mean value Mv= 21.8 m^3/day and a standard deviation $\sigma = 5.93$. Figure 3.18b shows the distribution of the consumption for tis period. It can be shown that this distribution is well described by the normal distribution function. The minimum and maximum of the confidence interval at 95% are equal to 20.97 and 22.72 m^3/day, respectively.

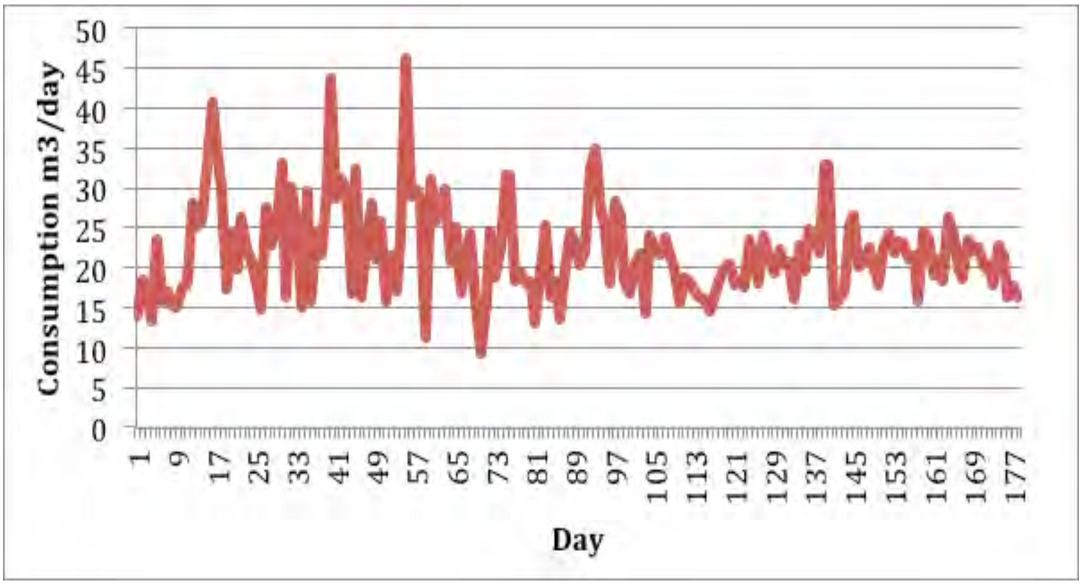


Figure 3.18a. Working days consumption - building C7 (2012)

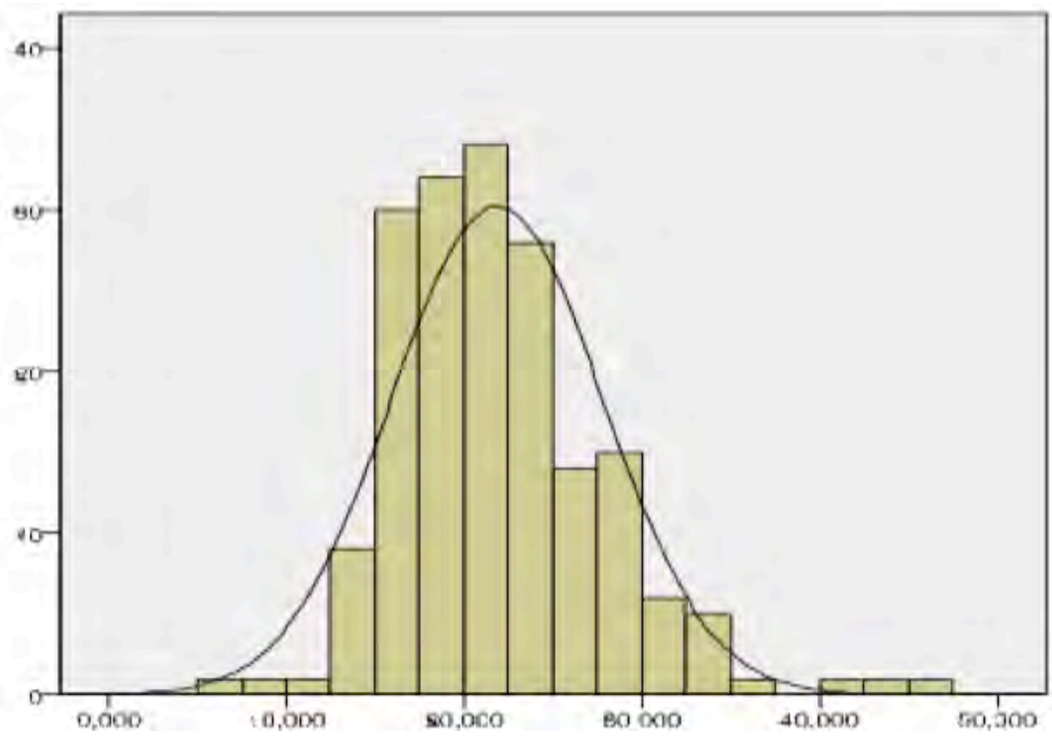


Figure 3.18b. Distribution of the working days consumption - building C7 (2012)

Figure 3.19a shows the variation of the consumption for the vacation days. It can be seen that the daily water consumption varies between 4.7 m^3/day and 31.7 m^3/day with a mean value Mv= 11.64 m^3/day and a standard deviation σ = 6.1. Figure 3.19b shows the distribution of the consumption for this period. It can be observed that this distribution does not follow the normal distribution function. The minimum and maximum of the confidence interval at 95% are equal to 10.7 and 12.5 m^3/day, respectively.

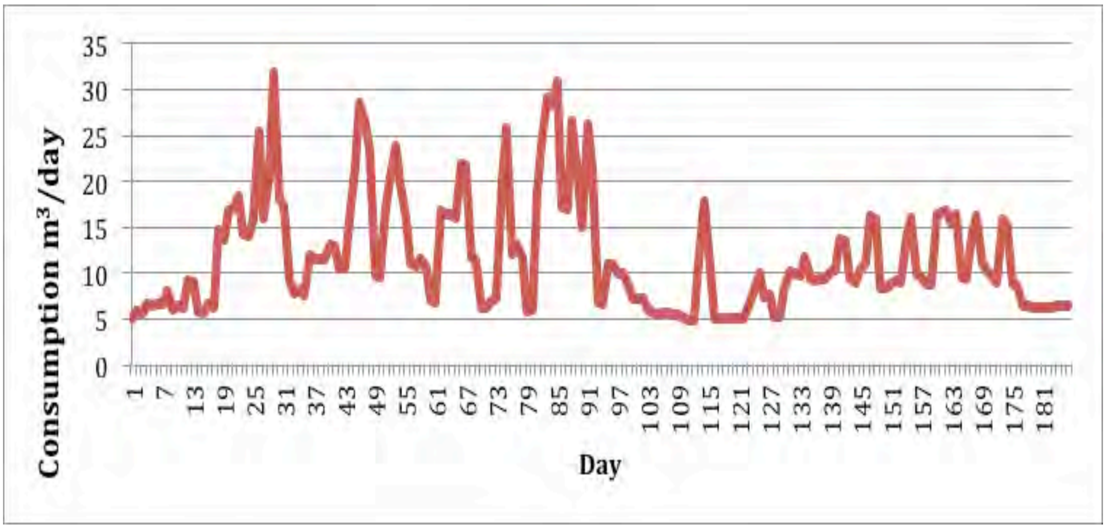


Figure 3.19a. Vacation days consumption - building C7 (2012)

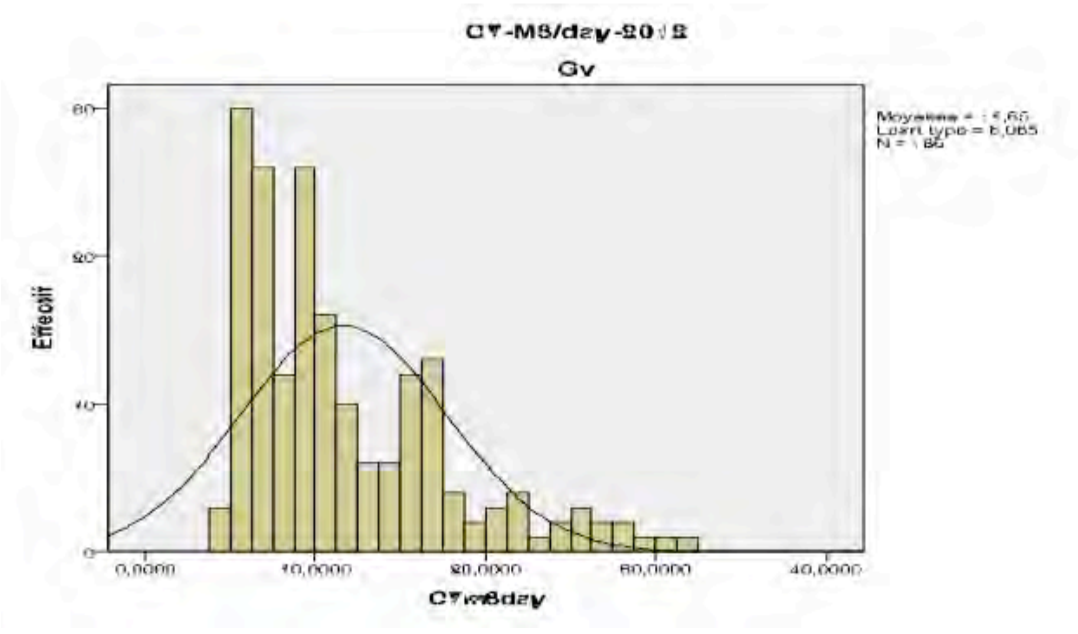


Figure 3.19b. Distribution of the vacation days consumption - building C7 (2012)

Building A3

Figure 3.20 shows the daily consumption of the administrative building A3 in 20012. It can be seen that this consumption varies between 0.5 m^3/day and 11.5 m^3/day with a mean value Mv= 4.1 m^3/day and a standard deviation $\sigma = 2.48$.

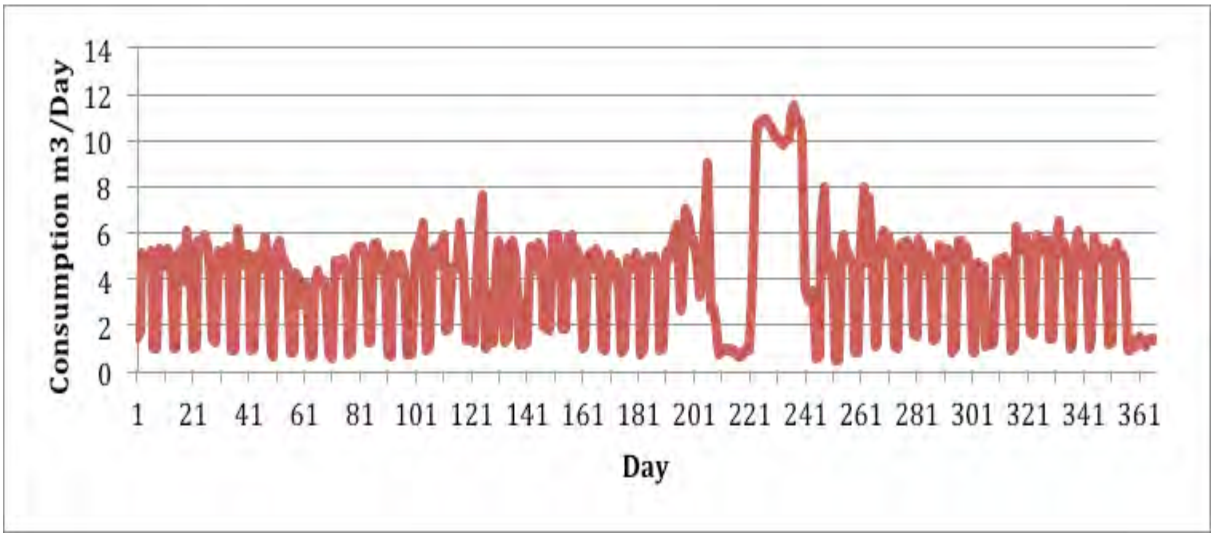


Figure 3.20. Daily consumption of the building A3 (2012)

In order establish the consumption profile of this building; the period of consumption is split into the two periods (i) vacation days and working days.

Figure 3.21a shows the working days consumption. It can be seen that this consumption varies between 0.7 m^3/day and 7.9 m^3/day with a mean value Mv= 5.1 m^3/day and a standard deviation $\sigma = 0.89$.

Figure 3.21b shows the distribution of the daily consumption for tis period. It can be shown this distribution is well described by the normal distribution function. The minimum and maximum of the confidence interval at 95% are equal to 4.95 and 5.21 m^3/day, respectively.

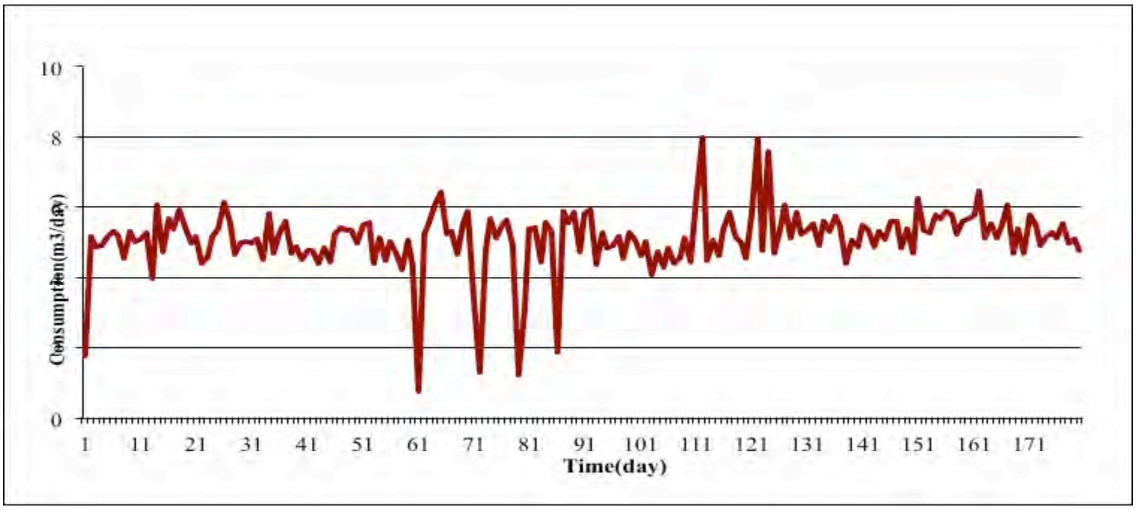


Figure 3.21a. Working days consumption of the building A3 (2012)

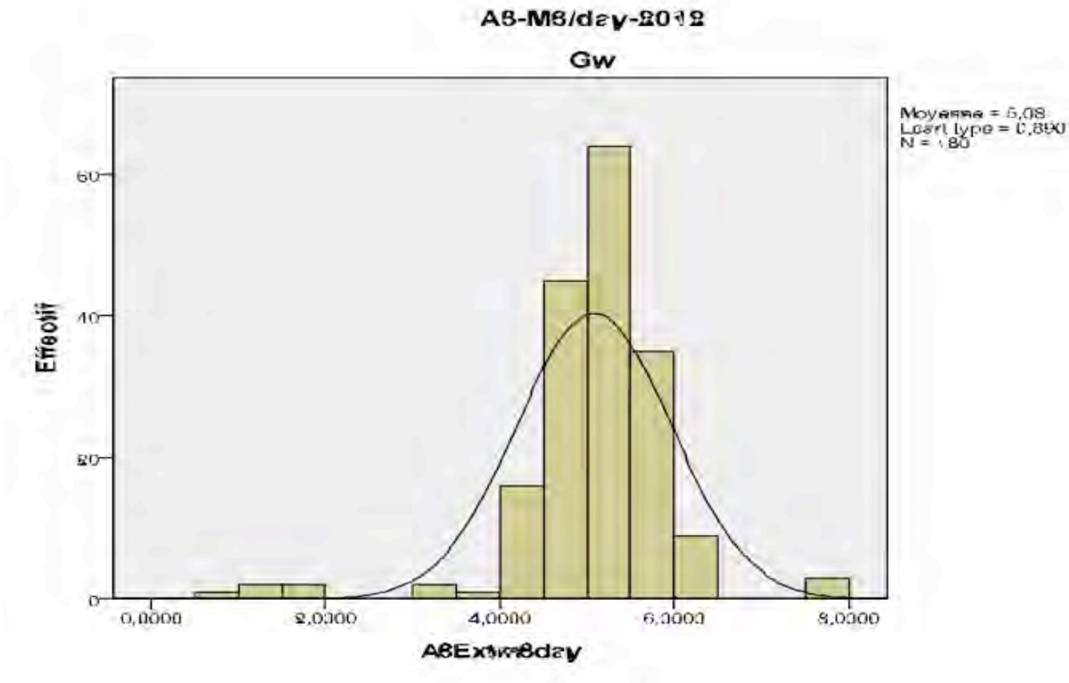


Figure 3.21b. Distribution of the working days consumption of building A3 (2012)

Figure 3.22 shows the variation of the consumption for the vacation days. It can be seen that the daily water consumption varies between 0.5 m^3/day and 11.5 m^3/day with a mean value Mv= 3.1 m^3/day and a standard deviation $\sigma = 2.9$. This figure shows an abnormal consumption during three weeks of the summer vacation (around 10m^3/day). This consumption could be related to water leakage. In order to establish the “expected” profile consumption of the building, the abnormal consumption period was removed from the analysis. Figure 3.23a shows the consumption variation after remove of the abnormal consumption. It could be seen that the daily water consumption varies between 0.5 m^3/day and 9.0 m^3/day with a mean value Mv= 2.2 m^3/day and a standard deviation $\sigma = 1.8$. Figure 3.23b shows the distribution of the daily consumption for this is period. It can be observed that this distribution does not follow the normal distribution function. The minimum and maximum of the confidence interval at 95% are equal to 1.98 and 2.53 m^3/day, respectively.

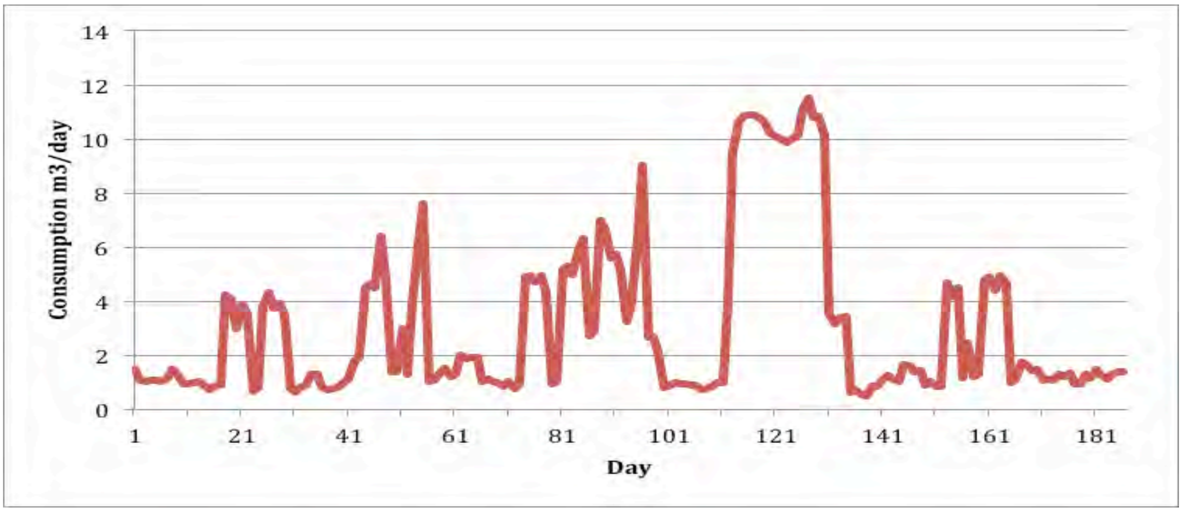


Figure 3.22. Vacation days consumption of building A3 (2012)

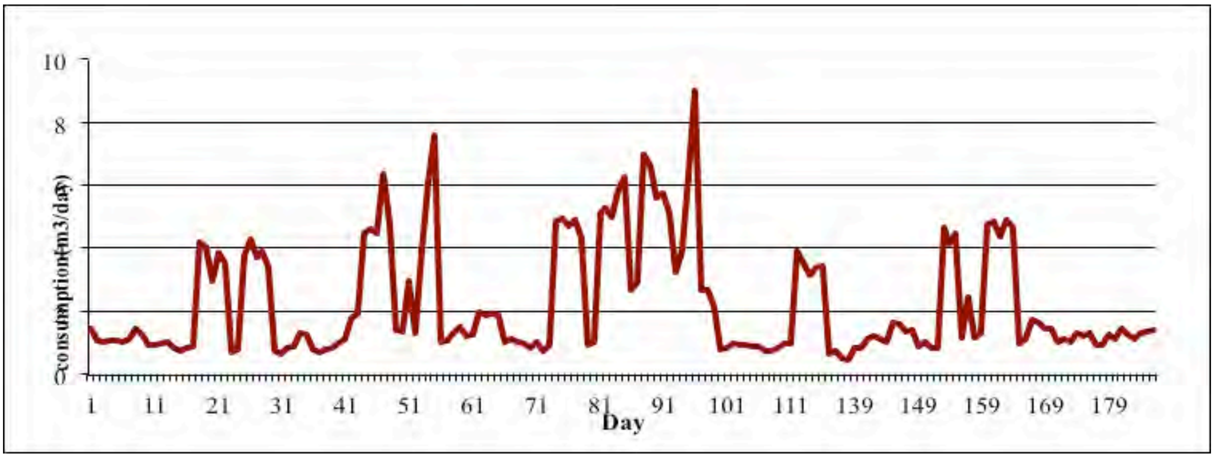


Figure 3.23a: Vacation days consumption of building A3 (after removal of the abnormal consumption in August)

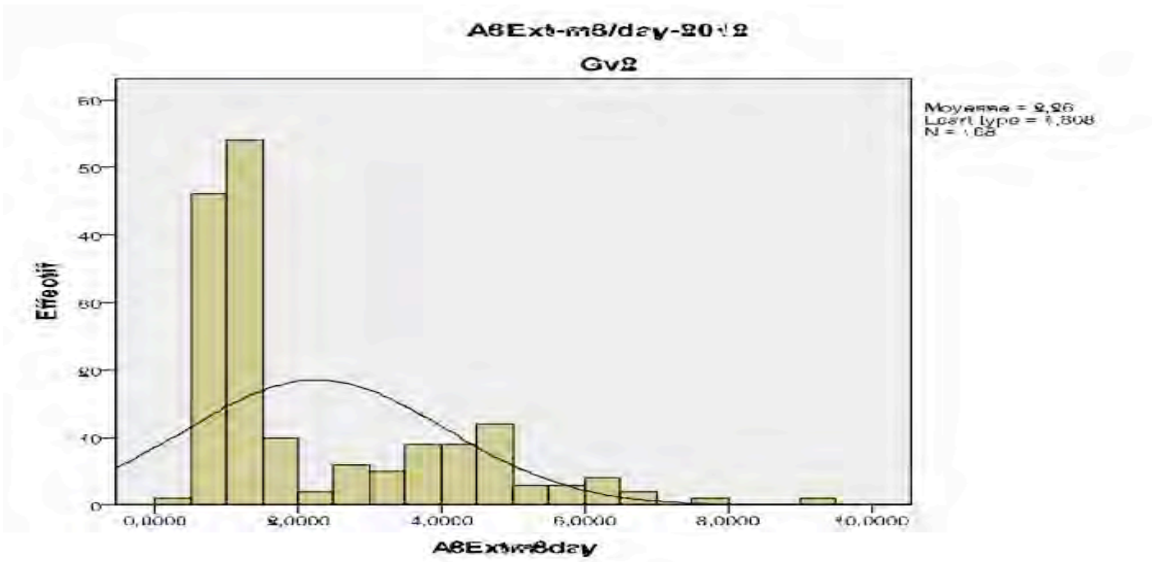


Figure 3.23b. Distribution of the working days consumption of building A3 (after removal of the abnormal consumption in August)

3.5 Hourly consumption analysis and modeling

In this section we present analysis of the hourly consumption of some buildings of the main sectors in order to establish the consumption profile of these buildings and (or) to identify abnormal consumption.

3.5.1 Sector of Chemistry

Building C6

Figures 3.24a and 3.24b and tables 3.4a-b describe the hourly consumption of the research building C6 during the first two weeks of April 2012. The consumption of the first week is characterized by (Figure 3.24a, table 3.4a):

- Very low consumption during the weekend (around 0.17 m^3/Hour).
- Very low consumption on Monday between 1:00 and 7:00 followed by an important increase between 8:00 and 11:00 and then by a quasi stabilization with a consumption rate around 2.5 m^3/Hour.
- A high consumption all over the day of Tuesday, Wednesday and Thursday, with a peak around 4 m^3/Hour and a minimum around 2.2 m^3/Hour.
- A high consumption on Friday between 1:00 and 16:00 followed by an important decrease in the consumption (around 0.17 m^3/Hour).

The consumption of the second week is characterized by (Figure 3.24b, table 3.6b):

- Very low consumption on Monday (around 0.17 m^3/Hour)
- Very low consumption on Tuesday between 1:00 and 7:00, followed by an important increase up to peak (4.2 m^3/Hour) at 14:00, then by a quasi stabilization with a consumption rate around 2.7 m^3/Hour.
- A high consumption all over the day on Wednesday, Thursday, Friday, Saturday and Sunday, with a peak around 4 m^3/Hour and a minima around 2.2 m^3/Hour.

The consumption of this research building is governed by the use of a research apparatus. It could be described as follows (Figure 3.24c) :

- Very low consumption during non-operating days (week end for the first week, Monday in the second week).
- Very low consumption between 1:00 and 8:00 followed by an important increase during the starting day of the process (Monday in the first week, Tuesday in the second week).
- High consumption all over the operating days with a mean value around 2.8 m^3/Hour (variation between 2.2 and 4 m^3/Hour).

Table 3.4a Analysis of the hourly consumption of C6 (First week, April 2012)

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Maximum	0.15	2.24	2.67	2.15	0.16	0.15	0.14
Minimum	2.82	4.08	3.87	3.43	3.04	0.18	0.16
Average	1.69	2.93	3.09	2.85	1.63	0.16	0.16
Standard Deviation	1.06	0.61	0.33	0.39	0.99	0.01	0.01

Table 3.4b Analysis of the hourly consumption of C6 (Second week, April 2012)

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Maximum	0.14	0.15	2.62	2.61	2.11	2.07	2.04
Minimum	0.17	4.24	3.87	3.20	4.08	2.28	2.27
Average	0.16	2.05	2.91	2.84	2.89	2.16	2.16
Standard Deviation	0.01	1.45	0.34	0.16	0.45	0.07	0.07

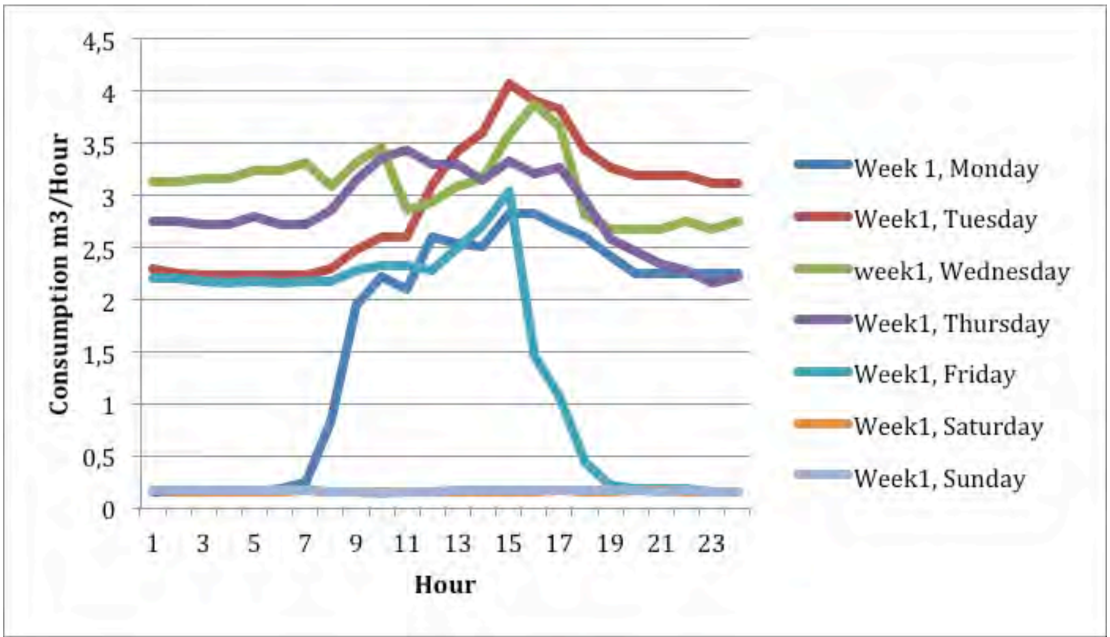


Figure 3.24a Consumption of the building C6 (First Week, April 2012)

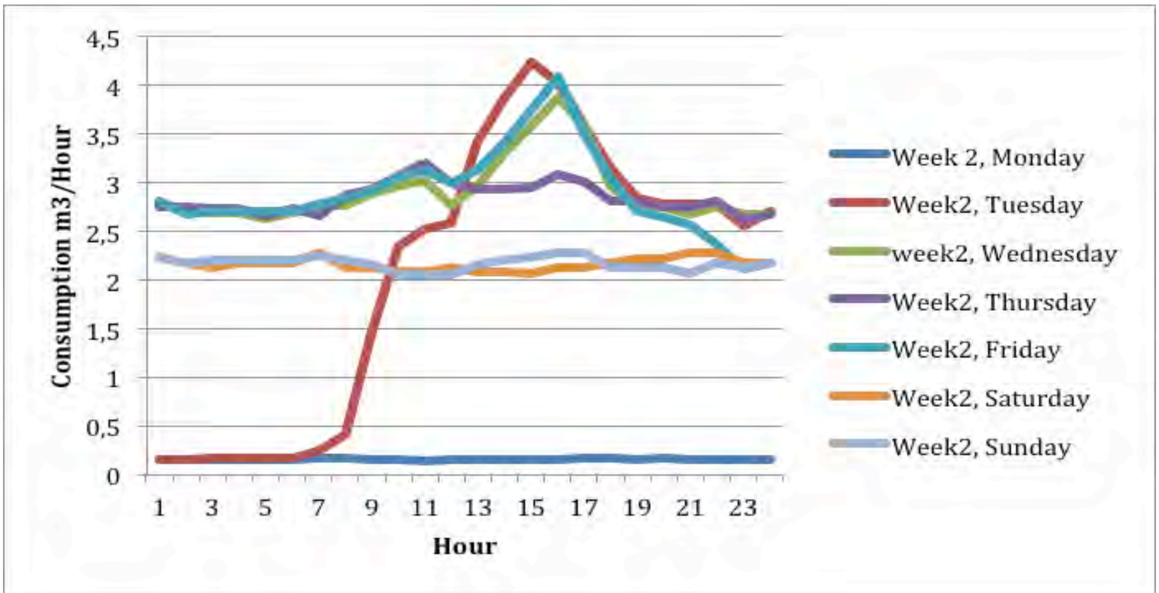


Figure 3. 24b Consumption of the building C6 (Second Week, April 2012)

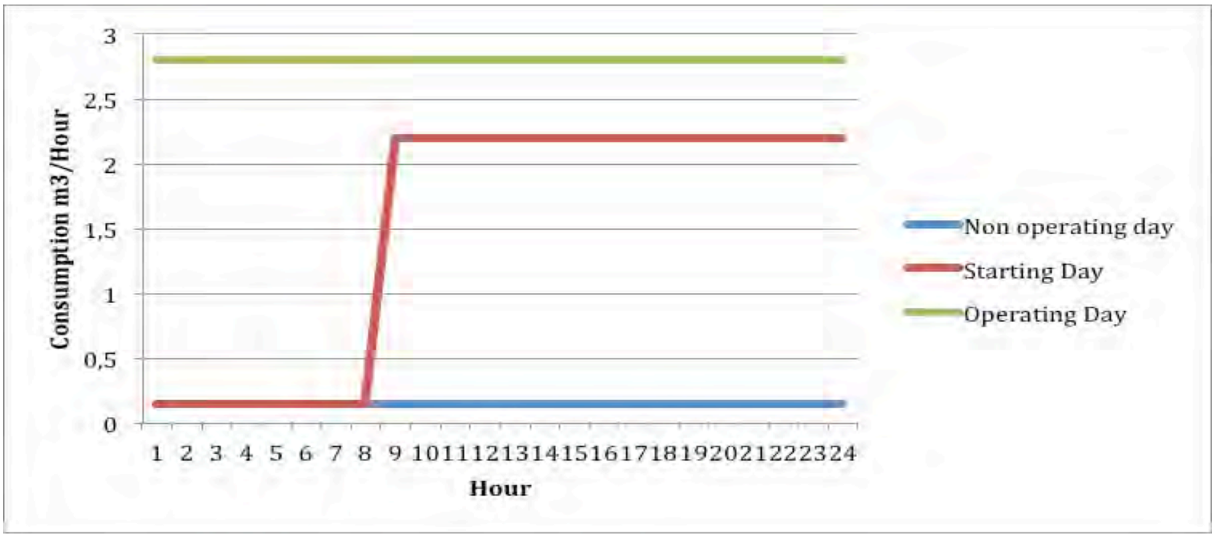


Figure 3.24c Simplified estimation of the hourly consumption of the building C6

Building C7

Figures 3.25a-b and tables 3.5a-b describe the hourly consumption of the teaching/research building C7 during the first two weeks of April 2012. We observe similar consumption trends in these two weeks, which are characterized by:

- Very low consumption during the weekend (about 0.3 m^3/Hour)
- Low consumption in the working days during the periods 1:00 to 9:00 and 19:00 to 24:00 (less than 0.7 m^3/Hour)
- Significant consumption during the working days between 10:00 and 18:00, with some time a drop in the consumption between 13:00 and 14:00.
- During the working hours the consumption in Friday and Tuesday (about 3 m^3/Hour) is higher than that in Monday, Wednesday and Thursday (about 2 m^3/Hour).
- During the high consumption days (Friday and Tuesday), the peak of consumption occurs at 12:00 and 17:00.

In order to establish the consumption profile of this building, we propose the simplified hourly consumption illustrated in figure 3.25c, which can be summarized as follows:

- Very low consumption during the weekend (about 0.3 m^3/Hour)
- Low consumption during the working days during the periods 1:00 to 9:00 and 19:00 to 24:00 (less than 0.5 m^3/Hour)
- Uniform consumption during the working days during the period 10:00 to 18:00 with a mean value around 3.2 for the high consumption days (Friday and Tuesday) and a mean value around 1.8 m^3/hour for the other days (Monday, Wednesday and Thursday).

-

Table 3.5a Analysis of the hourly consumption of Building C7 (First week, April 2012)

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Maximum	0.34	0.52	0.39	0.32	0.33	0.33	0.33
Minimum	2.17	3.62	2.12	2.19	3.40	0.42	0.36
Average	1.10	1.49	0.96	0.97	1.25	0.36	0.35
Standard Deviation	0.74	1.17	0.59	0.69	1.08	0.02	0.01

Table 3.5b Analysis of the hourly consumption of Building C7 (Second week, April 2012)

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Maximum	0.34	0.84	0.78	0.70	0.50	0.49	0.47
Minimum	1.53	3.36	1.33	2.11	2.67	0.54	0.53
Average	0.91	1.44	0.98	1.16	1.15	0.51	0.51
Standard Deviation	0.46	0.76	0.18	0.41	0.71	0.01	0.02

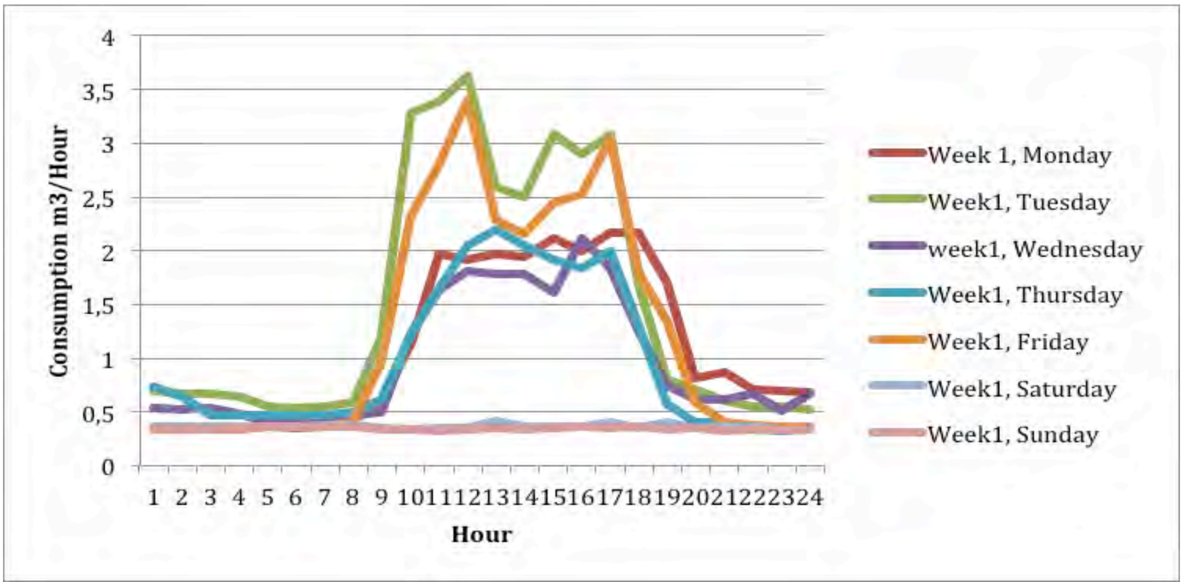


Figure 3.25a Hourly consumption of the building C7 (First Week, April 2012)

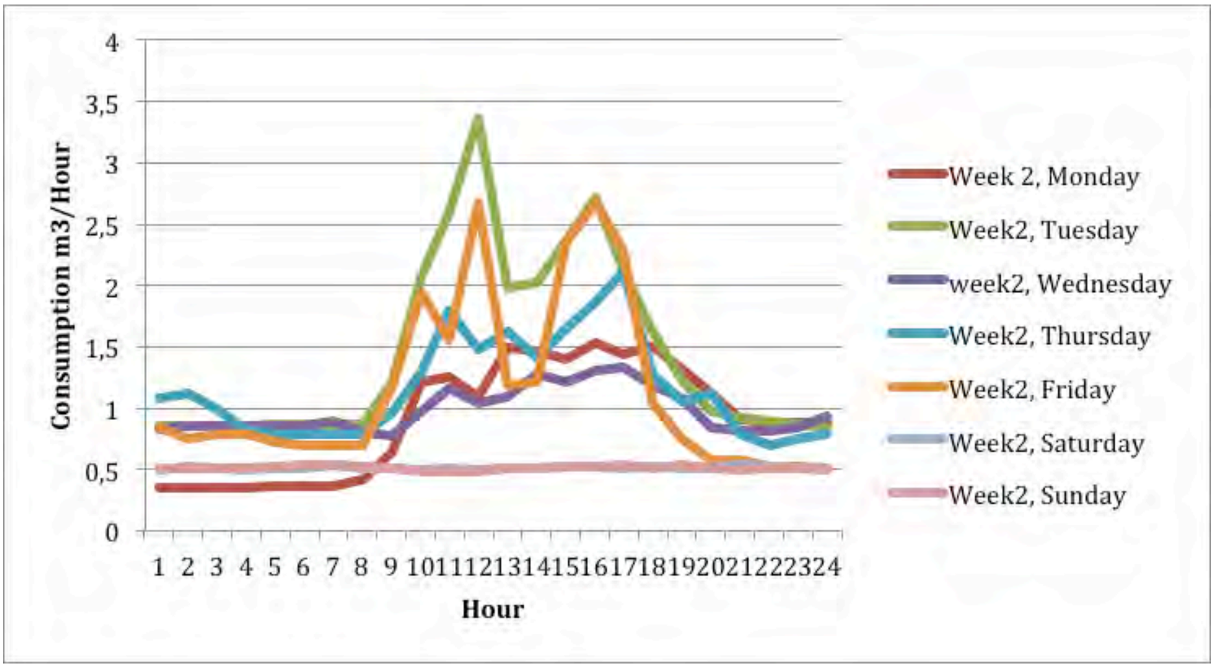


Figure 3.25b: Hourly consumption of the building C7 (Second Week, April 2012)

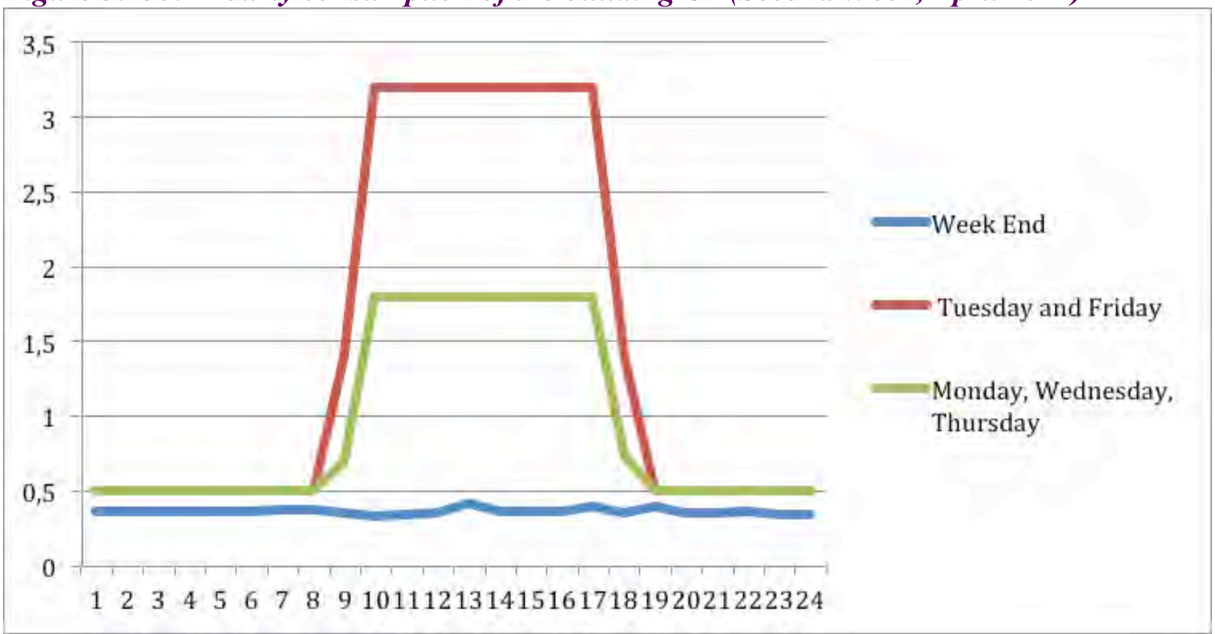


Figure 3. 25c Simplified estimation of the hourly consumption of the building C7

3.5.2 Sector of Physics

Figures 3.26a-b and tables 3.6a-b illustrate the hourly consumption of the research building Cerla during the first two weeks of April 2012. The consumption of the first week is characterized by (Figure 3.26a, Table 3.6a):

- Very low consumption during the weekend (around 0.28 m^3/Hour).
- Low consumption in Monday, Tuesday and Wednesday (less than 0.5 m^3/Hour).
- A significant consumption in Thursday and Friday during the working hours (between 8:00 and 18:00) with a quasi-uniform value around 1.1 5m^3/Hour.

The consumption in the second week is characterized by (Figure 3.26b, Table 3.6b):

- Very low consumption during the weekend and Monday (around 0.28 m^3/Hour)
- Low consumption in Friday (less than 0.5 m^3/Hour)
- A significant consumption in Tuesday during the working hours (between 8:00 and 18:00) with a quasi-uniform value around 1.15m^3/Hour.
- A significant consumption in Wednesday and Thursday with a pronounced peak, which reaches around 1.4 m^3/Hour.

Analysis of the consumption of this research building shows a very low consumption during the weekend. For the working days, it is difficult to establish general trends; this could be attributed to the use of a research apparatus, which highly affects the water consumption.

Table 3.6a: Hourly consumption of Building Cerla (First week, April 2012)

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Maximum	0.61	0.48	0.53	1.34	1.24	0.34	0.29
Minimum	0.23	0.26	0.22	0.22	0.22	0.25	0.29
Average	0.35	0.35	0.35	0.53	0.64	0.29	0.29
Standard Deviation	0.10	0.07	0.08	0.40	0.41	0.02	0.00

Table 3.6b: Hourly consumption of the Building Cerla (Second week, April 2012)

Day	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Maximum	0.33	1.19	1.35	0.94	0.53	0.28	0.25
Minimum	0.25	0.25	0.23	0.22	0.21	0.18	0.18
Average	0.29	0.62	0.52	0.40	0.35	0.23	0.22
Standard Deviation	0.01	0.38	0.28	0.19	0.09	0.02	0.02

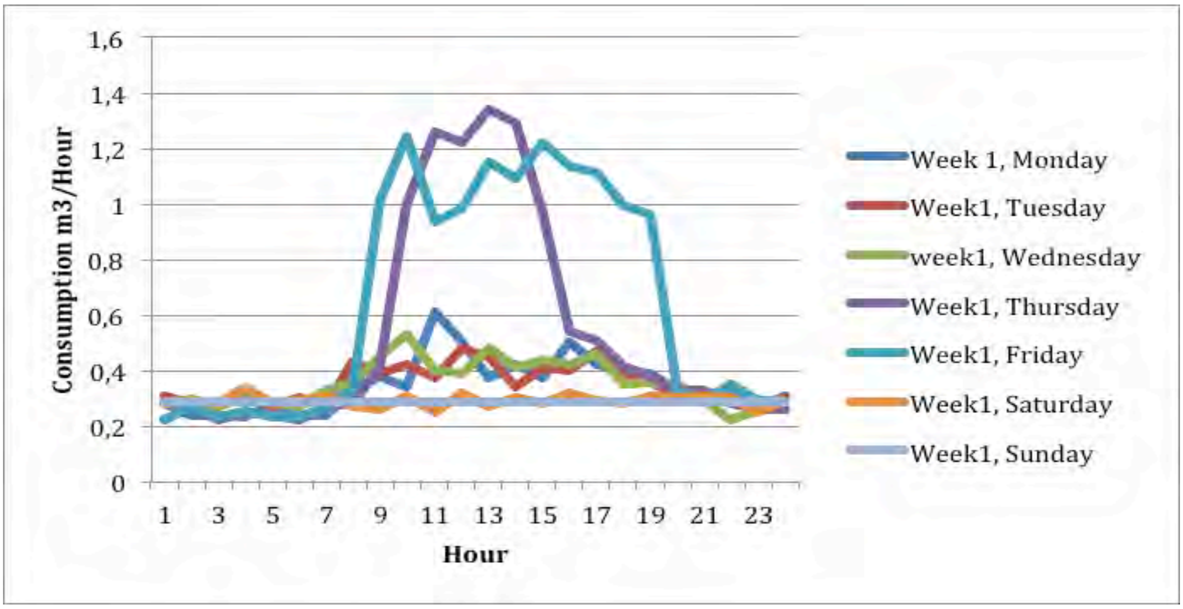


Figure 3.26a Consumption of the building Cerla (Week1, April 2012)

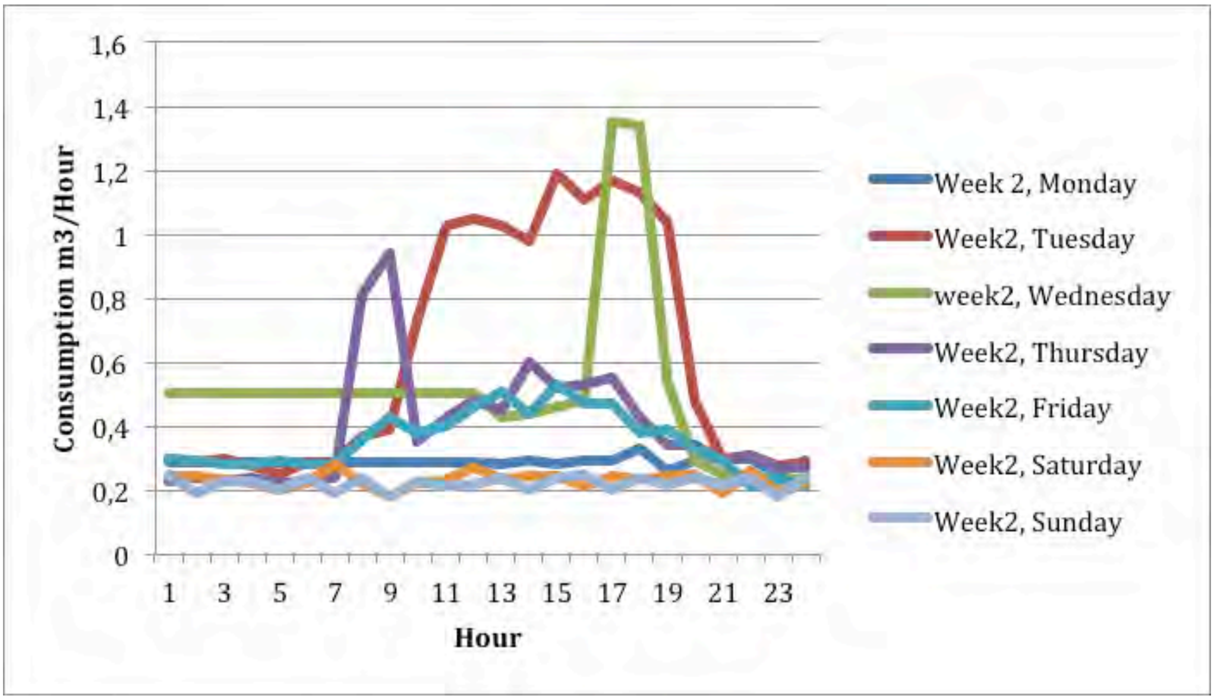


Figure 3.26b Consumption of the building Cerla (Week2, April 2012)

3.5.3 Sector of the administration & services – Buildings A1 and A3

Building A1

Figures 3.27a and 3.27b illustrate the hourly consumption of the center heating building A1 during the first two weeks of April 2012. The consumption of these two weeks shows similar trends: It occurs by short periods with either small peaks (0.3 to 0.6 m^3/Hour) or pronounced peaks (1.2 to 1.5 m^3/Hour). The latter could occur during the weekend or the working days.

Since the water consumption of this building is related to the industrial process used by the heating center, it is difficult to establish a simplified scheme for its water consumption.

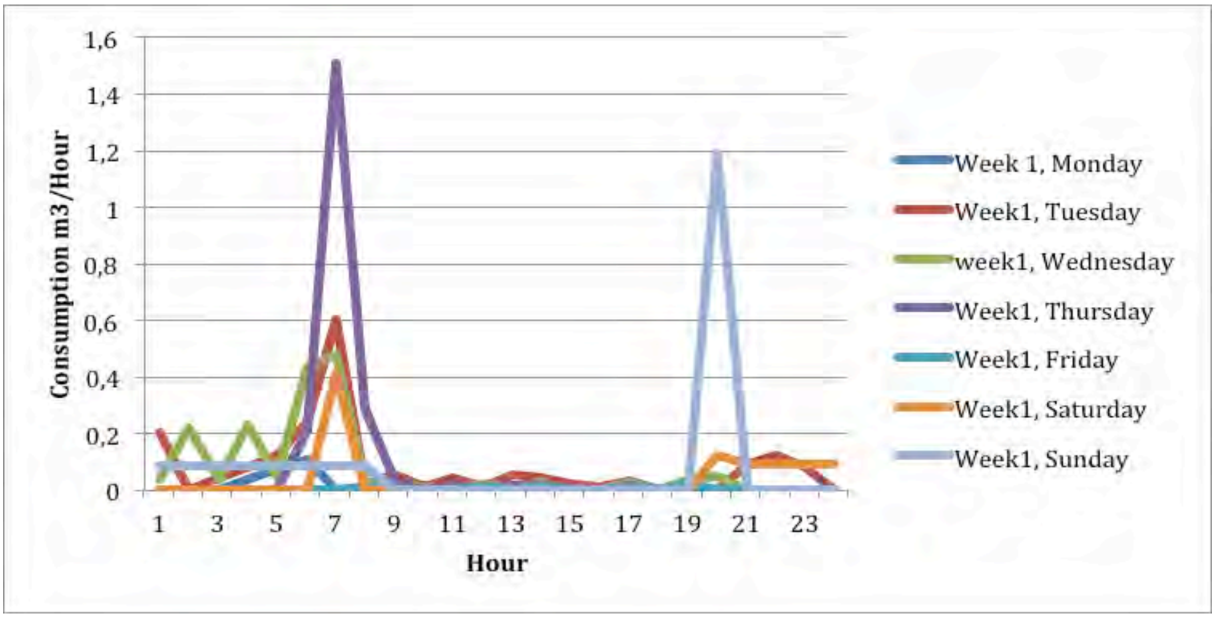


Figure 3.27a Consumption of building A1 (Week1, April 2012)

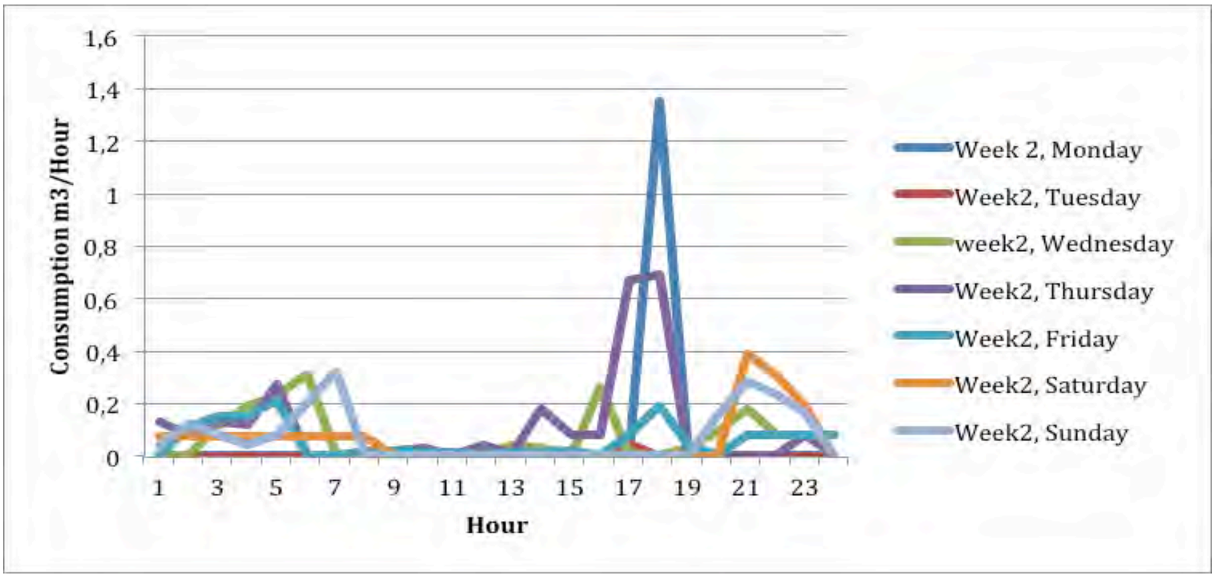


Figure 3. 27b Consumption of building A3 (Week 2, April 2012)

Building A3

Figures 3.28a and 3.28b illustrate the hourly consumption of the administrative building A3 during the first two weeks of April 2012. The consumption of these two weeks shows similar trends:

- Zero consumption during the weekend
- Very low consumption during the working days (maximum consumption rate average around 0.1 m3/Hour), with peaks at 9:00, 14:00 and 17:00 which would reach 0.3 m^3/Hour.

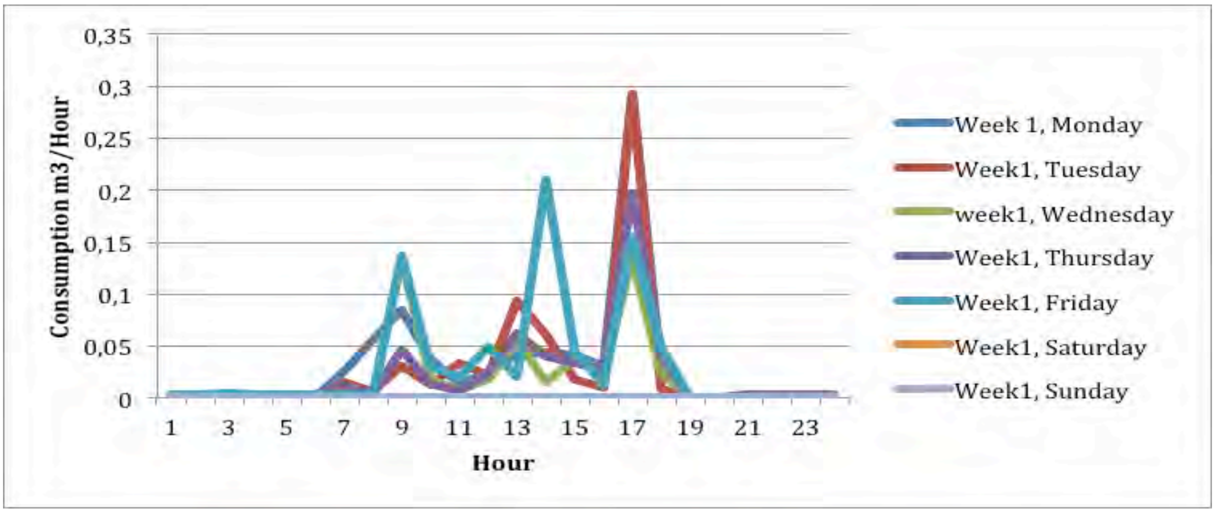


Figure 3.28a Consumption of the building A3(Week1, April 2012)

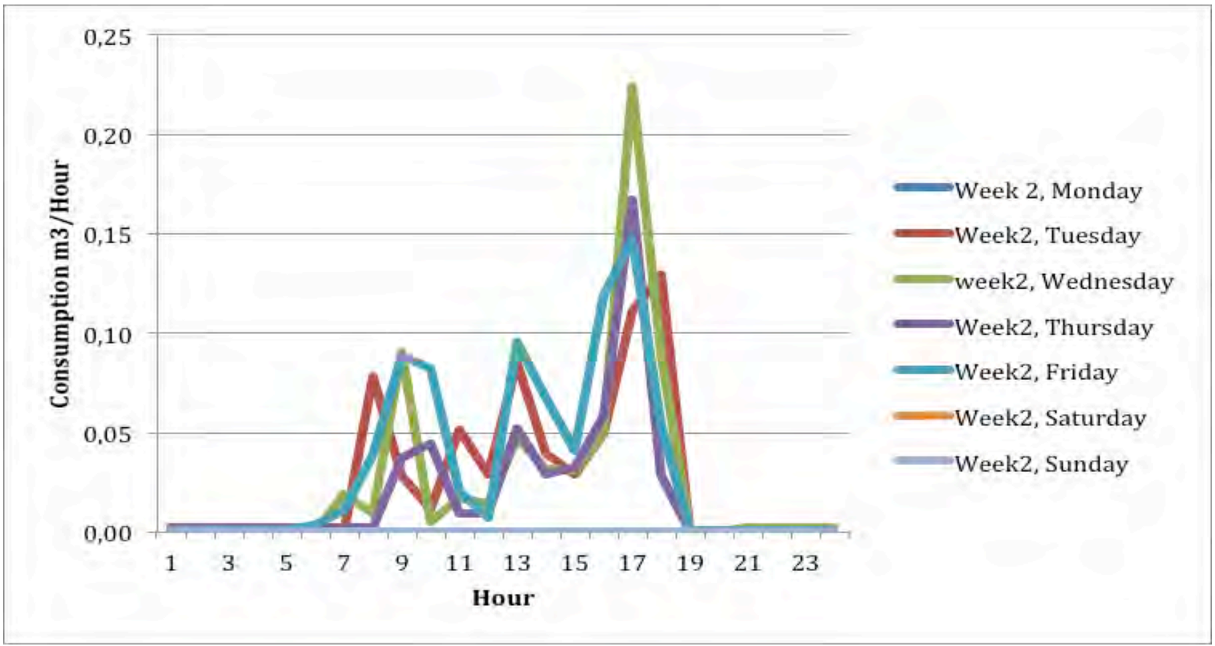


Figure 3.28b Consumption of the building A3(Week2, April 2012)

3.6 Conclusion

This chapter included analysis of the water consumption of the main sectors of the Scientific Campus: (i) students' residence, (ii) restaurants, (iii) administration & services, (iv) chemistry and (v) physics. These sectors cover the main buildings use: research, teaching, administration, residence and catering. Analysis was conducted at 4 times scales: monthly, weekly, daily and hourly. It aimed establishing consumption profile of the main buildings at these time scales. The consumption profile will be then integrated in the smart water system of the Campus for the detection and localization of abnormal water consumption, which could result from either leakage or abnormal use.

Analysis showed that the profile of the research buildings with high water consumption devices is highly dependent on the use of these devices. The water consumption management should focus on this use. Analysis shows also a need to control the water consumption of these devices in order to reduce their consumption.

The residence sector presents about 52% of the campus consumption. This consumption varies at the different scales: monthly, weekly and daily. Generally the consumption is low in the period of vacation. Unfortunately, due to the lack of the hourly consumption, we did not establish the profile consumption of this sector.

The water consumption of the administration buildings is generally very low, in particular during the weekend and the vacations. A consumption profile is proposed for the monthly, daily and hourly scales. For the daily scale, we proposed a probabilistic modeling.

The consumption profile of the teaching/research building could be summarized as follows : (i) very low consumption during the weekend and vacations, (ii) low consumption during the working days in the periods 1:00 to 9:00 and 19:00 to 24:00 (iii) uniform consumption during the working days in the period 10:00 to 18:00.

The consumption of profile of the sector of restaurants is characterized by: (i) very low consumption in the vacation, (ii) medium consumption (around 50 m^3/week) in May and June and (iii) high consumption (around 100 m^3/week) in the periods January to April and October to December

This analysis will be conducted for the totality of the campus buildings in order to establish their profile consumption. The consumption profile will also be established using the Neural Artificial Network, which will be then integrated in the smart water management system of the Campus.

4. Conclusion

This work is a part of a large project for the implementation of a smart water system in the Scientific Campus which is equivalent to a small city with about 25 000 inhabitants. The smart water technology incudes (i) the implementation of a real-time monitoring and control of the water distribution system (pressure, flow, water consumption, and water quality) and (ii) the development of expert system based on experience developed by the water and industry as well as basic and applied researches for the optimal management of complex systems. One of the major issues in this system concerns the water demand management. This work concerned this issue. It included a literature survey, analysis of the water consumption in the Scientific Campus of the University Lille1, which is equivalent to a small city with about 25 000 inhabitants.

The literature survey showed the importance of the development of a water distribution strategy based on the water demand management, because it allows minimizing the water losses in transport and storage systems and the reuse of water. It is also crucial in determining the water prices and evaluating investment projects. Selected case studies showed different approaches used in the water demand management. Monitoring is largely used for the determination of the water demand. Analysis of recorded data allowed recommendations for the reduction of the water demand.

Water leakage constitutes a major concern in the sustainable management of the water resources. It requires a particular focus on the deterioration of the water distribution system, which could be caused by (i) physical factors related to pipes and joints, (ii) environmental factors, which concern trench backfill, soil type, climate condition and pipe location and (iii) operational factors such as water pressure, water flow velocity, water quality and internal corrosion. The leak detection is also of major importance. It includes (i) identifying of leakage areas using mainly the District Meter Area (DMA) and (ii) the leak localization using different technologies, such as acoustic loggers, leak noise correlator, ground radar, gas injection and tracing techniques. Case studies showed that the DMA technology is largely used.

Literature analysis showed also a great interest in the implementation of the smart technology in the water management system. This technology constitutes an efficient emerging technology for (i) a rapid detection of the water leakage and contamination, (ii) the reduction of the energy used in the water supply and (iii) the improvement of the communication with end-users. The implementation of this technology requires checking the integration of (i) complex and heterogeneous technology and (ii) economic, social and governance strategies in the optimal management of water distribution system.

The work included analysis of the water distribution system in the Scientific Campus. This site presents several advantages for the development of a water management strategy based on the water demand management. The campus buildings have varied usages: students' residence, restaurant, sport, administration, research, teaching, teaching and research. In addition the site is equipped by an automatic metering reading (AMR). The consumption data is available for the main buildings at different time scales.

Analysis of the water consumption in the main buildings was conducted at 4 times scales: monthly, weekly, daily and hourly. It aimed establishing consumption profile of the main buildings at these time scales. The consumption profile will be then integrated in the smart water system of the Campus for the detection and localization of abnormal water consumption, which could result from leakage or abnormal use.

Analysis showed that the profile of the research buildings with high water consumption devices is highly dependent on the use of these devices. The residence sector presents about 52% of the campus consumption. This consumption varies at the different scales: monthly, weekly and daily. Generally the consumption is low in the period of vacation. The consumption profile of the sector of restaurants is characterized by: (i) very low consumption in the vacation, (ii) medium consumption (around 50 m3/week)in May and June and (iii) high consumption (around 100 m3/week) in the periods January to April and October to December. The water consumption of the administration buildings is generally very low, in particular during the weekend and the vacations.

A consumption profile is proposed for the monthly, daily and hourly scales. For the daily scale, we proposed a probabilistic modeling. The consumption profile of the teaching/research building could be summarized as follows: (i) very low consumption during the weekend and vacations, (ii) low consumption during the working days in the periods 1:00 to 9:00 and 19:00 to 24:00 (iii) uniform consumption during the working days during in period 10:00 to 18:00.

This analysis will be conducted for the totality of the campus buildings in order to establish their profile consumption. The consumption profile will also be established using the Neural Artificial Network, which will be then integrated in the smart water management system of the Campus.

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