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UNIVERSIDAD AUTÓNOMA DE SAN LUIS POTOSÍ
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INTEGRATION OF WATER IN GLOBAL ENERGETIC BALANCE OF SUSTAINABLE HOUSING

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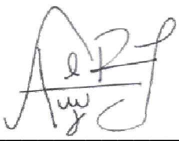

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A Dios por darme la oportunidad de vivir esta experiencia,
A mi monita, que siempre me acompaña desde el cielo,
A mi mami por creer en mí en cada momento,
A mi papá por la educación que siempre me ha inculcado,
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A Diego por ser mi guía y mi fortaleza,
Para ellos, con todo mi amor,

Angie.

INTEGRATION OF WATER IN GLOBAL ENERGETIC BALANCE OF SUSTAINABLE HOUSING

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List of Symbols

SYMBOL	DESCRIPTION	UNITS		
A_c:	Collection Area	(m^2)		
C_r:	Run-off coefficient			
C_P:	Heat Capacity at constant Pressure	$(J/kg \cdot K)$		
D:	Internal diameter of a pipe	(m)		
E:	Energy	(J)	$(kW \cdot h)$	$(oil\ equivalent\ tons)$
f:	Friction Factor			
g:	Local acceleration of gravity	(m/s^2)		
H:	Enthalpy	(J)		
h:	Specific Enthalpy	(J/kg)		
h_l:	Losses due to flow	(m)		
L:	Length	(m)		
m:	Mass	(g)		
$\dot{m}$:	Mass Flow	(kg/s)		
P:	Pressure	(Pa)		
Pp:	Precipitation	(mm)		
Q:	Heat	(J)		
$\dot{Q}$:	Heat Flow	(J/s)		
q:	Specific Heat	(J/kg)		
Re:	Reynolds number			
T:	Temperature	$(°C)$		
t:	Time	(s)	$(year)$	
U:	Internal Energy	(J)		
u:	Specific Internal Energy	(J/kg)		
V:	Volume	(L)	(m^3)	
$\dot{V}$:	Volumetric Flow	(L/s)	$(m^3/year)$	(m^3/s)
v:	Velocity	(m/s)		
W:	Work	(J)		
$\dot{W}$:	Work per time (Power)	(J/s)		
z:	Height	(m)		
ρ:	Density	(kg/m^3)		
μ:	Viscosity	$(kg/m \cdot s)$		

ABSTRACT

The concept of Sustainable Development has been used in recent times for the development of projects involving environment, society and economy, looking for a reduction of impacts and the maximization of benefits. Some of these projects are being developed at the building sector, but they have a special focus on energy topics, contributing with less data about management of resources like water. The purpose of this work is to tackle the sustainable development topic with a focus on water resources at home environments, analyzing its use and energetic requirements associated to water consumption. Currently, in most efficiency indicators, the two resources are not fully included or related in houses consumption balances. As the principal aim, it is proposed to draw up a model to account for domestic water consumption in single-detached dwellings and to include the related water-induced energy required. Furthermore, it is projected to group those variables inside one energetic balance to indicate and identify critical efficiency and consumption points. The final goal is to propose solutions for a more integrated housing design with a high efficiency in both, energy and water use. The analysis of indicators of consumption of water and its related energy allows to illustrate the relationships between those indicators and to calibrate the model with real- world consumption figures.

KEY WORDS: Sustainable Development, Water, Energy, Energetic Balance, Sustainable Housing.

RESUMEN

El concepto de desarrollo sostenible ha sido usado recientemente para el desarrollo de proyectos que tienen en cuenta el medio ambiente, la sociedad y la economía buscando la reducción de impactos y maximizando los beneficios. Algunos de estos proyectos han sido desarrollados en el sector de la construcción, pero teniendo un enfoque especial en temas energéticos y contribuyendo con menos información acerca del manejo de recursos como el agua. El propósito de este trabajo es abordar el tema de desarrollo sostenible con respecto al recurso agua a nivel de viviendas, analizando su uso y los requerimientos energéticos asociados a su consumo, ya que estos dos recursos no son totalmente incluidos y relacionados en balances de consumo en proyectos de viviendas sostenibles. Como objetivo principal se propone elaborar un modelo de contabilización de consumo de agua en viviendas unifamiliares y de la energía necesaria para poder llevar a cabo dicho consumo. Además se propone agrupar estas cantidades dentro de un mismo balance energético en las viviendas para evidenciar los puntos críticos de eficiencia y consumo con el fin de proponer soluciones para el diseño de viviendas con alta eficiencia en uso de agua y de la energía relacionada con este consumo. Dentro del estudio se realiza el análisis de indicadores de consumo de agua y energía asociada para luego presentar las relaciones entre estos indicadores, calibrando el modelo con valores reales de consumo en el mundo.

PALABRAS CLAVE: Desarrollo Sostenible, Agua, Energía, Balance energético, Vivienda Sostenible.

ZUSAMMENFASSUNG

Der Begriff der nachhaltigen Entwicklung wird für Projekte verwendet, die Umwelt, Gesellschaft und Wirtschaft einbeziehen, und einerseits den Nutzen zu maximieren, andererseits die Folgewirkungen zu reduzieren versuchen. Einige dieser Projekte werden im Bausektor entwickelt, und haben einen speziellen Fokus auf Energie-Themen, berücksichtigen aber kaum das Management weiterer Ressourcen wie etwa des Wassers. Ziel dieser Arbeit ist es, nachhaltige Wassernutzung im Haushalt zu analysieren, und dabei die Wasserverwendung mit den Energieanforderungen, die hierdurch entstehen, zu verknüpfen, denn in der Regel werden die beiden Ressourcen entweder unabhängig voneinander, oder nur sehr ungleichgewichtet in den Nachhaltigkeitsanalysen und –indikatoren berücksichtigt.

Im zentrum der Arbeit steht ein Modell für den häuslichen Wasserverbrauch und die ´dafür erforderliche Energie, bezogen auf ein frei stehendes Einfamilienhaus. Hierbei wird vorgeschlagen, Variablen jeweils innerhalb eines energetischen Gleichgewichts-Modells zu gruppieren, hierin die Wasser- und Energiedienstleistungen zu ordnen, um besonders kritische Systemelemente für die Effizienz identifizieren zu können. Dieses Modell soll zu besseren, integrierten Entwürfen beitragen, die in beidem. Energie- und Wasserverbrauch hoch efizient sind.

Abschließend wird das komplexe Modell durch generalisierende Indikatoren für den Ressourcenverbrauch abgebildet, um die Ergebnisse auch Laien zugänglich zu machen und eine weitere Verbreitung zu ermöglichen. Die folgende Analyse von Wasserverbrauchsmessungen und der aufgewandten Energie zeigt die Beziehungen zwischen beiden Verbrauchsbereichen, und erlaubt eine Kalibrierung des Modells anhand echter Verbrauchszahlen.

SCHLÜSSELWÖRTER: Nachhaltigen Entwicklung, Wasser, Energie, Energisches Gleichgewicht, Nachhaltige Wohnung.

1 INTRODUCTION

Water is the principle of life, is the compound in which all kind of life on earth is based on, so it is necessary to take care of it. In the world there are approximately 1,4 billion km^3 of water, for human basic purposes fresh water is only the 2,5% of it but only a small part could be easily used, as it is shown in Figure 1. Nowadays water consumption of humans is in some cases unconscious, excessive and unnecessary leading to the depletion and contamination of reserves and water bodies (Web site: UN Water, 2010).

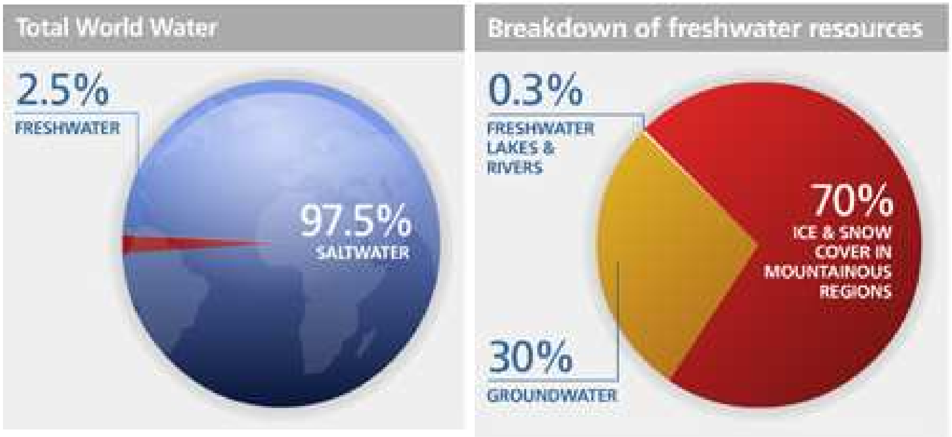


Figure 1: Distribution of Earth's Water (Web site: UN Water, 2010)

World water consumption is more than 5.000 km^3 per year and the distribution of this consumption shows that the 70% is consumed by agriculture activities, 30% by industries and 10% is used for domestic purposes. Industries and urban settlements are locations that use a lot of water, mostly in an inefficient way so they produce great quantities of wastes that go to oceans and kill water ecosystems along the route. Taking a view of this situation, on the world near of two million tons of wastes are being thrown every day producing 1.500 km^3 of waste water, so considering that one liter of waste water could contaminate eight liters of clean water it could be approximated that now there is near 12.000 km^3 of contaminated water in the World (Report: UNESCO, 2003)

The large increment in the use of water all around the world have helped to increase environmental problems, mainly those involved with water cycles in basins but affecting global trends of ecosystems. Human activities at a small scale could be dangerous for those cycles when putting together, promoting contamination of water sources, destruction of aquatic ecosystems and over-exploitation of resources. When water cycles are damaged or changed by anthropogenic factors, quality of water decreases affecting human health and food security. At a domestic scale, those anthropogenic factors are close bounded with lifestyles and education. Lifestyle make difference in quantities of consumption, importance of secondary uses of water as washing cars or watering gardens, and quality of water used according to the needs. Lack of education avoids people to know the importance of water even at a small scale, and the opportunities to make a better use of this valious resource (Report: PNUMA, 2007). Other important factors which affect water consumption are urban and turistic developments because they require more resources in one specific place, making more difficult the availability of resources and the supply of them for all population in the zone, and also needing more efforts for carring out activities like water treatment or recharging of aquifers. Figure 2 shows a proportion of domestic water uses in each country of the world, showing also how lyfestyle and habits make differences in some countries like USA or India, where water consumption is extreme large, or in African countries where water scarcity is severe.

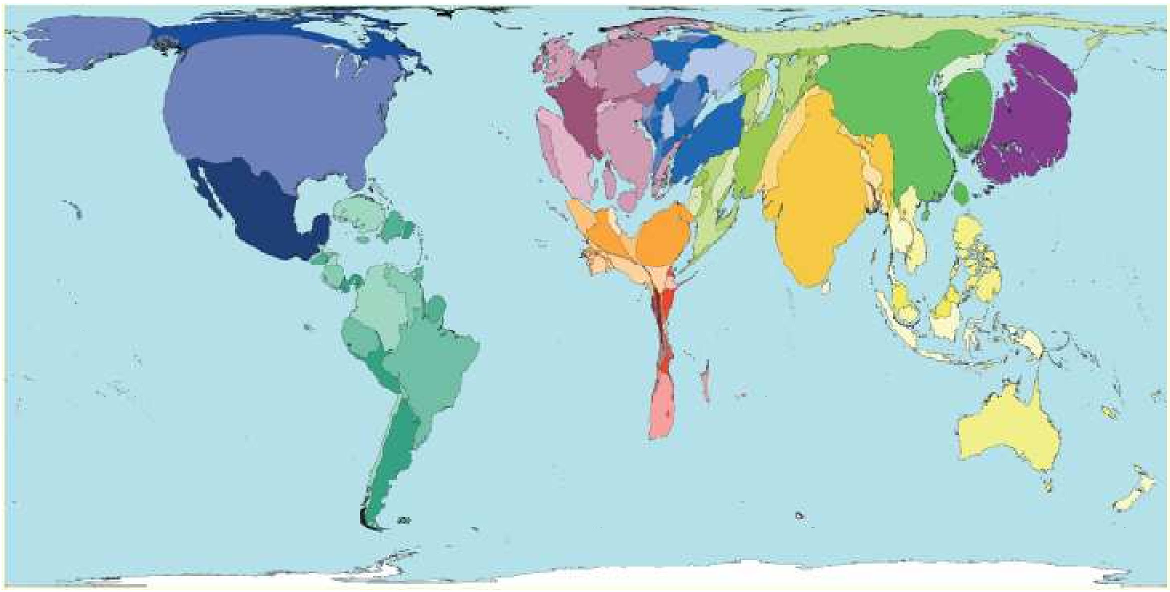


Figure 2: Domestic Water Use in 2005 (m^3/person). Territory size is proportional to water used for domestic purposes in each country (Worldmapper, 2011)

Primary energy consumption in the world in year 2008 was more than 11.000 million of oil equivalent tons, which means a consumption of about 127 PWh. From that consumption, between 80% and 90% are derived from fossil fuels (Web site: BP, 2011). Residential sector uses approximately 16% of primary energy and commercial sector uses around 6% of it (Report: Lawrence Livermore National Laboratory, 2011). These figures mean that energy related with buildings is around 29 PWh of primary energy basically for purposes like heating, cooling, lighting, and use of appliances. Industrial consumption of energy is the largest one achieving the 30% of primary energy. Transportation sector shares the second place with residential sector also with a contribution of 16% (Report: Lawrence Livermore National Laboratory, 2011). These shares are representative of the world, but could change widely in different countries according to different factors such as the level of development in each sector (Developed countries have a greater percentage of industrial consumption than the others), lifestyle including habits and demand (i.e. people from poor countries do not use devices such as computers, washing and dryer machines) and climate (Energy for air conditioning in hot and cold climates could change tremendously total energy consumption).

As it could be noticed, water and energy consumption at residential sector have not the biggest share over the total amount. Nevertheless there exist a vast potential to save those resources, reducing domestic consumption.

Sustainability is a new way of society development. Known as a concept at social, scientific, environmental and economic spheres, today comprises multiple approaches according to the specific topic in which is applied. Talking about resources and architectonical scenes, sustainability could be seen different ways such as the correct use of materials taking into their life cycle, the integration of buildings into the surrounding habitat and the use of clean sources of energy, but not so many works had been made regarding water uses and its relationship with energy. A real concept of sustainability must involve all the spheres mentioned, and because of this reason, resources like water and energy which are vital for human life, must be accounted and studied deeply in order to understand their mutual dependency. Therefore sustainability could be achieved as a more integral conception.

Small scale sustainable projects could also take into account dependency between water and energy in order to reduce consumptions in every human activity and place, with the aim of affecting global trends when multiple projects are carried out at the same time.

1.1 Problem Statement

The access to energy and water is indispensable for the development of civilizations. Modern forms of energy are useful for the correct supply of clean water and sanitation and for providing reliable heating, cooling, lighting, cooking, transport and other facilities to human beings (Report: International Energy Agency, 2010). Accessibility to good quality and quantity of water is essential for assuring human health avoiding principally microorganisms, pathogens, heavy metals and persistent organic matter (Report: PNUMA, 2007).

International cooperation and regulations could give some aid to guide actions at national levels to improve energy and water access, but only local actions could influence a change in the use of those resources by giving knowledge and awareness to people, so they could act by themselves to improve their uses and consumption of resources. There are some points to emphasize in the use of resources and energy at residential level like sustainable architecture, energy saving and water recovery.

The problem is that even when sustainable projects for housing are being developed all around the world, they are based principally on energy requirements and energy losses but projects regarding water consumption and its related energy at domestic scale are not reported in literature. So there is a need to join water and energy in a single analytical framework so that projects of sustainability could take into account both and give a better, more integrated solution for housing facilities.

1.2 Research question

Water consumption at housing scales is vital for the human being because this level embodies drinking water, which is needed for the proper function of the body (between one and seven liters per day depending on climate principally) (Web site: Deltawerken, 2004) . Other important uses of water in this level are sanitation activities like cleaning and washing, a basic requirement for health in entire societies.

Energy consumption, on the other hand, is important at housing level to give thermal comfort and to allow the development of activities like cooking, lighting and information that are indispensable for a good quality of life.

Reducing water and energy consumption but maintaining a good quality of life is a challenge for society and also a need in order to use efficiently the available resources for avoiding their depletion. An approach to sustainability therefore has to include water into sustainable housing programs which are designed principally for working efficiently in regards to their energy use.

1.3 Main Objective

With the panorama described, the principal aim of this work is to study the use of water in single-detached dwellings to find a way for including water expenses into energetic balances at that level.

Detailed knowledge of water and energy use at diverse global conditions at the level of urban single-detached dwellings allows developing a model in order to quantitatively describe and explain the relationship between water and energy and to integrate resources to achieve better sustainable designs.

1.4 SUBSIDIARY OBJECTIVES

To achieve the main objective there are three subsidiary objectives which are going to be developed.

- Study and analyze water uses and consumption in an urban house level, looking for information in data bases, governmental institutions and recent investigations with the aim of collecting data and understanding systems in order to develop the respective water use model.
- Create indicators which include the most important concepts of water consumption in single-detached dwellings. These indicators will foster a better understanding of the model in terms of synthetic indicators for each process inside the household and the relationship between them.
- Analyze some examples of consumption in the world in order to evaluate how water and energy are taken into account using the modeled relationships. This part of the work seeks to validate and calibrate the model with a proper case study.

2 THEORETICAL FRAMEWORK

It is important to define some key concepts and to understand the framework of this study in order to comprehend the structure and the objectives of the work in a deeper way. Main concepts and some significant figures are explained and shown in this section, beginning with World figures of water and energy consumption for then explaining the need of the develop of sustainable housing and the parameters that are most important in this type of households. After knowing the World situation and a possible way to decrease some environmental problems by sustainability, some key variables of water and energy fields are explained in order to determine which quantities are of interest for this study and how could them be arranged by means of balance equations.

Some important tools for this study are indicators and indexes of information which are also explained in this section with some real examples used in sustainability calculations and designs. Stakeholders who could be affected or influenced by developing this work are also established with the aim of delimiting the space and objective fields of the study.

Finally, a conceptual approach in which all concepts are connected and organized is made and all those connections are also explained.

2.1 URBAN WATER AND ENERGY CONSUMPTION

Population growth is one of the principal causes of environmental impacts. With the increment of population around the world, the demand of different resources also increases. Moreover if it is consider that a great part of this growth is taking place on urban settlements, where people use more resources and develop more technologies for systems of transportation, infrastructures, distribution, recreation and organization of land (Report: Roosa, 2008).

Figure 3 shows how population growth has had a very important impact on total population and more over after 1950's when some after-war effects like the baby boom or the industrial explosion took place and cleared the way to a new demographic state with less death rates and persistently high birth rates. Those changes also promoted a new organization of people who looked for new opportunities of work, finding them easier in cities of in industrialized settlements, incrementing urban population in this way (Report: Adams & S.J, 2008).

This triggered high demands for natural resources, with water not being an exception. World water consumption has increased tremendously during the last century, as it could be seen on Figure 3. It is known that one of the largest uses of water is agriculture, but urban settlements have also a high consumption of water, so for satisfying this demand it was necessary to build dams and reservoirs. This tendency is also shown in Figure 3 (Report: UNESCO, 2003).

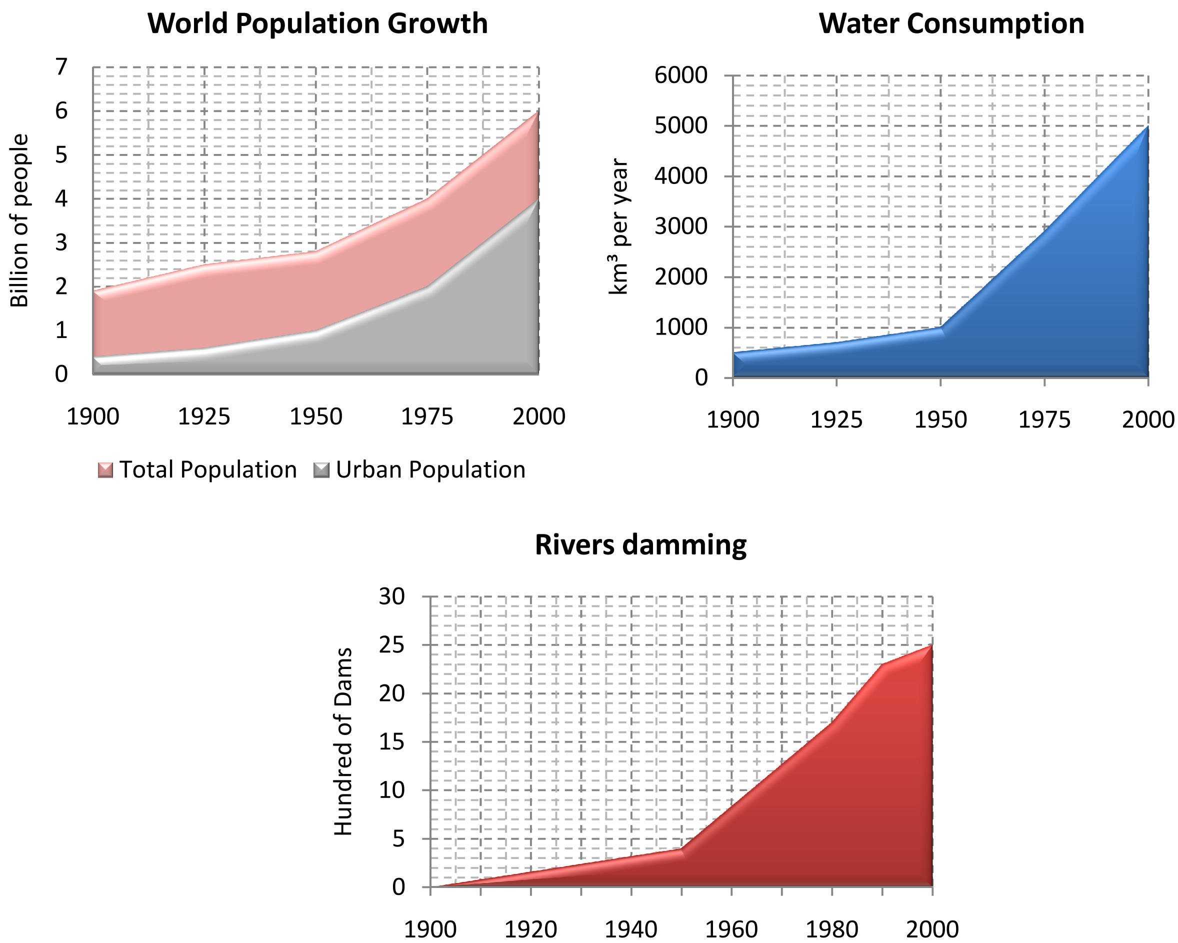


Figure 3: Behavior of World's population and water usage from 1900 to 2000 (Report: Adams & S.J, 2008)

Domestic water consumption is distributed into some principal uses: Showers and Baths (35%), toilet flushing (30%), laundry (20%), kitchen and drinking (10%) and cleaning (5%)(Report: Environment Canada, 2001). The percentages of those activities change depending on the location in the world.

Another cause of environmental impacts is the increase of energy use (Report: Roosa, 2008), linked specially with urban settlements which consumes roughly three quarters of the world's energy and it is constantly increasing with the time (Report: Rogers, Jalal, & Boyd, 2008). This incremental consumption will cause depletion of non-renewable energetic resources reserves like natural gas, coal, and oil which have an estimation of 60, 200 and 42 years of life respectively (Report: British Petroleum, 2009).

Energy consumption has had the same growth tendency as water consumption. Figure 4 shows the behavior of primary energy consumption along XXI century. It is important to see that energy consumption have also a higher increment after 1950, the same period of the world´s demographic explosion.

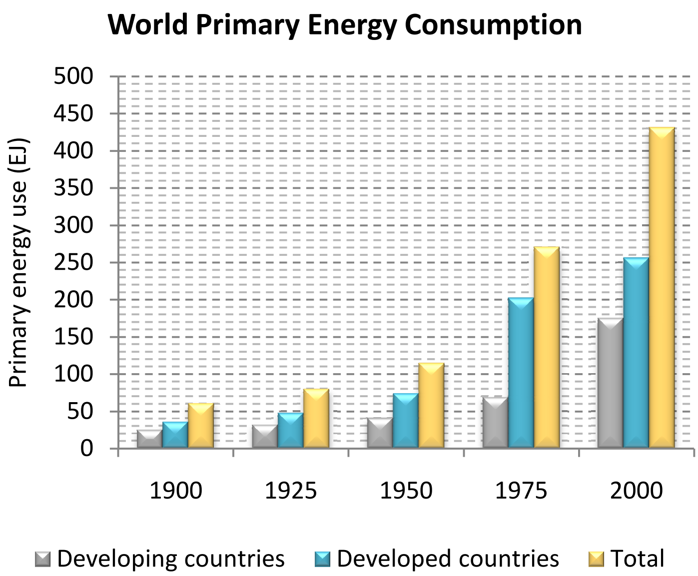


Figure 4: Behavior of Primary Energy Consumption in the World from 1900 to 2000 (Article: Grubler, 2011)

From total primary energy consumption, almost 25% is lost because of transformation processes principally in forms like heat and noise (Report: Lawrence Livermore National Laboratory, 2011). Remaining energy is used finally in four principal sectors as it is shown in Figure 5.

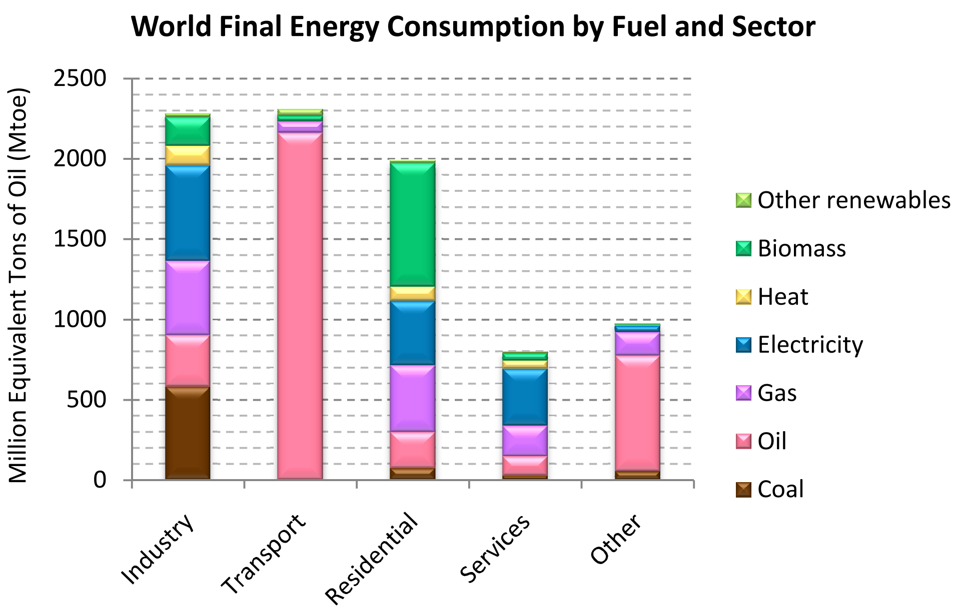


Figure 5: World Final Energy Consumption by Fuel and Sector in 2007 (Report: International Energy Agency, 2009)

Residential sector is the third consumer of final energy and this energy comes from almost all primary energy sources, varying the proportions varying widely among different regions of the World.

End use of energy in household sector varies according to the location and depending on climate, energy sources, customs, habits and available technology principally. One example of energy share by end use was made by the International Energy Agency in 2005 for 19 countries from Europe, North America Oceania and Asia, in which 53% of household energy use was for providing space heating, 21% for the functioning of appliances, 17% for water heating, 5% for lighting and another 5% for cooking (Report: International Energy Agency, 2008).

2.2 SUSTAINABLE HOUSING

Nowadays sustainability is an established concept, principally in environmental fields, but it also have different meanings and definitions according to the specific topic in which it is related. For this work, sustainable concepts are related principally with architecture and resources management.

Looking at the spheres of interest, there are three most important or used concepts of sustainability. The first is involved with design in architecture, and it describes a sustainable project as the one which have to create solutions to solve economic, social, and environmental challenges simultaneously, with solutions powered by sustainable energies(Book: Williams, 2007). Another concept states that "sustainability explores the relationship among economic development, environmental quality and social equity" (Report: Rogers, Jalal, & Boyd, 2008) and going deeply in the social dimension sustainable development is expressed as "an approach that will permit continuing improvements in the quality of life with a lower intensity of resource use, thereby leaving behind for future generations an undiminished or even enhanced stock of natural resources and other assets"(Book: Munasinghe & Ernst, 1991). The third and more global definition is the one established by Bruntland Commission in which sustainability is the key for preserving resources for future generations (Book: United Nations, 1987). There are other concepts developed for sustainable projects, but the essence of them is almost the same: a mix between society, environment and economy to achieve an equilibrium focusing on the use of natural resources.

The application of sustainable concepts to the housing sphere could be made also in different forms like bioclimatic design, carbon neutral houses, zero emissions houses, green design and passive houses among others. Nevertheless, the main topics they consider are use of renewable energies, increase in energy efficiency, recycling and reuse of materials (Book: Jenks & Wall, 2007), and the use of resources like water is not fully included.

Some criteria taken into account in housing projects including sustainability are the use of solar light to minimize electricity consumption for lighting purposes; the use of adequate materials to provide a thermal confort inside the house, as well as the use of natural and low energy systems for space heating and cooling. Recycling and reuse of construction materials is sometimes include as well as the life cycle analisis for all or some resources needed in the building step. Another important point that is included in housing sustainability is the powering with renewable sources preferable with the ones without pollution problems. Advances of wastes treatment inside houses are carried out in some cases with the aim of extracting energy and nutrients from wastes (solid and liquid ones) and reuse them inside households(Book: Williams, 2007).

Efficiency is another crucial point in sustainable buildings, more especific resources and energy efficiencies including greenhouse gas emissions reduction(Book: Kim & Rigdon, 1998).

All those concepts must be incorporated with culture and habits of people which is going to live in the builiding and with environment and surrounding of the building in order to have acceptance and become a succesful project(Book: Kim & Rigdon, 1998).

2.3 ENERGY AND WATER VARIABLES

2.3.1 WATER VARIABLES

The basis for this study is in the major part linked with water. Because of this fact it is imperative to define some variable parameters which could change composition, quality and state of water when it is used in urban domestic sectors. These variables could be arranged in three principal categories: Physical, Chemical and Biological ones.

2.3.1.1 PHYSICAL VARIABLES

Physical variables or properties of a substance are defined as quantities which could describe the state of a substance and can be measured without affecting the composition or identity of the substance. They could be divided into two categories: Extensive and Intensive. The first category refers to properties which depend on the quantity of matter of the substance like volume and mass. On the other hand, intensive properties do not change with the quantity of matter; some of those properties are temperature and pressure (Book: Howell & Buckius, 1990).

Each physical property that has importance for water and energy balances in this work is analyzed in this section and the role they play on such balances is also explained.

- Volume and Volumetric Flow Rate

Definition of volume is very simple. It is the three dimensional space occupied by a substance which could be solid, liquid, gas or plasma (Web site: The American Heritage Dictionary of English Language, 2010). Units of measurement used in this thesis are liters (L) for small quantities and cubic meter (m^3) for the bigger ones. The importance of this variable is to quantify water consumption in devices with storage capacity or in batch processes. When the process is continue is more useful to use volumetric flow rate which accounts the volume of fluid that passes through a specific point per time unit. The units in this case are liters per second (L/s) for small flows or cubic meter per year for bigger quantities (m^3/year).

- Temperature

To understand the term of temperature it is important to define first the Thermal contact and Thermal equilibrium. Thermal contact refers to the situation when two objects can exchange energy when putting together by means of heat transfer or electromagnetic radiation. Thermal equilibrium is the situation in which two objects would not exchange energy by those means if placed in thermal contact, so they have the same quantity of energy. So temperature can be defined as "the property that determines whether an object is in thermal equilibrium with other objects". In other words, temperature indicates the level of energy of an object to determine if it could or could not have an exchange of energy with other objects. Temperature is measured by thermal equilibrium with some dispositive like thermometers, thermocouples and thermal sensors. (Book: Serway & Jewett, 2004)

Temperature is then important for this work because its relevance in the measurement of energy level of water. This energy could change in some devices depending on the user and the application so in those that this happens, temperature is calculated in the inlet and outlet of the process, considering the energy losses and the energy given to water by other means like fuels. Scale of measurement for temperature in this thesis is the Celsius one because it is the more known around the world.

- Pressure

Pressure is defined as "force per unit area". It is more helpful to use pressure rather than force to describe the influences upon a fluid behavior (Book: Himmelblau, Basic Principles and Calculations in Chemical Engineering, 1997). The most important effects that could be measured in a fluid (liquid or gas) by means of pressure are the work made by an equipment like a pump or the work given to a turbine by the fluid, the influence of atmospheric pressure or vacuum in processes of storage and the losses of energy by friction when a fluid, especially liquids are being transported through pipes.

The evaluation of pressure in some of the processes inside a house could help with the measurement of energy linked to the use of water. Not all processes affect changes in pressure, so the evaluation of this variable is only developed in the ones that have a major influence. Unit of measurement pressure for this thesis is Pascal (Pa) that could be expressed also as (kg/ (m·s^2))

- ELECTRICAL CONDUCTIVITY (EC)

This indicator measures the ability of a solution to conduct an electric current. This conductivity is increased when the concentration of ions in that solution is incremented, so this measurement is linked with dissolved solids, especially when those solids are salts. This measurement is important when water is going to be used for irrigation because a high quantity of ions could damage the earth and avoid plants growth (Book: Metcalf & Eddy, Inc., 2003).

2.3.1.2 CHEMICAL VARIABLES

Opposing to physical variables, chemical ones affect the chemical identity of the substance and could only be determined by affecting the internal structure of the substance. Variables shown in this section are designed to help in the measurement of water quality.

- CHEMICAL OXYGEN DEMAND (COD)

This indicator shows the equivalent of oxygen that is needed to oxidize organic matter with some chemical treatment. Usually it is measured with Potassium dichromate in an acid solution.

The importance of this indicator is that some compounds could not be digested by biological means like lignin so they are not taken into account when measuring BOD, but sometimes the reaction of dichromate with other substances could affect the measurement (Book: Metcalf & Eddy, Inc., 2003).

- DISSOLVED OXYGEN (DO)

This parameter indicates the quantity of oxygen that is dissolved in water. Although the maximum quantity of oxygen which could be present in water is small, it is very important for the correct develop of aquatic life. The factors that could affect this quantity of oxygen in water are partial pressure of the atmosphere, temperature, solubility of oxygen in water and concentration of other compounds in water, like salts or other solids.

It is important to maintain certain levels of oxygen in water, not only for preserving water life, but for the effect that oxygen has preventing the formation of noxious odors.

This parameter is also useful for measuring water quality because a large composition of solids or other substances diminish it (Book: Metcalf & Eddy, Inc., 2003).

- POTENTIAL OF HYDROGEN (PH)

This parameter indicates the alkalinity or acidity of a solution. It is defined as the negative logarithm of the Hydrogen-ion concentration as shown in

$$pH = -log_{10} [H^+]$$

The concentrations of that ion in which biological life could exist are limited. The range is between pH 6 and pH 9. It is important to maintain water pH inside those limits for preserving water life and for avoiding problems when consuming it (For water consumptions limits are more restricted, only pH 6 or 7 are allowed) (Book: Metcalf & Eddy, Inc., 2003).

- TOTAL SUSPENDED SOLIDS (TSS)

The measurement of suspended solids indicates the quantity of solid matter that can be retained by filtering a sample of water. This kind of solids causes turbidity and diminishes the solar light penetration into water so water life could be affected and the proliferation of undesirable microorganisms could be carried out (Book: Metcalf & Eddy, Inc., 2003).

- TOTAL DISSOLVED SOLIDS (TDS)

These kinds of solids are the ones that remain in water when it passes a filter with pore size of 2,0 μm. A high quantity of dissolved solids in water could affect humans if this water is drunk. Potable water could contain a limit of 500 mg/L of dissolved solids. For rivers it is estimated a quantity of 120 ppm (Book: Metcalf & Eddy, Inc., 2003).

- TURBIDITY

This measurement is linked with the light transmitting properties of water. It indicates in an indirect way the concentration of colloidal particles and suspended matter. Other measurements which indicate the turbidity of a solution are absorbance and color tests. OMS has defined that water for human consumption will not exceed 5 NTU (Nephelometric Turbidity Units) in the turbidity test.

One important effect of turbidity in water is that it increments water temperature and by this mean reduces the oxygen concentration and avoid the reproduction of some water species. In water bodies, turbidity decreases the quantity of light inside water and with this photosynthetic activity also decrease, propagating dead of algae and plants (Book: Metcalf & Eddy, Inc., 2003).

- NITROGEN CONTENTS

Nitrogen could exist naturally in different states because of the change in the oxidation state as it is shown in Equation 1. Those changes could be produced by some organisms like aerobic and anaerobic bacteria, giving each one a different state to nitrogen, and also could be produced by chemical reactions. Nitrogen is essential to the growth of organisms, because is part of nutrients and proteins.

$$\begin{array}{ccccccccc} -III & -II & -I & 0 & I & II & III & IV & V \\ NH_3 & N_2H_4 & NH_2OH & N_2 & N_2O & NO & N_2O_3 & NO_2 & N_2O_5 \\ NH_4^+ & & & & N_2O_2^{2-} & & NO_2^- & N_2O_4 & NO_3^- \end{array}$$

Equation 1: Oxidation states of Nitrogen (Metcalf & Eddy, Inc., 2003)

Nitrogen could also form different compounds adding one hydrogen ion or one oxygen ion. Taking into account all the forms which could contain nitrogen, the most important are ammonia (NH_3, -III), ammonium (NH_4^+, -III), nitrogen gas (N_2, 0), nitrite ion (NO_2^-, +III) and nitrate ion (NO_3^-, +V) (Book: Metcalf & Eddy, Inc., 2003).

Ammonia is easily biodegradable, and is used like manure and for the production of textiles, plastics, foods and beverages but in a high concentration is harmful for health.

Ammonium is a toxic waste from the metabolism of animals and is toxic for humans in high concentrations. It is used for the production of detergents.

Nitrites and nitrates are very important in the biochemical cycle of nitrogen in nature but in high concentrations in soil could affect pH and avoid the growth of some species. Those compounds are also toxic for human health, causing cancer, and decreasing the quantity of oxygen in blood.(Web site: Lenntech, 2009)

Because of all toxic effects of nitrogen compounds in humans and in the environment, it is vital to measure them and to maintain controlled the levels of concentration in ranges that could help with essential processes of life.

- PHOSPHORUS CONTENTS

Phosphorus is a vital compound for life in view of the fact that DNA, RNA and phospholipids contain it. It is also important for the storage and transport of energy in living cells. Nevertheless there exist a wide variety of organic compounds which contain phosphorus and are extremely toxic. Some of those compounds are used frequently as pesticides or as weapons because of its neurotoxicity. Inorganic compounds containing phosphorus are less toxic and they are the ones which are essential for life but when they are in large quantities in soil, they could promote eutrophication.(Web site: Suarez, 2011)

Measurement of phosphorus in water needs that all phosphorus compounds will be converted in an orthophosphate form which have and oxidation state V. They are PO_4^{3-}, HPO_4^{2-}, $H_3PO_4^{-}$ and H_3PO_4. Other forms of inorganic phosphate are shown in Equation 2.

$$\begin{array}{cccccc} -III & -II & 0 & I & III & V \\ PH_3 & P_2H_4 & P & H_2PO_2^- & P_2O_3 & P_2O_5 \\ PH_4^+ & & P_4 & & HPO_3^{2-} & PO_4^{3-} \end{array}$$

Equation 2: Oxidation states of Phosphorus (Web site: Suarez, 2011)

- ALKALINITY AND SALINITY

Alkalinity is caused principally by the presence of hydroxyl ion (OH^-), carbonates (CO_3^{2-}) and bicarbonates (HCO_3^-) in a solution and in a less proportion by borates (BO_3^{3-}), silicates (SiO_4^{4-}) and phosphates (PO_4^{3-}). The most common compounds present in water are calcium and magnesium bicarbonates.

Salinity is measured principally for irrigation water. It is determined by means of electrical conductivity. The presence of salts affects the growth of plants with osmotic effects (promoting the flow of water inside or outside the plant depending on the case), with toxic ions and with soil particle dispersion (making more difficult the entrance of nutrients inside the roots) (Book: Metcalf & Eddy, Inc., 2003).

Presence in water of compounds that increase alkalinity and salinity is not desirable in processes like laundry, because this kind of water requires more soap or detergents. In some equipment those compounds produce incrustations and generate the decrease of efficiency in heat transference. For drinking purposes, high alkalinity or salinity gives an undesirable flavor to water.

- OILS AND GREASE

These are esters of alcohol or glycerol with fatty acids in liquid (oils) or solid state (greases or fats). These kinds of compounds are located in waste water by industrial processes and also because of domestic wastes for the use of butter, oils and vegetable fats.

When oils and greases stay in water bodies, they could interfere in biological processes due to the fact in which they form unsightly films above water which do not allow the interchange of oxygen and other gases and decrease the quantity of light that could be available at some depths. These compounds are also difficult to degrade by biological means because of its low solubility in water.(Book: Metcalf & Eddy, Inc., 2003)

- SURFACTANTS

Surfactants are compounds that affect the contact surface of two liquid phases, lowering the surface tension. They could be divided in detergents, wetting and foaming agents, dispersants and emulsifiers. They are usually composed by a long organic and hydrophobic chain bounded with a strongly hydrophilic group. There are two types of hydrophobic groups: the anionic and the nonionic ones.

Some of those compounds, especially the alkyl-benzene-sulfonate (ABS), are not biodegradable and form a lot of foam in water, so they are very difficult to extract with simple treatments. Linear-alkyl-sulfonates (LAS) are biodegradable and do not form too much foam (Book: Metcalf & Eddy, Inc., 2003).

Some surfactants are toxic in animals, ecosystems and humans and because of their properties with surface tension; they contribute to the increment of toxic compounds in water (Article: Murphy, Alkhalidi, Crocker, Lee, Oregan, & Acott, 2005).

- METALLIC COMPOUNDS

Some metallic compounds are essential for life development like copper, lead, mercury, iron, cadmium, nickel, zinc and chromium, but the concentration in which they are in water is limited. Most of those components of water are highly pollutant in large concentrations or could interfere with some biological processes but its absence could also generate problems, principally in ecosystems. Therefore controlling metals concentrations in water is of vital importance for the ecosystem and also for human health.

Trace elements needed for biological growth are: arsenic, cadmium, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, mercury, molybdenum, nickel, potassium, selenium, sodium, tungsten, vanadium and zinc. Priority metallic pollutants are arsenic, barium, cadmium, chromium, lead, mercury, selenium and silver. Other toxic compounds found in water are copper, nickel and zinc (Book: Metcalf & Eddy, Inc., 2003)

- OTHER TOXIC COMPOUNDS CONCENTRATION

Toxic compounds are defined as those which could cause adverse effects on living organisms (Book: Metcalf & Eddy, Inc., 2003). Some toxic compounds that sometimes are present in water (excepting the metallic ones) are: phenol and its derivates, pesticides, trihalomethanes (THMs), fluoride, uranium and radioactive compounds. If exists the possibility of having one of those compounds in water, is necessary to measure, control and remove the major quantity of them because of their harmful effects in nature and in human life.

- BIOLOGICAL OXYGEN DEMAND (BOD)

This parameter measures which quantity of dissolved oxygen is needed for microorganisms to oxidize organic matter by biochemical means. If the oxygen present is enough for carry out the oxidation of all organic matter, an aerobic digestion will be done until all compounds are consumed.

This measurement is important for determining the quantity of oxygen needed for consuming wastes in water and with this value is easier to size equipments for water treatment. It is also useful for measuring the efficiency of treatments and to know which quantity of wastes could be allowed in regulations or laws (Book: Metcalf & Eddy, Inc., 2003).

2.3.1.3 Biological Variables

Biological variables in water indicate the presence of microorganisms which could cause some problems when using water for diverse purposes. Main variables are measured for assuring drinking quality and avoid diseases generated by biological contaminated water.

- Coliforms

A Bacterial indicator is very important when measuring water quality. Coliforms bacteria are present in the intestinal tract of humans and because of that they are associated with pathogenic organisms in feces. There are some genera of species included into the coliforms classification. The most important are *Escherichia, Klebsiella, Enterobacter* and *Citrobacter.* It is important to mention that some organisms of the *Escherichia* genera growths in soil, so the determination of total Coliforms is not an absolutely measurement of pathogens content, There are other measurements that shows only the content of fecal Coliforms or *Escherichia Coli* (*E. Coli*) and they are a better indicator of contaminated water (Book: Metcalf & Eddy, Inc., 2003).

2.3.2 Energy Variables

Some thermodynamic concepts are essential for the quantification of energy in any system. They are temperature, pressure, height (z), internal energy (U), enthalpy (H), heat (Q) and work (W). The first two concepts were already explained in water variable section. The others are described following.

- Height (z)

This variable shows the vertical distance between the street floor and the bottom level of a storage water points like tanks. This measurement is important to quantify potential energy which is directly related to height, mass and the gravity constant. Unit used for height is meter (m). When a liquid is stored, a pressure column of liquid acts in the way that the liquid in the bottom of the tank have a major pressure than the liquid at the top, so it is important to take in account this kind of behavior in processes where a storage of liquid happens.

- INTERNAL ENERGY (U)

Internal energy is defined as the sum of all microscopic forms of energy, or energy related with molecular activity. The units of internal energy are Joules [J] (Book: Cengel & Boles, 2006)

- ENTHALPY (H)

This property of substances is associated with a simplification of a frequently used expression shown in Equation 3. This expression is often used for power generation and refrigeration processes (Book: Cengel & Boles, 2006).

$$H = U + PV \quad [J]$$

Equation 3: Thermodynamic expression for total enthalpy

- HEAT (Q)

Heat is a form of energy that is transferred between two systems by means of a difference of temperature. This transference could be done by three mechanisms known as conduction, convection and radiation. Conduction refers to the transference of heat between two adjacent substances of different temperature each one. Convection is carried out when a solid surface and a fluid in motion are involved in the transference (motion of the fluid is promoted by difference of temperature in different parts of the fluid which generate a difference of densities and with that a movement). Finally, radiation is the transference done by electromagnetic means because of the emission of waves or photons. Heat is a directional quantity which means that it requires a magnitude and a direction specification for having a correct meaning. When heat is transferred to a system it is a positive quantity and when heat is transferred from a system is a negative quantity (Book: Cengel & Boles, 2006).

Equation 4 is used for heat transference estimating, in order to have a global notion of heat required or provided for certain processes.

$$Q = m \times C_P \times \partial T \qquad [J]$$

$Q: Heat \ [J]$
$m: Mass \ [kg]$
$C_P: Heat\ Capacity\ at\ constant\ pressure \ [J/kg \cdot K]$
$\partial T: Change\ of\ temperature \quad [°C], [K]$

Equation 4: Heat transference in a system with constant pressure (Book: Smith & Abbot, 1996)

- WORK (W)

Work is a common word for every person, but the definition that is used in our context is the one given by Smith and Van Ness as follows: “Each time that a force acts along a distance, a work is done” (Book: Smith & Abbot, 1996). When talking about fluids, work is associated with the change of volume of those substances or the transferred mechanical energy between the fluid and its surroundings, as the case of processes like compression or expansion. Work is a directional quantity as heat, so work magnitudes require a direction for having a correct meaning, so the sign convention is positive when the work is done by the system and negative if the work is done on a system (Book: Cengel & Boles, 2006).

2.3.3 ENERGY AND WATER BALANCES

A balance equation is a mathematic scheme of accounting any quantity of substances capable of being transported (Book: Smith & Abbot, 1996) like water or energy. Nevertheless accounting quantities not necessarily means to conserve initial values because some part of them could be lost or changed into another substance. So the principal issue to take into account for doing a balance is to develop a general equation to apply it to a specific case.

A key concept to develop a balance equation is the control volume, that is an arbitrary volume in a 3D space where is contained the system to analyze. Volume control surroundings are the local part of universe that interacts with this system (Book: Smith & Abbot, 1996). An example of these concepts in housing is a balance of energy in a house, where the system is the house itself and its surroundings are webs of energy outside the house that gives it electricity, combustibles, heat and every service that provide energy.

Energy measurement and control is important to diminish consumption with arrangements for its correct use and also for avoiding high loses of energy in different forms like heat and friction. The better way to measure and analyze energy is by means of energy balances. An energy balance in a closed system with interaction with its surroundings could be defined as a simple equation:

$$(Energy\ Input - Energy\ output) + (Generated\ Energy - Consumed\ Energy) + (Lost\ Energy - Accumulated\ Energy) = 0$$

Equation 5: General Energy Balance (Book: Himmelblau, Principios Básicos y Cálculos en Ingeniería Química, This equation must be applied to a closed system with defined boundaries so inputs and outputs could easily be recognized. Generated energy is defined as a work that is converted into energy, for example in the functioning of wind turbines movement is converted into electric energy, so that energy is generated. Consumed energy is defined as energy that is consumed and converted into work, for example in the use of an electric motor; electric energy is converted into the rotor movement. Lost energy is the energy that is dissipated to the surroundings and is not possible to recover it, for example the heat that goes out of a house. Accumulated energy is the energy that is stored for a long period of time; this is the case of batteries, which storage energy until they are used.

$$\Delta\left\{\left[H + (g \cdot z) + \left(\frac{v^2}{2}\right)\right] \cdot \dot{m}\right\} = \dot{Q} + \dot{W} \qquad \left[\frac{J}{s}\right]$$

$H: Enthalphy \quad [J/kg]$
$g: Gravity\ velocity \quad [m/s^2]$
$z: Height \quad [m]$
$v: Flow\ velocity \quad [m/s^2]$
$\dot{m}: Mass\ flow \quad [kg/s]$
$\dot{Q}: Heat\ flow \quad [J/s]$
$\dot{W}: Work\ per\ time\ (power)\ [J/s]$

Equation 6: Energy Balance based on first law of thermodynamics (Book: Perry & Green, 1999)

Energy consumption is one of the key points of this work and it is used to calculate energy balances in each process and also the global energy balance of the house. To do such calculation it is possible to use Equation 6 or Equation 7, depending on the type of data obtained in the house and the type of analysis that is carried out. For Equation 6, first term refers to water change of enthalpy which is function of temperature and pressure; the second one is the change of potential energy, depending on height and gravity; third term shows change of kinetic energy, given by velocity of the fluid. Those terms are multiplied by mass flow to give to the equation a notion of time. The other part of the equation shows the heat flow and the work per time given to water from external sources. With Equation 8 it is possible to analyze energy consumption in time, so it is useful for global balances.

$$\Delta\left\{U + \left(\frac{P}{\rho}\right) + (g \cdot z) + \left(\frac{v^2}{2}\right)\right\} = Q - W_s \qquad \left[\frac{J}{kg}\right]$$

$U: Internal\ Energy \quad [J/kg]$
$P: Pressure \quad [Pa]$
$\rho: Density \quad [kg/m^3]$
$g: Gravity\ velocity \quad [m/s^2]$
$z: High \quad [m]$
$v: Flow\ velocity \quad [m/s^2]$
$Q: Specific\ Heat \quad [J/kg]$
$W: Specific\ Work \quad [J/kg]$

Equation 7: Energy Balance per mass of fluid based on first law of thermodynamics (Book: Levenspiel, 1993)

Equation 7 is better for using in batch processes, where continuity is not carried out and time notion is not so important, so energy is expressed in terms of mass, in this case of kilograms of water. For this equation, first term refers to the change of internal energy of the fluid, the second one to the change of pressure. These two terms could be replaced by the enthalpy change divided by the mass of fluid if necessary. The change in potential and kinetic energy are expressed in the same way as Equation 6. Second side of Equation 7 shows the heat and work given to the water from external sources.

It is important to differentiate when the quantities are given in terms of time or mass to manage them adequately.

In the same way of energy, mass flows could be measured and controlled by a balance equation as follows:

$$(Mass\ Input - Mass\ output)\ - Consumed\ Mass + \\ (Lost\ Mass - Accumulated\ Mass) = 0$$

Equation 8: General Mass Balance (Book: Himmelblau, Principios Básicos y Cálculos en Ingeniería Química, 1997)

The only difference between mass and energy balances is that mass could not be generated. All other terms have the same meaning in both equations.

Water balance could be done as a mass balance, looking for the inlet and outlet flows of the system, but also could be seen as a energetic balance looking at the energy content of those flows (as temperature for example).

Some variables that must be considered to arrange both balance (energy and mass ones) into a house are the input and output conditions and all the conditions of mass and energy in each process inside the house: heating, pumping and disinfecting water, laundry, etc. Those conditions are basically temperature, quantities and height levels.

When talking about a fluid, another type of balance equation could be done with the aim of indicate how is the flow inside a tube. This kind of balance is given by Bernoulli's theorem, shown in Equation 9. This equation shows two points of measurement 1 and 2, where total energy of the fluid is given by its height, pressure and velocity. Energy loses by friction are also included in the last term of the equation.

$$Z_1 + \frac{P_1}{\rho_1 g} + \frac{v_1^2}{2g} = Z_2 + \frac{P_2}{\rho_2 g} + \frac{v_2^2}{2g} + h_L$$

$Z = Height\ [m]$
$P = Pressure\ [Pa]$
$\rho = Density\ [kg/m^3]$
$v = Velocity\ [m/s]$
$g = Aceleration\ of\ gravity\ [m/s^2]$
$h_L = Loses\ due\ to\ flow\ [m]$

Equation 9: Bernoulli's Theorem (Book: Crane, 1987)

Equation 9 could be transformed for different purposed. One of these transformations is useful for join energy requirements into Bernoulli's theorem. This could be done by multiplying all terms in the equation by gravity constant (g) and adding work requirements per mass in the left side of the equation. Resultant expression is shown in Equation 10.

$$Z_1 g + \frac{P_1}{\rho_1} + \frac{v_1^2}{2} + \frac{W}{m} = Z_2 g + \frac{P_2}{\rho_2} + \frac{v_2^2}{2} + h_L g$$

$Z = Height\ [m]$
$g = Aceleration\ of\ gravity\ [m/s^2]$
$P = Pressure\ [Pa]$
$\rho = Density\ [kg/m^3]$
$v = Velocity\ [m/s]$
$h_L = Loses\ due\ to\ flow\ [m]$
$W = Work\ give\ to\ the\ fluid\ [J]$
$m = Mass\ \ [kg]$

Equation 10: Transformed Bernoulli equation for accounting work needs

When a fluid flows into a pipe, there is always friction between particles of the fluid and interior walls of the pipe and also with accessories like valves and joints. This friction generates loses of energy, which is reflected in a loss of pressure. These losses are sometimes difficult to calculate because in most of the cases a lot of measurements must be done and also many specifications of pipes and accessories must be known. Because of this fact, some authors have developed simplified equations to account this quantity. Those equations are often related only with loses in pipes because losses in accessories could be negligible. Nevertheless for detailed calculations is recommended to take all possible losses into account (Book: Crane, 1987).

One of the most important equations for estimate loses by flow in pipes was developed by Henry Darcy and is shown in Equation 11.

$$h_L = f \times \frac{L}{D} \times \frac{v^2}{2g}$$

$h_L = Losses\ due\ to\ flow\ [m]$
$f = Friction\ factor$
$L = Lenght\ of\ pipe\ [m]$
$D = Internal\ diameter\ of\ pipe\ [m]$
$v = Velocity\ [m/s]$
$g = Aceleration\ of\ gravity\ [m/s^2]$

Equation 11:Darcy´s general equation for pressure loses in pipes (Book: Crane, 1987)

Friction factor has to be determined rigorously by experimental data. Nevertheless there exist some equations in order to estimate the value of this factor. Those equations are related with Reynolds Number (Re) which is a dimensionless number that allows predicting the type of flow of a fluid. Equation 12 shows how this number could be calculated.

$$Re = \frac{\rho \times D \times v}{\mu}$$

$Re = Reynolds\ number$
$\rho = Density\ [kg/m^3]$
$D = Internal\ diameter\ of\ pipe\ [m]$
$v = Velocity\ [m/s]$
$\mu = Viscosity\ [kg/m \cdot s]$

Equation 12: Reynolds number (Book: Perry & Green, 1999)

Going on with friction factor, there are two main equations for calculate it. First is the Hagen-Poiseuille equation for laminar flows which means a Reynolds number below or equal to 2100

$$f = \frac{16}{Re} \qquad Re \leq 2100$$

$f = Friction\ factor$
$Re = Reynolds\ number$

Equation 13: Hagen-Poiseuille equation for friction factor in laminar flow (Book: Perry & Green, 1999)

The second equation was developed by Blasius, and is designed for turbulent flows between a Reynolds number of 4000 and 10^5. This expression is shown in Equation 14.

$$f = \frac{0{,}079}{Re^{0{,}25}} \qquad 4000 < Re < 10^5$$

$f = Friction\ factor$
$Re = Reynolds\ number$

Equation 14: Blasius equation for friction factor in turbulent flow (Book: Perry & Green, 1999)

So after knowing Reynolds number, friction factor could be calculated and then loses due to flow could be estimated using the equation of Darcy. Another option for this estimation is the equation of Veronesse-Datei which was designed for PVC pipes and turbulent flow with a Reynolds number between 40000 and 10^6.

$$h_L = 9{,}2 \times 10^4 \times \left(\frac{Q^{1,8}}{D^{4,8}}\right) \times L$$

$h_L = Losses\ due\ to\ flow\ [m]$
$Q = Caudal\ [m^3/s]$
$D = Internal\ diameter\ of\ pipe\ [m]$
$L = Length[m]$

Equation 15: Veronesse-Datei equation for losses due to flow in turbulent flow (Web site: Miliarium Aureum, 2004)

2.4 Decision making process

There are some tools which could be used for evaluating correctly balances and for defining how variables could be organized in order to analyze whether a process is or is not sustainable.

A possible way is by creating indicators and indexes which evaluate some important characteristics of a system and decide how is the behavior of that system among others, giving a proportional scale in order to be more understandable. Nevertheless when an index is created, stakeholders in the systems are the ones who could act and decide if the results given by indexes or indicators are going to be borne in mind.

An explanation of how indicators and indexes work is made in the following section, as well as a description of the stakeholders who possibly be influenced by developing of this work.

2.4.1 Indicators and Indexes

Data are the basis for the construction of Indexes. Some data have no meaning for the work, so is important to filter them and use only the relevant ones. It is also important to take into account data availability, quality and collection. With data selected, indicators could be derived. Indicators are defined as the most basic tools for analyzing changes in a studied state, so they could serve as assessment tools to understand trends. They are also easier to be interpreted than other analysis tools as statistics ones, thus they help with the communication between different levels of stakeholders making it easier (Book: Senegstam, 2002).

When two or more indicators are combined, they form an index, which is used as an aggregated tool for analysis of complex phenomena which is hard to understand using individual indicators. However, indices could be so difficult to create when aggregating different kind of data or indicators (Book: Senegstam, 2002).

Some companies have developed indexes for sustainability in different fields. With regard to households sustainability some of the most used systems are LEED, BREEAM and SHIFT. Table 1 show a resume with the indicators which are managed by these three sustainable indexes. As it could be seen, no one covers all general topics and inside those general topics not all variables are taken into account.

INDICATOR	LEED	BREEAM	SHIFT
Innovation and Design Processes	X		
Location & Linkages	X		
Sustainable Sites	X		
Water	X	X	X
Energy	X	X	
Materials	X	X	X
Indoor Environmental Quality	X		
Awareness & Education	X		
Resources	X		
Wastes		X	
CO2		X	X
Pollution		X	X
Health & Well-being		X	X
Management		X	
Ecology		X	X

Table 1: Topics taken into account in different household sustainable indicators (Report: U.S. Green Building Council, 2008), (Report: Department for Communities and Local Government, 2010), (Report: Wain, 2003).

Water indicators included in LEED are more complete than in the other indices. It takes into account rainwater collection, efficiency of irrigation systems and reduction of indoor consumption while BREEAM only takes into account indoor and outdoor consumption and SHIFT accounts the reduction of water consumption. These three examples also give low weights for water indicators when giving a total index value. These weights are 11%, 9% and 8,6% respectively (Report: U.S. Green Building Council, 2008), (Report: Department for Communities and Local Government, 2010), (Report: Wain, 2003).

Energy indicators are more complete than water ones, including efficiency of equipments and distribution systems, use of renewable energies; reduction on lighting, appliances, heating and cooling consumption; correct materials for insulation an windows, reduction of CO_2 emissions, use of low energy external lighting systems, use of appropriate spaces for clothes drying, use of labeled appliances, use of low or zero carbon technologies among others. Energy is also the indicator which have the higher weight in the three analyzed systems, with 27,9%, 36,4% and 31,4% respectively (SHIFT energy indicator is made with CO_2 emissions, so the percentage of energy is the one of the CO_2 indicator)(Report: U.S. Green Building Council, 2008), (Report: Department for Communities and Local Government, 2010),(Report: Wain, 2003).

2.4.2 Stakeholders in the decision making process

Principal stakeholders for sustainable projects at housing levels are the users or the people that live in households because they need to know the better way to use resources and to manage a household in a sustainable way, and also the alternatives and opportunities to have a better performance of the house.

There are also other stakeholders that could be involved in the sustainability of a house and in the management of resources that are used inside those buildings. Architects, designers and engineers are essential for the construction of the household and it is very important that they understand all the concepts involved in sustainability and the role that they play in society, economy and environment to develop those concepts in a real sustainable way.

Another group of stakeholders that play an important but indirect role in sustainability of houses are governmental institutions and organization that promote the use of that type of household. They are also important because they develop the norms and regulation that are taken into account for the construction of buildings and also regulations for the use of resources.

All stakeholders could be influenced with the development of this work, because understanding all the processes that involve water and energy related with water consumption is a way to develop sustainable projects with a different point of view and to include not only energy, but water consumption with most of the variables linked with this topic.

2.5 Conceptual Approach

After reviewing the principal concepts and actors for this work, is necessary to link them into the problematic described before. Figure 6 shows a scheme which describes those links between concepts, problems and possible solutions.

In the first place, growth of urban population states as a social problematic generated which leads to some difficulties in environmental topics. One of those difficulties is the scarcity of resources in urban settlements and the need to provide large quantities of water and energy to those zones, generating the construction of dams and electric centrals near to cities.

With a larger number of dams, supply of water is easier and demand increases, achieving higher water consumptions. Something similar happens with energy, special with electricity when big networks are built to provide an urban settlement.

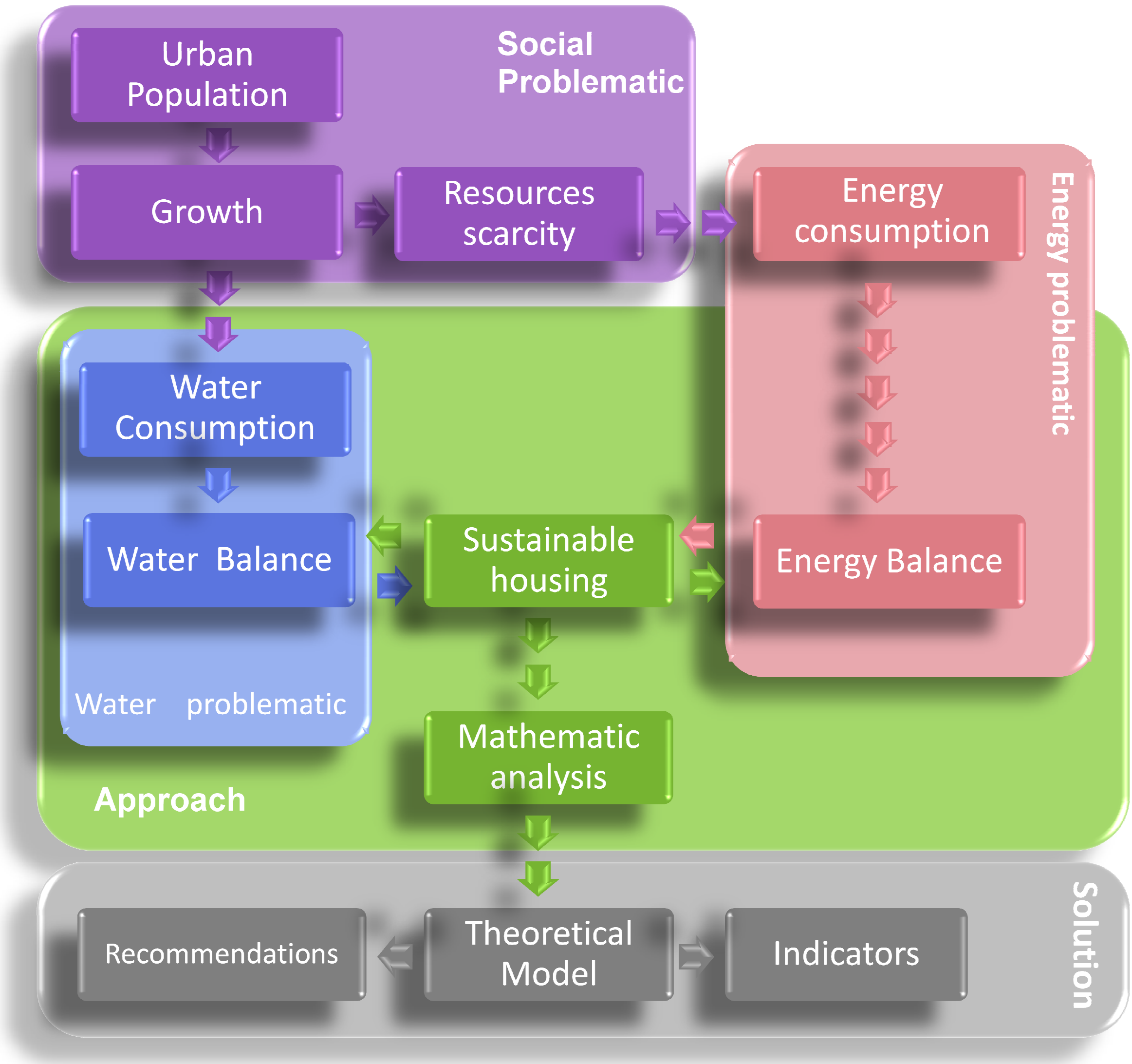


Figure 6: Conceptual Framework

Society has developed the concept of sustainability, with the aim of trying to measure consumption of resources and to diminish it, in order to provide people with these resources for many years and to have equilibrium with the ecosystem.

The sustainability concept has been applied to different spheres and housing is one of them, but the trends of projects carried out in this topic tend to focus on energy requirements and ways to reduce energy consumption and to increase efficiency of appliances in households among others, but use of resources, specially water was not studied with the same insistence as energy. This fact leads to a gap between water and energy which could be solved using both, water and energy balances and integrating them into a single mathematical model with the aim of include water consumption inside sustainable housing solutions. From that, some more comprehensive indicators could be developed as tools for understanding how the mathematic model works. Thus stakeholders could use it, learn and create awareness about potentials to reduce consumption, and improve the behavior of tenants regarding their water consumption and energy consumption related with it.

The purpose of this work is to develop the model and the proper indicators in order to link energy and water consumption in a sustainable concept. Following chapters illustrate how the model is built and which considerations must be taken into account when doing a theoretical model of the reality.

3 METHODOLOGY

A short description of methodology used in this work is shown in Figure 7.

- The first step defined a model of a single-detached household and includes secondary data about water uses, types of technologies and energy consumed for water usage. Then all the information was categorized into small systems or processes.

- The second step was to select and analyze the variables with more relevancies in consumption, followed by the analysis of energy consumption for theses uses of water inside the household. Finally, these small systems were integrated with the others in order to define connections and relationships between them.

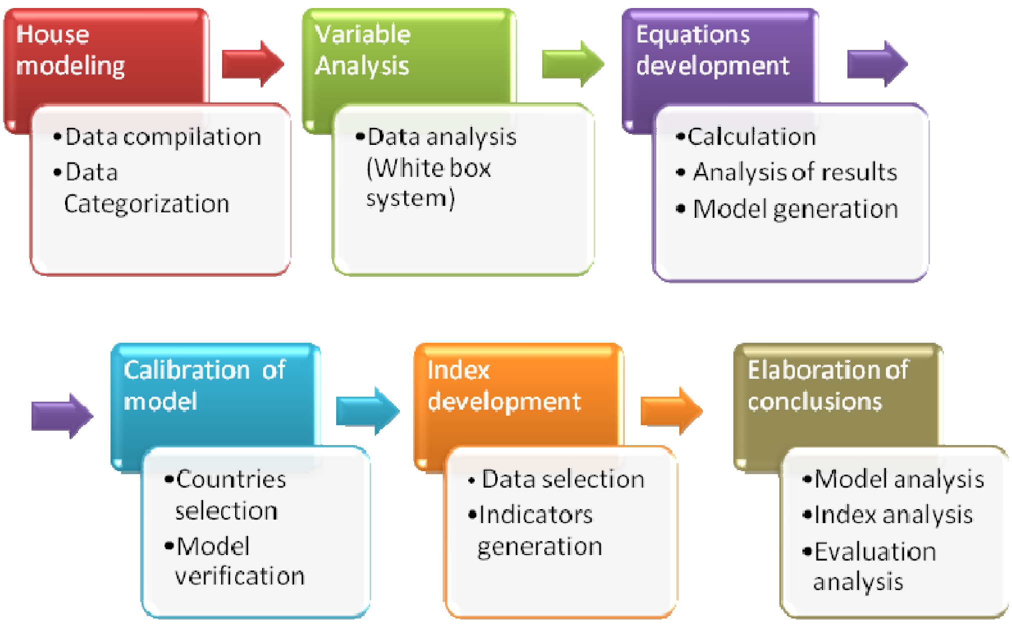


Figure 7: Methodology Flowchart

- The third stage was to develop equations in which analyzed variables could be related. This aimed at having a better understanding of how all systems work and how could they be managed for having a sustainable development. At this point the model was considered completed but still left the possibility of make some changes considering the next steps.

- After the analysis and the elaboration, a validation of the model was needed, so the next step was to calibrate it with data from different places or countries. This calibration was done to evaluate if the data provided by the model fit the real behavior of people at different locations and to help with the final analysis and to develop of the indicators.

- Finally, an index and some indicators were defined in order to allow a better communication and understanding of the model. Some recommendations and further analysis were elaborated.

3.1 Data needs

For the development of the model and the indicators there are some data requirements. Some of them are water consumption per capita and per day in some different places, type of water uses in households, energy and water consumption of some appliances, availability of different sources of water, water requirement per capita and per day for basic needs and for other needs, types of water treatment for water reuse at households and volume of water need for each appliance.

3.2 Data sources

Primary data are the one collected by the investigator in order to use them to develop his own work. In the case of this Master thesis there will be no primary data because experiments are not considered as part of the study.

Secondary data refers to information took from external authors of articles, books and other sources. For this work, main information like data of water and energy consumption are going to be taken from government institutions, other information is going to be taken from suppliers of services and equipments.

Sources of investigation will be principally documental, based on real architectures. Different types of technologies for using and treating water and are also going to be taken into account, looking for literature and for the actual market on those topics.

3.3 Modeling

When a model is developed, some criteria must be present in order to achieve a good result. Scientific models would achieve some main characteristics which have a different importance according to the topic in which the model is involved. Some of those characteristics are that the model gives a simplified representation of the reality, that this representation is made for the concepts that are consider essential to the reality; the model have to be testable and conceptual and must allow the possibility of measurements or calculations and also allow the explanation of the reality. Models must also be a fictive representation of the reality and the systems that make up that reality and they must be isomorphic to the systems represented (Article: Franck, 2002)

Some other specific characteristics for doing a model about sustainability are that it must involve the three basic spheres of sustainability: Environment, society and Economy in a way that each one of them interacts with the others finding an equilibrium point.

4 MODEL DEVELOPMENT

Develop a method for accounting water and energy in a single equation is the first step to achieve a real sustainable view. For this develop there are some key actions to take into account: understand the problem with all its variables, define the volume of control and its boundaries and define the restrictions and also the assumptions for the model.

4.1 CALCULATION METHOD

The principal method used in this study was the white box system analysis. This method consists on analyze a volume of control or universe of study that must have defined boundaries, and inputs and outputs between the surroundings and the universe itself. In this kind of analysis universe can be observed in its interior, so processes or systems working inside it and connections between them are visible for the observer in order to be studied and analyzed(Report: Niu, Cai, & Simon, 2010). A scheme of this type of system is shown in Figure 8.

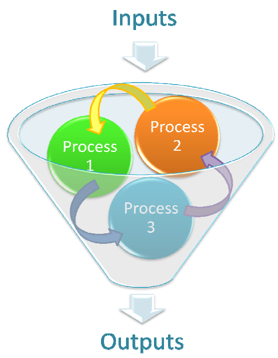


Figure 8: Scheme of the White Box System

The first decision for beginning with the calculation and the development of the model is to define the boundaries of the universe that is going to be studied. In this study boundaries were defined as the physical boundaries of a single-detached house, this means walls, roofs, and floors and in some cases the outside fences which borders gardens or green spaces.

Having a defined universe of study, inside processes must be selected to make water and energy balances in each one of them according to the type of process. Variables like pressure, temperature, volume or caudal, heights, quality of water and energy consumption are analyzed in this step.

With all specific balances, a general one must be done and all variables should be joined and analyzed. Afterwards, some indicators and graphics are done in order to explain the model for the later analysis.

4.2 Model Description

The mathematic model shows the relationship between the environment outside a single-detached dwelling and the processes inside it. Those processes are the ones that include water consumption. Some of them also include energy consumption and in those cases both consumptions are taken into account. A simple scheme for the white box system of a single detached dwelling is shown in Figure 9.

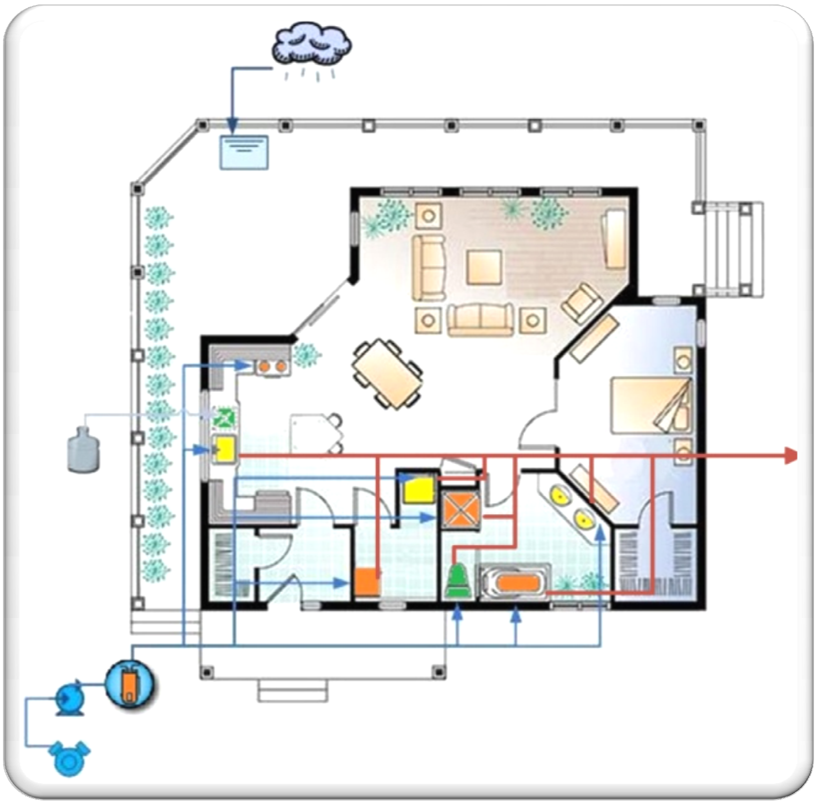


Figure 9: Household system with water flows inside and from and to the surroundings. Appliances with orange color possibly use energy for warm water, the yellow ones could function with cold water, so their energy need is less (Own adaptation from (Web site: Un blog Verde, 2010)).

There is important to define how energy consumption and water quality are evaluated and calculated. A description of those methodologies is given in the following section.

Processes inside the household were grouped in six categories: inputs, water management, bathroom, kitchen, other uses and outputs. Each category and process is explained also in the following section as well as variable and equations for each one.

4.2.1 ENERGY CONSUMPTION

Consumption of energy in a household is linked with some activities like cooking, heating water, warming or cooling the environment, lighting, using electronic devices, pumping water and so on. For the purpose of this work, only energy consumption that is directly related with water consumption is taken into account, nevertheless in some parts of the work there are comments of other energy applications, but they are not included in the objective of study.

Different sources of energy could be used for the application inside a house. The use of primary energy is given by gases (methane, propane, butane and natural gas), coal, biomass, oil and solar energy principally. Those primary resources are converted into heat, noise, light or electricity. The principal secondary energy used at households is electricity which is converted into light, information, heat and sound to develop different activities. All those kinds of energy could be measured and expressed in different units depending on the type but all could be expressed in Joules (J) or kilowatts hour (kWh) using some conversions, so in this thesis the unit for energy consumption is that.

4.2.2 QUALITY OF WATER

One of the most important issues when talking about water resources is quality. It is essential to know the characteristics of the water with the aim of knowing which applications could be done with each kind of water. Sometimes water could be reused or treated in different ways and the decisions which determine what to do depend greatly on water characteristics.

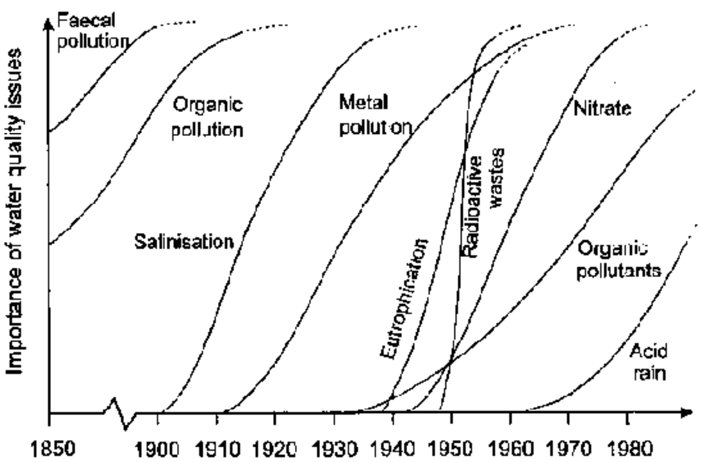


Figure 10: Sequence of Water Quality issues arising in industrialized countries (Book: UNESCO/WHO/UNEP, 1996)

Since more than a hundred years many studies were done in order to find which characteristics of water are the most important to measure quality. First investigations were focused on organic contamination and the presence of microorganisms which could be a risk for population health, especially fecal coliforms. In the first part of 20th century, salty and metallic compounds were found important to quantify due to the discovering of dangerous consequences when drinking high concentrations of certain elements and also because of the damage that them could make to environment. After that, other aspects were taken into account like radioactivity, Nitrogen and Phosphorus content, the effect of acid rain and the damage to water species in different ecosystems. This evolution is shown in Figure 10.

After all those years of investigations, some measurements were done, but only some of them were widely used because they showed water characteristics that were common for different sources or that showed a behavior of some classes of important compounds. In some other cases, a key issue was the toxicity of certain compounds which were prejudicial for health in some concentrations, so they were imperative to be measured.

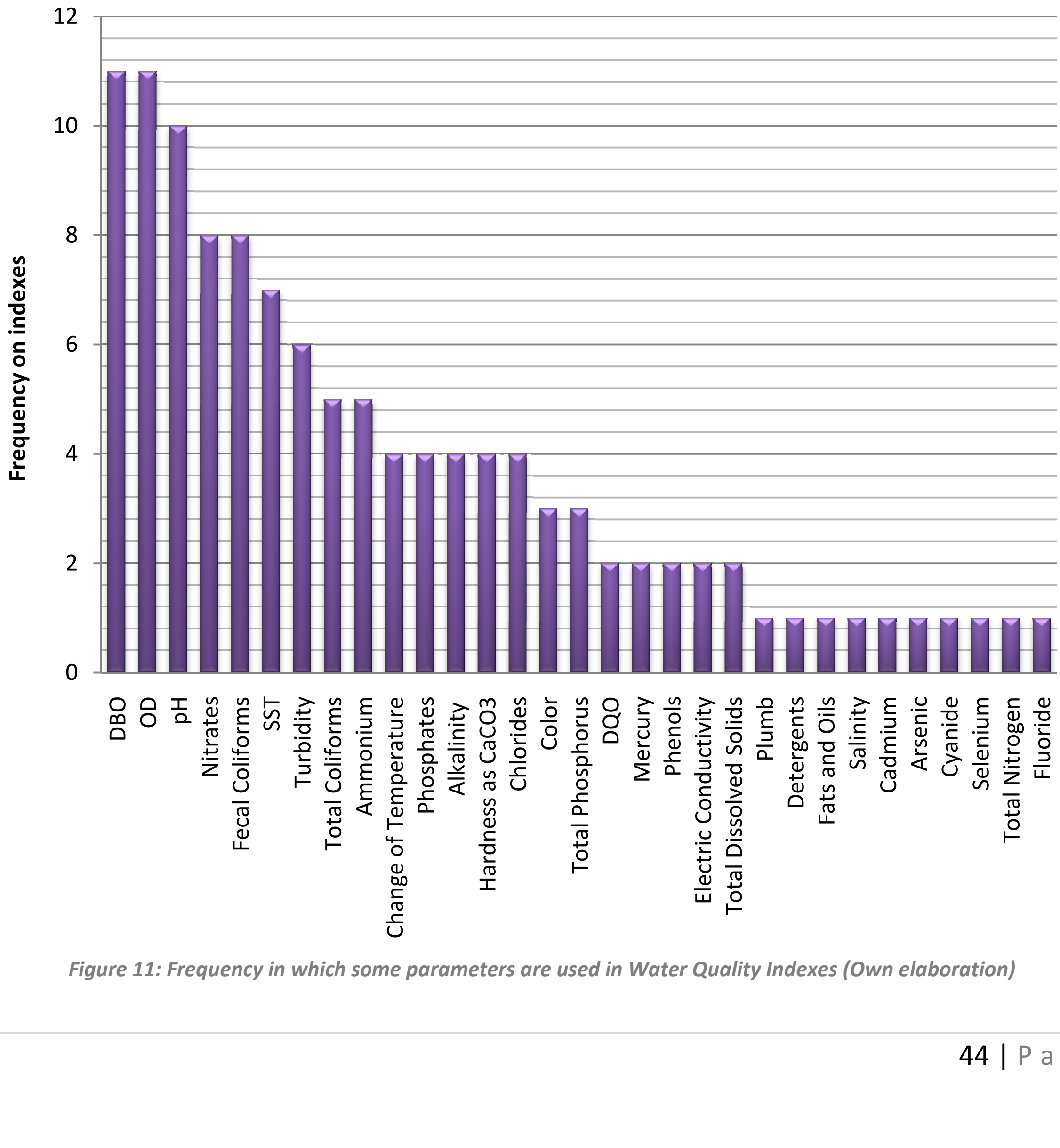


Figure 11: Frequency in which some parameters are used in Water Quality Indexes (Own elaboration)

With the compiled information about different characteristics of water, some authors began to evaluate the importance of each variable of quality to assign them a weight into a quality index with the aim of defining only one value and make easier the management of information, the categorization of water and the understanding of time evolution of some water bodies. Each quality index measures different variables depending on the specific source of evaluated water, but some measurements are present in all indexes as the Oxygen Demand.

For the evaluation of water quality in this work, eleven quality indices were studied: The Water Quality Index (WQI) of the National Sanitation Foundation (NSF) of the United States of America(Book: Ramirez, 1999, pp. 117-142), the Water Quality Index for the Des Moines River (DMR) in Iowa(Book: Ramirez, 1999, pp. 117-142), the Water Quality Index of Montoya developed in Mexico(Book: Ramirez, 1999, pp. 40-116), the Index of Quality for recreational Cuban coastal water(Article: Miravet, Ramirez, Montalvo, & Delgado, 2009), the Water Quality Index (ICA) of the Mexican National Water Commission(Report: Comisión Nacional del Agua, 1999), the Water Quality Index WQI Dinius developed in the United States of America(Article: Torres, Cruz, & Patiño, 2009), the Water Quality Index of the European Union (UWQI) (Article: Torres, Cruz, & Patiño, 2009), the Water Quality Index for the Cauca River in Colombia (ICA Rojas) (Article: Torres, Cruz, & Patiño, 2009), the Water Quality Index of the University of the Valley for the Cauca River (ICAUCA) (Article: Torres, Cruz, & Patiño, 2009), the Index of Water Quality for Bogota (ICAGUA) (Web site: Secretaria Distrital de Ambiente, 2010) and the Water Quality Index for the Lerma-Chapala Basin (ICA) in Mexico (Article: León, 2003).

Parameters shown in those indexes are DBO, OD, pH, Nitrates, Fecal and Total Coliforms, SST, Turbidity, Ammonium, Change of temperature, Phosphates, Alkalinity, Hardness, Chlorides, Color, Total Phosphorus, DQO, Electric conductivity, TDS, Detergents, Fats and Oils, Salinity, Total nitrogen and content of some toxic elements and compounds like Cadmium, Plumb, Mercury, Arsenic, Phenols, Cyanide and Fluoride. The frequency in which they are used in the indexes is exposed in Figure 11 and the percentage of those parameters in each one of the investigated indexes is sketched in Annex 9.1 .

The parameters that showed more importance depending on the frequency in which they were used in water quality indexes are OD, DBO, pH, nitrate content, TSS, Turbidity and Total Coliforms.

From those listed before, only five are going to be of importance for this work: DO, BOD, pH, total coliforms and TSS. Nitrate content is not so useful because usual processes carried out in a dwelling do not affect this variable; it is more important when talking about agriculture or industrial processes.

Calculation of water quality needs three steps: First to measure the indicator and give a value in the standard units of measurement of each one. After having those values, a conversion must be done to have all the parameters in the same scale. Finally the converted values are going to be used as shows Equation 16.

$$WQI = \sum_{i=1}^{n} q_i w_i$$

WQI: $Water\ Quality\ Index$
n: $Number\ of\ Parameters$
q_i: $Quality\ scaled\ value\ for\ the\ i\ Parameter$
w_i: $Weight\ of\ the\ i\ Parameter$

Equation 16: General expression for a water quality index, using a weighted arithmetic mean (Book: Ramirez, 1999, pp. 27-35)

The conversion step is carried out by means of mathematical functions based on the investigations studied. Expressions for each parameter are shown in Equation 17, Equation 18, Equation 19, Equation 20 and Equation 21. Graphics representing those functions are located in Annex 9.2.

$$OD_{SV} = (-1{,}33 \times 10^{-4}\ OD^3) + (2{,}11 \times 10^{-2}\ OD^2) + (1{,}90 \times 10^{-1}\ OD) + (2{,}12 \times 10^{-1})$$

OD_{SV}: $Scaled\ Value\ for\ OD$
OD: $Measured\ OD\ value\ [\%\ of\ Saturation]$

Equation 17: Scaling function for Oxygen Demand

$$BOD_{SV} = (-1{,}667 \times 10^{-7}\ BOD^5) + (4{,}805 \times 10^{-5}\ BOD^4) - (5{,}184 \times 10^{-3}\ BOD^3) + (2{,}624 \times 10^{-1}\ BOD^2) - (6{,}773 \times 10^{0}\ BOD) + 9{,}917 \times 10^1$$

BOD_{SV}: $Scaled\ Value\ for\ BOD$
BOD: $Measured\ BOD\ value\ [mg/L]$

Equation 18: Scaling function for Biological Oxygen Demand

$$FC_{SV} = 100 \times FC^{-0{,}32}$$

FC_{SV}: $Scaled\ Value\ for\ Fecal\ Coliforms$
FC: $Measured\ Fecal\ Coliform\ value\ [Colonies/100\ mL]$

Equation 19: Scaling function for Fecal Coliforms

$$pH_{SV} = \left\{\left[\frac{1}{2{,}087 \times (2\pi)^{1/2}}\right] \times \left(e^{-1/2}\right) \times \left[\frac{(pH - 7)}{2{,}087^2}\right] \times \left[\frac{10}{1{,}91151}\right]\right\} \times 100$$

pH_{SV}: $Scaled\ Value\ for\ pH$
pH: $Measured\ pH\ value\ [pH\ Units]$

Equation 20: Scaling function for pH

$$TSS_{SV} = [(-5{,}26 \times 10^{-4}\ TSS) + 1{,}056] \times 100$$

TSS_{SV}: $Scaled\ Value\ for\ TSS$
TSS: $Measured\ TSS\ value\ [mg/L]$

Equation 21: Scaling function for Total Suspended Solids

The weights proposed for each of those variables were calculated by statistic means, taking into account the weights proposed by expertise in the studied investigations about water quality. The weights obtained and their respective standard deviations with parameters encountered in those researches are listed in Table 2.

PARAMETER	MEASUREMENT UNITS	AVERAGE WEIGHT (%)	STANDARD DEVIATION
DO	% Saturation	31,63	0,0996
BOD	mg/L	25,54	0,0639
Fecal Coliforms	Colonies /100 mL	21,12	0,1394
pH	pH units	14,05	0,0685
TSS	mg/L	7,66	0,0923

Table 2: Parameters and weights used for water quality index

4.2.3 Inputs

Inputs refer to water incomes to the house. They could be tap water, bottled water or provided from water bodies or from a rainwater collection system.

- Tap Water

This is the principal kind of supplied water in urban settlements. Tap water goes into houses by means of pipeline systems from reservoirs or treatment plants constructed for providing determinate zone.

Sometimes, tap water has a high quality which is enough for drinking or cooking, but there are also other cases in which it could contain contaminants like metals and chemical compounds in higher concentrations as the ones allowed by laws.

It is important to know the quality of inlet tap water in a house, in order to define which applications could be done with this water, without affecting health of people living there.

Measuring inlet tap water is easy when there is a water counter in the entrance of the house. For this work water is going to be measured by consumption in each inside process of house, this means that possible losses due to leakages or similar escapes are not taking into account.

- WATER BODIES AND AQUIFERS

Water bodies are large extensions of superficial water. The term could include either stationary of moving water sources. Aquifers are deposits of groundwater in a bed of impermeable rocks or sediment which could be extracted for different purposes.

Water from theses sources is considered as an inlet to the house when people go by themselves to sites where contains water and carry it to their houses, or when in the house exist a way to take water directly from the source, for example from streams or small wells. Water of those sources is used in most of the cases without treatment and could cause diseases to population if its use is not regulated.

These sources are more common in rural areas or in small communities so they are not taken into account in this work.

- BOTTLED WATER

Sometimes is necessary to bring bottled water to houses for personal consumption and for cooking because tap water does not fit quality for these purposes. It is an important source for taking into account when used.

- RAINWATER

Rainwater harvesting is a possible option for single-detached dwellings. Nevertheless there are two main limitations when thinking about harvest rainwater. First to have enough area for collection, this could be made easily on roofs. Second, to have space for storage collected water. There are also other limitations for the correct use of this kind of water like energetic and technologic requirements for pumping collected water inside the house for the planned uses and sometimes is also need to treat water after use. For knowing the quantity of water that could be harvest, Equation 22 is the appropriate.

$$W_c = \frac{Pp \times C_r \times A_c}{1000} \qquad [m^3]$$

$W_c: Collected\ water\ [m^3]$
$Pp: Total\ annual\ precipitation\ [mm]$
$C_r: Run - off\ coefficient$
$A_c: Collection\ area\ [m]$

Equation 22: Maximum collected water for a rainwater harvesting system

Run-off coefficient is used to indicate the quantity of water that cannot be collected by the porosity of the material in the collection area. Some coefficients are listed in Table 3.

MATERIAL OF COLLECTION AREA	RUN-OFF COEFFICIENT
Metallic Roof	0,9
Wooden Roof	0,9
Clay Tiles	0,8
Straw Roof	0,6

Table 3: Run-off coefficients for different materials for rainwater collection area (Report: Unidad de Apoyo Técnico en Saneamiento Básico Rural (UNATSABAR), 2001)

When a rainwater harvesting system is installed, some calculations of energy must be done in order to include this value into the global balance. Principal quantification is about pumping needs. For this purpose Equation 10 is used but it must be arranged for the conditions of this process.

VARIABLE	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6
Diameter (m)	0,15	0,15	0,15	0,23	0,23	0,23
Velocity (m/s)	0,00691	0,01381	0,02072	0,00307	0,00614	0,00921
Caudal (m^3/s)	1,26E-04	2,52E-04	3,78E-04	1,26E-04	2,52E-04	3,78E-04
Density (kg/m^3)	1000	1000	1000	1000	1000	1000
Viscosity (kg/m s)	0,001	0,001	0,001	0,001	0,001	0,001
Reynolds number	1052,7	2105,4	3158,0	701,8	1403,6	2105,4
Friction factor	0,0139	0,0117	0,0105	0,0153	0,0129	0,0117
h_L (m) Darcy	1,11E-06	3,73E-06	7,57E-06	1,61E-07	5,43E-07	1,10E-06
h_L (m) Veronesse	3,67E-06	1,28E-05	2,65E-05	5,25E-07	1,83E-06	3,79E-06

Table 4: Cases of study for calculating losses due to flow

First, it is assumed that two storage tanks are used, one at street level for collection and another one in the roof for distribution and both tanks are not pressurized, so atmospheric pressure is the one of each tank. Second assumption is that water in both tanks is stagnant so velocity is zero in the two cases.

Third assumption is that losses due to flow are negligible, this could be supposed after making some calculations and analyze the proportion between other terms of the equation and h_L. Table 4 shows six cases of study for supporting this assumption. Cases 1, 2 and 3 are calculated with a pipe diameter of ½" (0,15m) and cases 4, 5 and 6 with a pipe diameter of ¾" (0,23m). Cases 1 and 4 have a caudal of 2 gpm (1,26 E-4 m^3/s), cases 2 and 5 of 4 gpm (2,52 E-4 m^3/s) and cases 3 and 6 of 6 gpm (3,78 E-4 m^3/s).

Equations of Darcy and Veronesse were used in each case to see variations between those formulas. It could be seen that all values of hL have magnitudes between 10-5 m and 10-7 m, which compared with heights of a house are negligible.

After all assumptions, Equation 10 could be arranged for the system that is studied in this work as follows. Difference of heights could also be named height head.

$$W = m \times g \times (Z_2 - Z_1)$$

Equation 23: Bernoulli equation for the specific case of this work

Work given by Equation 23 is only the needed for elevate water from one tank to another, but for knowing the energy needed for pumping it is necessary to take into account the efficiency of the pump used.

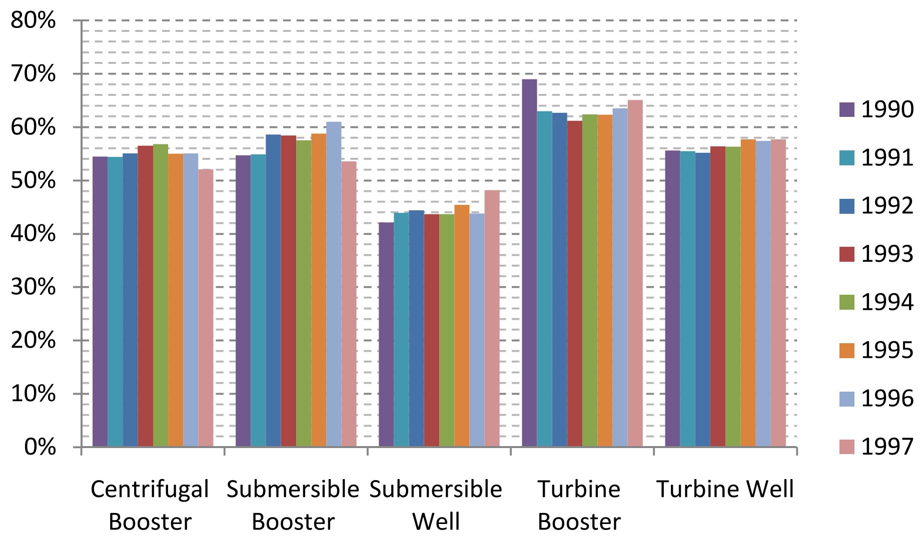


Figure 12: Evolution of pump efficiencies (Article: Conlon & Weisbrod, 1999)

Figure 12 shows the variation in efficiencies of five types of pumps used for agriculture and domestic uses, which could be useful to know approximates values of efficiency for finish the calculation of energy requirements for pumping rainwater from storage tank to distribution tank. Average values for those efficiencies are listed in Table 5. These values are inside the range provided by literature, between 50% and 85% of efficiency (Book: Spellman, 2003, p. 205)

PUMP TYPE	AVERAGE EFFICIENCY (%)
Centrifugal Booster	55,4
Submersible Booster	58,4
Submersible Well	44,2
Turbine Booster	62,8
Turbine Well	56,4

Table 5: Average overall Efficiencies for different types of pumps (Article: Conlon & Weisbrod, 1999)

Booster pumps are the ones that could be used for incrementing pressure in the fluid and well pumps are designed also for suctioning fluid from a deep site and impulse it to a high elevation. Centrifugal pumps are the most commons ones; they have a rotating impeller which accelerates the fluid when it passes perpendicular to it. Submersible pumps are vertical centrifugal pumps which could be submersed into the fluid in a well or a pool; they have a special seal for maintain the motor insulated from the fluid. Turbine pumps are also vertical rotating pumps but impellers are quite different to centrifugal or submersible ones; they are used for applications which need a lot of energy, especially for deep wells or industry. A picture of each type of pump is shown in Annex 9.3.

4.2.4 Water Management

For managing water in a house some processes could be needed depending on how water arrives to households. Pumping is one activity that could be necessary for using water in the house because tap water does not have enough pressure to go through all appliances or to go to high heights.

Another process that is sometimes useful is water disinfection. For this purpose the more common methods are designed to eliminate microorganisms from water, degrade organic matter and separate suspended solids. Disinfection is done principally for improving quality for drinking water.

Finally, waste water treatment is another important process of water management. This is done with residual water, principally black and brown water, but there are also some treatments including gray water. The principal objective of these treatments is to degrade organic matter and sometimes oxygenate water so outputs could leave houses with an improved quality.

These three types of water management are explained deeper in the following section.

- PUMPING

When tap water pressure is not enough for give water to all appliances of the house at an adequate pressure it is necessary to implement a pumping station for incrementing flows inside the house.

There are different types of pumps that could be used for this purpose, but the most common are centrifugal booster and submersible booster pumps. Table 5 shows efficiencies of these types of pumps. Annex 9.3 shows pictures of these types of pumps.

For calculate the requirements of pumping, the same assumption as with pumping rainwater could be done. They are listed as follows.

First, is that atmospheric pressure is the one for inlet and outlet of the pump system. This assumption could be done in both cases having a centrifugal or a submersible pump. With a centrifugal one, there must be a priming system before water enters into the pump, for allowing the correct functioning of the pump and for avoid cavitations in the impeller. This priming system could be a small tank where tap water comes and flow then to the centrifugal pump, or it also could be a big pipe where tap water lost velocity and seems stagnant. In both cases pressure could be assumed as the atmospheric one. With a submersible pump there is only one option that is having a small pool filled with tap water, where the pump is submersed for its correct functioning, so pressure could also be assumed as the atmospheric one. In both cases having a centrifugal or a submersible pump, it is also assumed that they pump water to a storage tank located in the roof for distribution of water inside the house and that this is not pressurized, so atmospheric pressure is the final pressure of the system. Storage tank at the top of the house is the better option when tap water pressure is not enough for using it inside the house because after water is storage at a high level, it could arrive each appliance with enough pressure due to the action of gravity.

Second assumption is that water after pumps (in the priming system or in the pool) and in the storage tank at the roof is stagnant so velocity is zero in the two cases.

Third assumption is that losses due to flow are negligible, for the same reason exposed for pumping rainwater, which is that the quantity of loses is very small compared with height head of the system.

After these assumptions, Equation 10 could be used also for pumping needs of the house.

- Disinfection

There are some ways to improve water quality from tap water in order to allow it to be drunk at household level. These kinds of treatment could be divided in two principal categories: Solids separation and disinfection.

Operations for separate solids from water to give it a drinkable quality are basically filtering and sedimentation.

There are different kinds of filters which could be used in houses, nevertheless most used are sand filters and activated carbon filters. Both must be designed according to the type of solids required to eliminate, taking into account principally the size of those solids. Sometimes these procedures are not fully trustable because filters could be blocked up, so quality of water would decrease. Because of this fact is important to have a regular maintenance program.

Sedimentation is useful when water contains solids which could be settled. This is not as efficient and fast as filtration, but could be a good option for a pretreatment for then filtrate water and eliminate remaining solids. This kind of treatment is not usually done at urban households because tap water in most of the cases has a pretreatment in which a large quantity of solids is eliminated.

Disinfection purpose is to destroy selectively organisms which could cause diseases. Principal mechanisms of disinfection include addition of chemical substances as chlorine, ozone, brome, iodine and hydrogen peroxide; boiling, storage, UV treating, and distillation. All these processes could be done at a household level; nevertheless some requirements could not be achieved easily (Book: Spellman, 2003).

Addition of chemicals is sometimes difficult because of the correct dosage of them into water. Those compounds are oxidizing agents which help in the elimination of bacteria and degradable matter but they are not very efficient with protozoa pathogens and viruses (Report: Ellas, 2010).

Boiling water could be an excellent option for its sterilization. Some bacteria and viruses die after a few minutes of boiling, but for assuring a total sterilization, 20 minutes are needed. Main disadvantage of this treatment is the high consumption of energy (Report: Practical Action, 2010).

Storage of water in the appropriate conditions, with a slow outlet flow could allow solids to sediment and also provide enough time for pathogens to die. Storage tank must be protected to avoid breeding of mosquitoes and algae (Report: Practical Action, 2010).

UV treatment is a good option when the quantity of solids in water is small, so they could not block the light. UV light is high efficient eliminating pathogens, protozoa, bacteria, yeasts, viruses, algae and fungi when used between 180 nm and 320 nm of wavelength. It does not remove chemical or solids components; nevertheless it could be act as a catalyst when using Ozone treatment (Report: Ellas, 2010).

Distillation is a very efficient operation to remove salts, solids, metallic compounds, pathogens and biological contaminants. Main disadvantage of this process is the high consumption of energy. An alternative option is to use solar energy but in this way a low volume of water could be treated and the system must be insulated to avoid algae and mosquitoes breeding (Report: Ellas, 2010).

Values of energy consumption of different types of disinfection systems are shown in Table 6. Those values were obtained from different providers on each category of disinfection like Atheramex, Ozone3, Triangular Wave Technologies Inc., Pluzono, Environmental Technology Initiative, Aquazone, Delozone, Lenntech, Spartan Environmental Technologies, Gamasud, Solzaid, Idenor Ingeniería, Copenica, Merck Millipore, Texer; Productos, Procesos y Tecnología; Paher and Hidroquímica de México.

DISINFECTION TREATMENT	ENERGY CONSUMPTION (kWh/L)
Ozone Generation	9,167E-06
UV treatment	3,712E-02
Sand Filter	0
Activated Carbon	0
Chlorination	0
Boiling	0,1045

Table 6: Energy consumption of selected disinfection treatments

- WASTEWATER TREATMENT

When there is enough space in the house, it could be possible to install a system for treating black and/or gray water, with the aim of increase the quality of water given to drainage systems, reuse water treated or produce energy for certain purposes.

At a household level, one process that is used is the anaerobic digestion, in which wastes are treated by biological means in absence of oxygen, in order to decompose organic and inorganic matter and produce biogas and sludge with fewer BOD than inlet matter.

In most of the cases neither energy nor water is additionally need, whereas energy is produced in form of biogas, which could be used for cooking, heating water or using gas lamps.

Designing a bio-digester is a complicate work and the quantities of generated gas could vary in accordance to type of digester, retention time, temperature, alkalinity and presence of inhibitor substances, so the quantification of energy outputs at this step is not going to be taken into account in this work.

Other types of wastewater treatment that could be carried out in houses are septic tanks in which there is only reduction of pathogens but not of organic matter, single pit which is designed only for excreta and could be a good option for treating sludge, but have problems of odors and insects growth. Wetlands are also used for treating black and gray water but their construction must be done carefully for allow a correct functioning of the system.

4.2.5 BATHROOM

There are different processes in the bathroom, according to the use of water. The ones that were studied were toilet, shower, faucet and bathtub. A description of each of those processes is given below.

- TOILET

Nowadays toilet technologies offer different options for the user. Toilets could be split in two large categories: on-site and off-site systems. Off-site systems are associated with urban facilities and high density developed areas with a reliable water supply, sewerage systems and in the most of the occasions, centralized wastewater treatment. In the other hand, on-site systems are isolated from a network of ware or sewage, nevertheless sometimes a sewage system is connected with them, but the most important characteristic is that some level of treatment is carried out at the toilet location. On-site systems are often used in rural areas (Report: Practical Action, 2008)

For the concerning of this work, only off-site systems were deeply studied because they are the most common systems in urban areas which are the aim of this project.

Off-site or flush systems could also be divided in some categories, depending principally in the type of flush and water storage for discharge. Flushing can be divided in two big groups: one discharge or two discharges. For the storage of water there are different capacities of the tank between ten and five liters.

For the purpose of this thesis four types of toilets are taken into account: Economizer, short discharge interruption, large discharge interruption and the normal one. Those kinds were selected from toilets founded with the following providers: American Standard, Contrac, Corona, Duravit, Exergis, Gerber, Glacier Bay, Kohler, Lamosa, Mancesa, Mansfield Plumbing, Niagara Conservation, Orion, Peerless Pottery Inc., Proflo, St Thomas Creations, Vitra, Vitromex, Vortens, Western Pottery LLC and Xinqi. Characteristics of the selected toilet types were normalized using data from the producers and are displayed in Table 7. Pictures of each type of toilet and tank are shown in Annex 9.4.

TOILET TYPE	FLUSHING TYPE	DISCHARGE (L)
Economizer	One discharge	5
Short Discharge interruption	Two discharges	3 - 6
Large Discharge interruption	Two discharges	4 - 9
Oldest one	One discharge	10

Table 7: Characteristics of selected toilets

Water consumption in a single-detached dwelling per day is calculated with discharge values multiplied by number of persons living in the house and by the number of flushes per day of each person. Flushing times are calculated with the average quantity of production of urine per day per person which was divided in the maximum and minimum capacity of a normal bladder. An average of these two calculations is then the final value of flushing times, shown in Table 8. For systems with two discharges, one flush is calculated with the large discharge and the other three with a short one, this could be done, assuming that the average of times that a person defecates per day is only one.

FLUSHING TIMES CALCULATION	
Production (L/person day)	1,4
Minimum size of a normal bladder (mL)	250
Maximum size of a normal bladder (mL)	500
Max times to urinate	5,6
Min times to urinate	2,8
Average of times to urinate	4

Table 8: Characteristics for calculate flushing times.

- SHOWER

Talking about showers, the most important part in these equipments is the shower head. Depending of the position of the holes and the design of this essential part, the pressure allowed to flow could change and so the quantity of water per time, called volumetric flow or discharge.

In the market people could find different types of shower heads, but the most common are listed in Table 9 and some pictures of each type are shown in Annex 9.5. Values of discharge were normalized from values of different providers worldwide, nevertheless real values could vary a little from those listed.

SHOWER HEAD	DISCHARGE (L/min)
Rain shower	9,46
Rain shower with flow reduction	7,19
Sunflower shower	9,46
Water lily shower	9,46
Roadrunner shower	5,68
Jet Spray shower	7,57
Efficient shower	5,68
Ultra low flow shower	1,89
Electric Shower	1,89

Table 9: Characteristics of selected shower heads

Providers contacted for this part of the work are Alsons, American Standard, Aqualisa, Delta, Dornbracht, Grohe España S.A., Hansgrohe, Kohler, La Toscana, Moen Incorporated, Newport Brass, Oxygenics ®, Plumb Warehouse, Shower Start L.L.C., Speakman Company, Symmons, Trendir and Waterpik.

Water consumption for showers was calculated with discharge values according to shower head and with the time each person last taking a shower with water flowing.

TEMPERATURE CLASS	LOWER LIMIT (°C)	HIGHER LIMIT (°C)
Very cold	10	0
Cold	24	10
Warm	29	24
Hot	38	29
Very Hot	43	38

Table 10: Ranges for water temperature in shower

Another important variable in showers is water temperature. It indicates how much energy must be given to elevate the inlet temperature of water to the level needed for the user. Temperatures were organized in five classes: very cold, cold, warm, hot and very hot, and the ranges of each class are shown in Table 10. It is better to manage classes because users do not always know the exact temperature that they use and in the most of the cases this temperature changes with the time, so in this way there is a boundary to move in, when making the energetic balance.

For energy consumption in this stage, all requirements were measured in the water heater, excepting the consumption when electric shower is used. Nevertheless calculations were done in the same way, taking into account the highest value of temperature in each range and efficiency of 95% (Pers. Comm: Vesta Bathrooms, 2011). A complete explanation is described in water heater section. When the selection of the user is "very cold", no requirements of energy are assumed.

- FAUCET

For this work, faucets have the same important variables as showers: Heads for calculating the discharge and with that the consumed volume, and temperature to measure the energetic level and the quantity of energy required for using water in these dispositive. Types of faucet heads are shown in Table 12 and pictures of each type are located in Annex 9.6.

FAUCET HEAD	DISCHARGE (L/min)
Compression valves	8,3
Cartridge Type	8,33
Ball Type	13,5
Electronic sensor and aerator	8,3
Disco Valves	5,7
Push type	6,5
Swan Neck	12

Table 11: Characteristics of selected faucet heads for bathroom

For faucet, providers selected were: Alsons, American Standard, Blanco, Central Brass Company, CHG group Inc., Danze, Delta, Elkay, Fisher, Gerber Plumbing Fixtures®, Graff ®, Grohe, Hansa, Hansgrohe, Kohler, Moen, Price Pfister, Symmons® and Toto. Discharge values were normalized and only the most common types of faucet were used.

TEMPERATURE CLASS	LOWER LIMIT (°C)	HIGHER LIMIT (°C)
Very cold	10	0
Cold	24	10
Warm	29	24
Hot	38	29
Very Hot	43	38

Table 12: Ranges for water temperature in faucet

The same categories used in shower for temperature were applied to faucet. They are listed in Table 12.

Water consumption in faucets was calculated with the times a person lasts brushing tooth and washing hands multiplied by the time used for the person in each of those activities and by the discharge value according to the type of head faucet the person uses.

Energy consumption in this process is calculated with the maximum value of temperature of the range of temperature of Table 12 selected by the person and accounted in water heater calculations. This consumption is zero when the range "very cold" is selected or when all showers in the house are electric because in that case it is assumed that no water heater exists in the house.

- BATHTUB

One bathroom appliance that is common but not always used is the Bathtub. There are some types and sizes of bathtubs in the market, so for the aim of this work five types were selected: Three walls Tub, Drop-in Tub, Claw foot Tub, Freestanding Tub and Corner Tub. Each type could be found in different sizes, so the capacity that they can stand was normalized between values of different providers and the final capacities are listed in Table 13.

BATHTUBE TYPE	SMALL CAPACITY (L)	MEDIUM CAPACITY (L)	LARGE CAPACITY (L)	EXTRA-LARGE CAPACITY (L)
Three walls Tub	147,6	188,0	213,9	244,2
Drop-in Tub	177,9	201,2	313,2	378,5
Claw foot Tub	147,6	171,6	209,9	321,8
Freestanding Tub	174,1	213,9	246,9	391,8
Corner Tub	227,1	283,9	354,6	567,8

Table 13: Characteristic of selected Bathtubs

The same values of temperature ranges as in shower and faucet were used in Bathtubs as is shown in Table 14.

TEMPERATURE CLASS	LOWER LIMIT (°C)	HIGHER LIMIT (°C)
Very cold	10	0
Cold	24	10
Warm	29	24
Hot	38	29
Very Hot	43	38

Table 14: Ranges for water temperature in Bathtub

Water consumption for bathtubs is calculated with the times per week a person uses the bathtub multiplied by the capacity of the bathtub selected by the user. Energy consumption of this process is calculated with the high value of each range of temperature and it is accounted in water heater calculations except when all showers are electric ones, so energy is accounted as Bathtub energy consumption with the procedure explained in water heater section. When temperature of use is set as “very cold” energy consumption is zero.

4.2.6 KITCHEN

For the kitchen, washing of clothes is included as well as dish faucet, dishwasher and the consumption of water for drinking and cooking.

- DISH FAUCET

Faucets used in the kitchen have often similar or the same volume flow as bathroom faucets, because of that, the same faucet heads and discharges used in section ⍰ are applied here, as shows Table 15.

FAUCET HEAD	DISCHARGE (L/min)
Compression valves	8,3
Cartridge Type	8,33
Ball Type	13,5
Electronic sensor and aerator	8,3
Disco Valves	5,7
Push type	6,5
Swan Neck	12

Table 15: Characteristics of selected faucet heads for Kitchen

TEMPERATURE CLASS	LOWER LIMIT (°C)	HIGHER LIMIT (°C)
Very cold	10	0
Cold	24	10
Warm	29	24
Hot	38	29
Very Hot	43	38

Table 16: Ranges for water temperature in Kitchen Faucet

Faucets could also need energy for heating water for its use, depending on the preferable temperature for the user. For energy balances purposes, temperature is divided in the five classes shown on Table 16.

Consumption of water is accounted with discharge according to the faucet head multiplied by the times for washing dishes and by the time used for it. Energy consumption is calculated with the high value of the range of temperature selected by the user and it is accounted in water heater calculation. When water range is “very cold” energy requirement is zero.

- DISHWASHER

Automatic dishwashers are often used in developed countries, but some developing countries also count with these facilities. Because of that it is important to take these appliances into account when talking about water and energy consumption.

Some investigations about the behavior of dishwasher say that water consumption could be reduced when using these appliances but in some cases energy consumption could be higher than hand washing, so an interesting point to evaluate is whether is better to use automatic dish washers or hand washing(Article: Stamminger, 2003), (Report: Market Transformation Programme, 2004).

CONSUMPTION CLASS	STANDARD TYPE CONSUMPTION (L/cycle)	COMPACT TYPE CONSUMPTION (L/cycle)
A	5,9	8,0
B	8,6	9,1
C	11,3	10,3
D	13,9	11,4
E	16,6	12,5
F	19,3	13,7
G	22,0	14,8

Table 17: Water consumption per cycle in selected Dishwashers

Water consumption is calculated with consumption rate according to class consumption and type of dishwasher shown in Table 17, multiplied by times of using this appliance per week. Standard type is defined as dishwasher with eight or more place settings and compact ones have less than eight place settings (Web site: Energy Star, 2010).

For energy calculations there are two ways of calculation. First and most simple is to ask for data to the user because sometimes appliances have this value. The other way of calculation consist on ask to the user the class of energy of the appliance. With this class and with Table 18, Energy Efficiency Index (EEI) range could be known. For purposes of calculation, the worst case of consumption or the higher value of the range is used.

Dishwasher Energy Class	EEI range	
A +++		50
A ++	50	56
A +	56	63
A	63	71
B	71	80
C	80	90
D	90	100

Table 18: Energy efficiency classes for dishwashers (Article: European Parliament, 2010)

According to European Parliament, EEI for a dishwasher is defined as the annual energy consumption of the household dishwasher divided by the standard annual energy consumption of the household dishwasher as shows Equation 24.

$$EEI = \frac{SAE_C}{AE_C}$$

$EEI: Energy\ Eficiency\ Index$
$SAE_C: Standard\ Annual\ Energy\ Consumption\ of\ the\ household\ dishwasher$
$AE_C: Annual\ Energy\ Consumption\ of\ the\ household\ dishwasher$

Equation 24: Energy Efficiency Index (EEI) calculation for Dishwashers (Article: European Parliament, 2010)

Standard annual energy consumption depends on the type of dishwasher, and the number of place settings. For Standard type, Equation 25 shows how this value could be calculated. The same is for Compact type and Equation 26.

$$SAE_C = (7{,}0 \times ps) + 378$$

$SAE_C: Standard\ Annual\ Energy\ Consumption\ of\ the\ household\ dishwasher$
$ps: Number\ of\ place\ sttings$

Equation 25: Standard annual energy consumption for Standard Dishwashers (Article: European Parliament, 2010)

$$SAE_C = (25{,}2 \times ps) + 126$$

$SAE_C: Standard\ Annual\ Energy\ Consumption\ of\ the\ household\ dishwasher$
$ps: Number\ of\ place\ settings$

Equation 26: Standard annual energy consumption for Compact Dishwashers (Article: European Parliament, 2010)

Then, energy consumption could be calculated knowing type and place settings of dishwasher and using equations for Standard Annual Energy Consumption and then work out the value of annual energy from Equation 24 using also values from Table 18.

- CLOTHES WASHING

Nowadays, there is a significant quantity of urban dwellings in which washing machines are used. Some examples of this behavior are Mexico and China, where 78,4 % and 96,8% of urban families own a washing machine (Article: Xing, 2010), (Book: Burton & Rhoda, 2010). There is also important to mention that people living in urban settlements want to obtain certain comforts according to the place they are living on, and washing machines are one of them. Because of this fact, washing machines are considered important to be measured as water and energy consumption in an urban single-dwelling for this work.

Worldwide market of washing machines is extensive, with some large producers but with many references and models. They could be classified by its functions in three categories: washers, semi automatic and fully automatic machines, which are defined as follows.

Washers, as it name indicates, washes clothes but does not dry them and does not have many functions. Their price is very low but they are inefficient in some functions and are becoming obsolete in urban settlements (Article: Benazir, 2010).

Semi automatic machines are also called Twin tubs because they are made up of two tanks, one for washing and the other for drying. They have more functions than washers, but duration of cycles and sequences of them have to be done manually as well as the transference between tanks which is not a good characteristic for users(Article: Benazir, 2010).

Fully automatic machines also wash and dry clothes but all in the same drum. They are equipped with some automatic programs depending on type and quantity of clothes. They require a continuous water flow for the correct operation. Because of its functionality, this kind of washing machine is broadly accepted in urban dwellings, therefore they are selected to be studied deeper in this work (Article: Benazir, 2010).

Fully automatic washing machines can be also divided in two types according to the way that the drum is disposed and so the ways in which clothes are loaded in the machine: Top loading and Frontal loading. The last of them offers some advantages to the user than the first one, but traditionally, top loading machines are more often used (Web site: Jensen-Van Heste, 2011).

The principal advantage of front loading machines are the efficiency about water consumption, needing up to one third of water that use a top loading machine for the same loading of clothes. Front loading machines also offers more space for clothes due to the absence of central agitator and a faster mechanism for agitation, giving a better drying cycle. Disadvantages of front loading machines are the initial and maintenance costs, which are higher in this kind of washing machines (Web site: Jensen-Van Heste, 2011).

This work takes into account top loading and front loading machines for loading of clothes between 8 kg and 14 kg, which are the more common values for domestic purposes. Consumption values were obtained from some providers like Miele, Whirlpool, General Electric, LG, Kenmore, White Westinghouse, Speed Queen, Frigidaire, Samsung, Inglis, Maytag and Haier.

Table 19 shows water consumption values for each type of washing machine. For top loading type, there are two categories because there were found a wide difference on values for consumption in appliances of the same loading in small loading values, so they could not be grouped as only one category.

CAPACITY (kg Clothes)	TOP LOADING CONSUMPTION (L/Cycle)	TOP LOADING ECON. CONSUMPTION (L/ Cycle)	FRONT LOADING CONSUMPTION (L/Cycle)
5	151	63	53
6	132	115	58
7	89	66	63
7,5	151	95	57
8	145	79	72
9	101		85
10	103		87
11	102		95
12	113		98
13	109		98
14	106		103

Table 19: Water consumption of selected Washing Machines.

Water consumption is then calculated as the consumption per cycle multiplied by the number of cycles per week used in the house.

For energy consumption, there are two options similar as the ones for dishwasher. The most simple is to ask the user the energy consumption per year of the appliance if know, the second option is to select energetic class of washing machine and with values of Table 20, select the higher value of the corresponding EEI.

WASHING MACHINE ENERGY CLASS	EEI RANGE	
A +++		46
A ++	46	52
A +	52	59
A	59	68
B	68	77
C	77	87
D	87	

Table 20: Washing Machine Energy Class (Article: European Parliament, 2010)

Then with capacity of washing machine and Equation 28, Standard annual energy consumption could be calculated for finally calculate the Annual Energy Consumption working out the value from Equation 27.

$$EEI = \frac{SAE_C}{AE_C}$$

$EEI: Energy\ Eficiency\ Index$
$SAE_C: Standard\ Annual\ Energy\ Consumption\ of\ the\ household\ dishwasher$
$AE_C: Annual\ Energy\ Consumption\ of\ the\ household\ dishwasher$

Equation 27: Energy Efficiency Index (EEI) calculation for Washing Machines (Article: European Parliament, 2010)

$$SAE_C = (47 \times c) + 51{,}7$$

$SAE_C: Standard\ Annual\ Energy\ Consumption\ of\ the\ household\ dishwasher$
$c: Capacity\ of\ the\ household\ washing\ machine\ [kg]$

Equation 28: Standard annual energy consumption for Washing Machines (Article: European Parliament, 2010)

Energy requirements are calculated as the addition of energy consumption and energetic requirements for heating water needed for washing. This last value is calculated in water heater section. Temperature ranges for washing machines are listed in Table 21.

TEMPERATURE CLASS	TEMPERATURE MAX (°C)	TEMPERATURE MIN (°C)
Very Cold	10	5
Cold	20	10
Warm	40	21
Hot	60	41
Very Hot	90	61

Table 21: Temperature Classes for Washing Machines.

- DRINKING WATER

This part of the work refers to the water consumed by people basic needs, which means water for drinking and preparing food. According to literature, water consumption could vary depending on climate, type of food to be prepared and personal habits principally (Report: The Sphere Project, 2011). Based on that fact, a range of consumption is considered for this work and it is shown in Table 22.

TYPE OF CONSUMPTION	MODERATE CONSUMPTION (L/person day)	HIGH CONSUMPTION (L/person day)
Drinking	2,5	3
Cooking	3	6

Table 22: Water consumption proposed for basic needs (Report: The Sphere Project, 2011)

A moderate consumption means that people do not stay all day at home, do not eat all meals there or live in places with cold climate, where water for drinking is not highly necessary. On the other hand, a high consumption could be carried out by a person who cooks all meals at home, stays usually at home or live in a hot climate where the quantity of water for drinking is high. It is important to mention that the quantities used in this work are the minimum required for the body but higher consumptions also happens.

Energy needed for cooking is not going to be analyzed in this work, because this is a difficult value to be estimated and it is out of the reach of its objectives.

4.2.7 OTHER USES

Other uses are related to activities like garden and plants watering, water heating and house cleaning.

- WATER HEATING

Energy requirements for water heating depend on the user behavior in terms of the temperature preferred to use in each device and in the quantity of water used in each one of the different process where warm or hot water is required.

Processes which could require hot water are shower, faucets, bathtub and washing machine. For each one of them, temperature of use is required and so required energy for heating is calculated with Equation 4, which is the one of heat transfer. For the use of this equation some considerations were made.

First assumption is that heat capacity of water at constant pressure (C_p) does not change with temperature. This consideration could be done because the change of this variable is negligible taking into account the magnitudes of the other variables. The value considerate is 4,18 kJ/kg K.

Second assumption is that water that comes into house has a temperature of 10 °C, this assumption could be done because this is the average temperature in which water comes to households(Web site: Rheem Manufacturing, 2011).

With the consideration done, Equation 4 could be arranged as follows:

$$Q = m \times 4{,}18 \frac{kJ}{kg\ K} \times (T_{need} - 10)$$

Equation 29: Equation 4 arranged with assumptions.

Consequently, Equation 29 is used for knowing the heat requirements of each process and then all quantities are added to calculate the total requirements for water heating. When electric shower is used in shower or bathtubs, these requirements of heating are not added to water heater, otherwise are added to shower or bathtub energy requirements.

Energy consumption of water heater was calculated taken into account efficiency of different types of heaters, as listed in Table 23 and energy requirements calculated as described before.

TYPE OF HEATER	EFFICIENCY (%)
Conventional gas storage	60
High-efficiency gas storage	65
Condensing gas storage	86
Conventional oil-fired storage	55
Minimum Efficiency electric storage	90
High-eff. electric storage	95
Demand gas (no pilot)	82
Electric heat pump water heater	220
Solar with electric back-up	120

Table 23: Efficiencies of Water heaters (Web site: American Council for an Energy Efficient Economy, 2011)

Electric heat pump water and solar heaters have efficiencies greater than 100% because they take energy from other sources than electricity or fuels, and calculation of efficiency is only taken into these sources as energy consumption.

Values of efficiency could vary between models and brands, and also according to the place in which they are installed as the case of electric heat pump and solar heaters.

- WATERING

In this category, two types of watering are accounted. First the one made to small plants which are sowed in flower pots indoor or outdoor. The second type is the watering of gardens, which includes watering of large grass extension or trees. The division is made because usually, small plants are watered with watering cans and gardens with hose, so water consumption differs a lot.

Table 24 shows average water consumption for watering small plants. There are two values due to different behavior of people when doing this operation (Web site: Fundación Vida Sostenible, 2005)

TYPE OF WATERING	CONSUMPTTION (L/week)
Economizer	9,6
Normal	19,2

Table 24: Water consumption for watering small plants (Web site: Fundación Vida Sostenible, 2005)

For gardens, three variables are taken into account: the type of system, the moment used for watering and the area watered. The system could be hose with economizer flow devices or normal hose dosage.

TYPE OF WATERING SYSTEM	WITH SUN (L/week m2)	WITHOUT SUN (L/week m2)
Economizer	11,54	7,69
Normal	34,6	23,1

Table 25: Water consumption for gardens watering (Web site: Fundación Vida Sostenible, 2005)

The moment of watering is an important variable because if the watering is done with high quantities of solar light, more water is going to be need for moisten correctly the earth. Table 25 shows the values for watering consumption in gardens per square meter, so for calculations of total consumption in this step, area of gardens is required.

- HOUSE CLEANING

Cleaning the house is other activity that requires water. Sometimes people do it like the traditional way with bucket, but others use hoses. Because of this fact, the way of cleaning is evaluated.

CLEANING PLACE	WITH BUCKET (L/ time)	WITH HOSE (L/ time)
Floors	5	200
Car	50	500

Table 26: Water consumption for cleaning purposes

Cleaning of cars is also accounted with the same technological variables as house cleaning. Table 26 shows the values estimated for each type of consumption in cleaning operations (Web site: Ecología y Desarrollo, 2011), (Web site: PADEC, 2011), (Web site: EPCOR, 2011)

4.2.8 OUTPUTS

Finally outputs refer to outcomes of water in the house like evaporation, personal consumption or the flow to drainage. Quantification of outlets could be done by measuring outlet flows or by estimating them with all requirements on each process of the house. For purposes of this work, estimation is the better option and for that, some assumptions were done:

First is that personal consumption for drinking and cooking is one outlet and that all water used for these activities does not go to other outlet ways.

Second assumption is that water lost by evaporation in applications in which water is heated is negligible, so this kind of outlet is going to be zero for all purposes.

As a third assumption is taken the outlet of watering as one output apart, because water consumption at this stage is not possible to be accounted in other output flows.

Another option which could be calculated is the rate of water reuse that is possible to achieve in the house. Water could be reused without any treatment from washing machine, shower and bathtub for purposes like flushing toilets, watering and cleaning floors and cars. Water from faucets and dishwasher could also be reused but with a preliminary treatment for removing greases and solids. In this work, only reusing options without treatment were taken into account.

5 ANALYSIS AND TECHNICAL ASSESSMENT

In order to understand how the model works and which results could be obtained from it, a detailed description is done in this chapter. Some cases of study are explained and analyzed, as well as some graphics illustrate tendencies of consumption and behavior of each case.

5.1 MODELING CASES OF STUDY

The model was created in an Excel® book as a multivariable model. Excel® was selected because is an understandable platform, known all around the world. Nevertheless all the model could be adapted to other platforms which support programming and multiple calculations.

This model include some options which could be changed for each one of the processes described in section 4.2, and some other variables about generalities of the house like number of persons living in the house. A list of these variables is shown in Table 27. This table also shows how these variables are introduced into the model. One way is asking for information to the user, so any answer could be taken, and the other way is to select information from a constructed list given in the model with the information explained in section 4.2 for each process.

CATEGORY	PROCESS	VARIABLE	TYPE OF VARIABLE
General Information		Number of inhabitants	Information
		Number of floors in the house(I)	Selection
		Covered Area (m^2)	Information
		Precipitation (mm/ year)	Information
Management	Pumping	Need of pumping tap water	Selection
		Pump type for tap water	Selection
	Disinfection	Use of disinfection methods for drinking and cooking	Selection
		Disinfection Type	Selection
Inlets	Rainwater collection	Collection of rainwater	Selection
		Roof type	Selection
		Pump type for tap water	Selection
	Use of Bottled water	Use of bottled water	Selection
		Quantity of bottled water consumed (L/week)	Information
		Use of tap water for drinking and cooking	Selection

CATEGORY	PROCESS	VARIABLE	TYPE OF VARIABLE
Bathroom	Toilet	Number of toilets[II]	Selection
		Flush type	Selection
	Shower	Number of showers[III]	Selection
		Shower type	Selection
		Shower temperature	Selection
		Time used in the shower/ person day	Information
	Faucet	Number of bathroom faucets[IV]	Selection
		Faucet type	Selection
		Faucet temperature	Selection
		Time used to wash hands/ person day	Information
		Time used to wash teeth/ person day	Information
		Times for wash hands/ day	Information
		Times for wash teeth/ day	Information
	Bathtub	Number of bathtubs[V]	Selection
		Tube type	Selection
		Tube size	Selection
		Number of persons who use Bathtub	Information
		Times for using tub/week person	Information
		Bathtub temperature	Selection
		Use of electrical shower for bathtub	Selection
		Quantity of bathtubs with electrical shower	Information
Kitchen	Dish Faucet	Number of Dish Faucets[VI]	Selection
		Faucet type	Selection
		Faucet temperature	Selection
		Time used by person to wash dishes	Information
		Times for wash dishes/ day	Information
	Dish Washer	Number of Dish Washers[VII]	Selection
		Dishwasher Size	Selection
		Dishwasher Water Class	Selection
		Times for using Dishwasher/ week	Selection
		Number of Place Settings	Information
		Dishwasher Energy Class[VIII]	Selection
		Dishwasher Energy consumption (kWh/year)[VIII]	Information
	Washing Machine	Number of Washing Machines[IX]	Selection
		Loading type	Selection
		Washing Machine Capacity (kg)	Selection
		Washing Machine Temperature	Selection
		Times for washing / week	Information
		Washing Machine Energy Class[X]	Selection
		WM energy consumption (kWh/year)[X]	Information

CATEGORY	PROCESS	VARIABLE	TYPE OF VARIABLE
	Personal Consumption	Drinking consumption	Selection
		Cooking consumption	Selection
Other Uses	Watering	Watering of plants	Selection
		Dispositive for watering plants	Selection
		Watering of the garden	Selection
		Dispositive for watering the garden	Selection
		Type of watering	Selection
		Area of garden (m2)	Information
	Cleaning	Washing of floors	Selection
		Dispositive for washing floors	Selection
		Washing of Car	Selection
		Dispositive for washing the car	Selection
	Water heater	Type of heater	Selection

(I) Max. 3 floors, (II) Max. 4 toilets, (III)Max. 4 showers, (IV)Max. 4 bathroom faucets, (V)Max. 4 bathtubs, (VI)Max. 2 Dish faucets, (VII)Max. 1 Dishwasher, (VIII)One of both Energy class and energy consumption is optional, (IX)Max. 1 Washing Machine, (X)One of both Energy class and energy consumption is optional.

Table 27: Variables taken into account in the model

After all calculations, the model gives total water consumption per person per year in the house as well as detailed consumption in each process in the house. It also gives total energy consumption per person per year (only energy which is bounded with water consumption is taken into account), as well as detailed energy consumption in each process.

Energy requirements are also calculated as the heat needed for elevate water temperature from inlet temperature to the house (Set in 10 °C) to temperature of use. Energy consumption includes energy requirements value and efficiency of the equipment.

All data obtained from this model are theoretical and could vary from reality because of some reasons like different behavior of people, cultural conduct, providers of technologies and systems of distribution (pipes could lost water by leakages or lost energy due to insufficient isolation) among others. Each process could be evaluated in a deeper detail to recognize how it works in a specific place, but this model only provides a short and generalized description of the situation of a single-detached dwelling.

To adjust the model was necessary to adjust some values of consumption related with flows in faucets and showers. This was done because nominal values given by providers are for the maximum flow that each device could give to the user. These values could only be achieved with all the faucets open with a high pressure in the pipe and these conditions are not often reached, so all calculation were done with the half of the nominal flow like one assumption which has to be proven with data of the cases of study.

For analyzing the model eight cases of study were developed. Characteristics of these cases are shown in Table 28.

VARIABLE	I	II	III	IV	V	VI	VII	VIII
Number of inhabitants	4	4	4	4	4	4	4	4
Number of floors in the house	2	2	2	2	2	2	2	2
Covered Area (m^2)	50	50	50	50	50	50	50	50
Precipitation (mm/ year)	686	686	686	686	686	686	686	686
Need of pumping tap water	No	No	No	No	No	No	No	No
Pump type for tap water	-	-	-	-	-	-	-	-
Use of disinfection methods for drinking and cooking	No	No	No	No	No	No	No	No
Disinfection Type	-	-	-	-	-	-	-	-
Collection of rainwater	No	No	No	No	No	No	No	No
Roof type	-	-	-	-	-	-	-	-
Pump type for tap water	No	No	No	No	No	No	No	No
Use of bottled water	No	No	No	No	No	No	No	No
Quantity of bottled water consumed (L/week)	-	-	-	-	-	-	-	-
Use of tap water for drinking and cooking	-	-	-	-	-	-	-	-
Number of toilets	2	2	2	2	2	2	2	2
Flush type	Short discharge interruption				Oldest one			
Number of showers	2	2	2	2	2	2	2	2
Shower type	Ultra low flow				Rainshower			
Shower temperature	Warm				Warm			
Time used in the shower min/ person day	5	5	10	10	5	5	10	10
Number of bathroom faucets	2	2	2	2	2	2	2	2
Faucet type	Disco Valves				Ball type			
Faucet temperature	Warm				Warm			
Time used to wash hands min/ person day	1	1	2	2	1	1	2	2
Time used to wash teeth/ person day	2	2	3	3	2	2	3	3
Times for wash hands/ day	5	5	5	5	5	5	5	5
Times for wash teeth/ day	3	3	3	3	3	3	3	3
Number of bathtubs	0	0	1	1	0	0	1	1
Tube type	-	-	3-Walls		-	-	Corner Tub	
Tube size	-	-	Small		-	-	X-large	

VARIABLE	I	II	III	IV	V	VI	VII	VIII
Number of persons who use Bathtub	-	-	4	4	-	-	4	4
Times for using tub/week person	-	-	1	1	-	-	1	1
Bathtub temperature	-	-	Warm		-	-	Warm	
Use of electrical shower for bathtub	-	-	No	No	-	-	No	No
Quantity of bathtubs with electrical shower	-	-	-	-	-	-	-	-
Number of Dish Faucets	1	1	1	1	1	1	1	1
Faucet type	Push Type				Ball type			
Faucet temperature	Warm				Warm			
Time used by person to wash dishes	3	3	5	5	3	3	5	5
Times for wash dishes/ day	1	3	1	3	1	3	1	3
Number of Dish Washers	1	0	1	0	1	0	1	0
Dishwasher Size	S	-	C	-	S	-	C	-
Dishwasher Water Class	A	-	A	-	G	-	G	-
Times for using Dishwasher/ week	3	-	6	-	3	-	6	-
Number of Place Settings	16		8		16		8	-
Dishwasher Energy Class	A+++	-	A+++	-	A+++	-	A+++	-
Dishwasher Energy consumption (kWh/year)	-	-	-	-	-	-	-	-
Number of Washing Machines	1	1	1	1	1	1	1	1
Loading type	Front				Top Normal			
Washing Machine Capacity (kg)	14	14	7	7	14	14	7	7
Washing Machine Temperature	Warm				Warm			
Times for washing / week	1	1	2	2	1	1	2	2
Washing Machine Energy Class	A+++	A+++	A+++	A+++	A+++	A+++	A+++	A+++
WM energy consumption (kWh/year)	-	-	-	-	-	-	-	-
Drinking consumption	Moderate		High		Moderate		High	
Cooking consumption	Moderate		High		Moderate		High	
Watering of plants	Yes		Yes		Yes		Yes	
Dispositive for watering plants	Economizer		Conv.		Economizer		Conv.	
Watering of the garden	No	Yes	No	Yes	No	Yes	No	Yes
Dispositive for watering the garden	-	Econ.	-	Econ.	-	Conv.	-	Conv.
Type of watering	-	No Sun	-	Sun	-	No Sun	-	Sun
Area of garden (m2)	-	10	-	10	-	10	-	10
Washing of floors	Yes		Yes		Yes		Yes	
Dispositive for washing floors	Bucket		Hose		Bucket		Hose	
Washing of Car	No				Yes		Yes	

VARIABLE	I	II	III	IV	V	VI	VII	VIII
Dispositive for washing the car	-	-	-	-	Bucket		Hose	
Type of heater	Electric heat pump				Oil fired storage			

Table 28: Conditions for study cases

All households were simulated with some common variables in order to give them a frame for comparison. So, the house is assumed to have four inhabitants, two floors and a covered area of $50m^2$ (area covered by roof) and precipitation of the zone was set in 686mm/year. Value of precipitation was selected analyzing precipitation data for different climates and selecting an average value for urban zones, nevertheless in the first analysis the value of precipitation does not have too much meaning. The house simulated does not need pumping for tap, no rainwater system is installed and only tap water is used. Other common specifications are that the house has two bathrooms each one with one shower, one faucet and one toilet; one kitchen with one faucet and one washing machine, and one garden of 10 m^2 outside the house.

Case I was made for a house with the best technology available in the model and with a good behavior in terms of use of water and energy. This means that times for using each process are moderate and the use of processes which consume a lot of water or energy is avoided, like the use of bathtubs. In this case, house is provided with a dish washer of a big size in order to wash dishes 3 times per week, the same happens with washing machine, which was set to have a large capacity in a frontal loading type, in order to make only one wash per week. Watering was selected only for small plants but garden was not included in watering, because it was supposed to be watered by rain.

Case II is similar to Case I, with the best technology and the best practices of use, but in this case dishwasher is not available, nevertheless house has the better technology in the kitchen faucet. Watering of garden is available in this case. Economic system for watering without sunlight was selected.

Case III shows the better technology with no convenient practices about water consumption, which means longer times in the use of faucets and showers, often usage of bathtubs and a high consumption of water for drinking and cooking. A small dish washer is selected in this case in order to wash 6 times per week, and also a small washing machine of 7 kg of capacity was selected to be used twice a week. With respect of watering, only plants were watered with a conventional system. Cleaning of floors is done using hose, which consumes more than bucket, used in the two cases before.

Case IV is a mix between cases II and III. It also shows a good technology with not convenient use of them as case III, but without dishwasher and with watering of garden with sunlight using hose.

Case V is about a house with the worst technology available in the model and good practices of use in water and energy consumption. Same values as case I of frequencies and time used in each process were used. Washing of one car in the house is calculated in this case, with bucket. Heater was set as a conventional Oil fired storage which is the one with the less efficiency between the selected ones for the model.

Case VI is also made with the worst technology and good practices, but without dishwasher neither bathtub. Practices for watering plants were set with economizer devices and for garden with conventional ones. Washing of floors is the same as cases I, II and V, which means with bucket. Car washing is also done with bucket.

Case VII shows the worst technology of the model with no convenient practices of water usage. Values of frequencies of usage and duration were the same stipulated for case III. An extra large bathtub was selected as well as a small dishwasher and a small washing machine. Watering of plants is done with conventional devices and garden is not watered. Washing of one car is made with hose.

Case VIII is the worst case, similar to Case VII, but without dishwasher. Watering of garden and washing of car is done with hose and watering of plants is made with conventional devices.

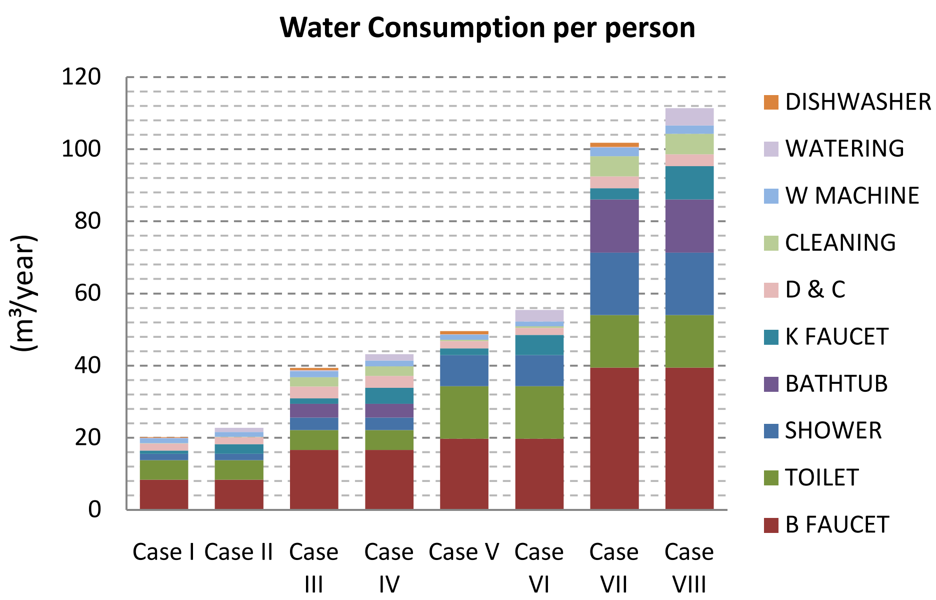


Figure 13: Water consumption per person (m^3/year), according to each case of study.

Figure 13 shows total water consumption for each case of study and the distribution of consumption according to different uses. Figure 14 shows each process apart and how is their behavior in each case of study.

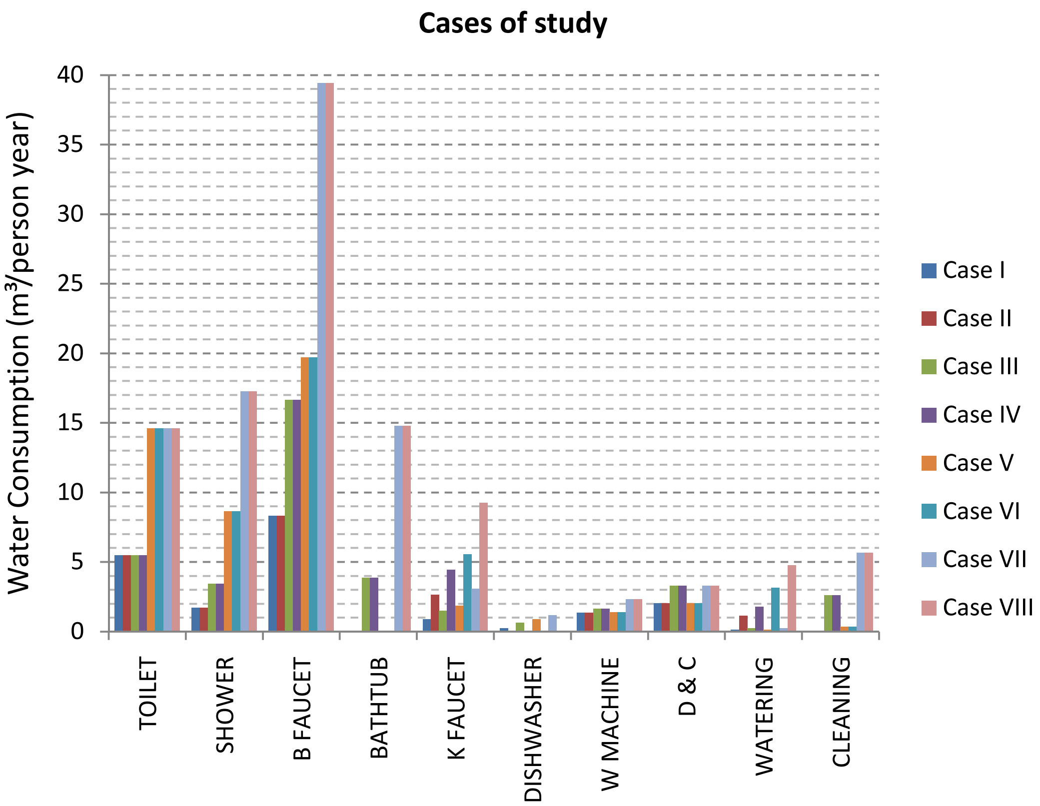


Figure 14: Water consumption per person (m^3/year), according to each process and case of study.

To calibrate the model and see if assumptions were done plausibly, total values of consumption were compared with consumptions in different countries in the world which were between values of 25 to 500 L/capita as listed in Annex 9.8, which means between 9,12 to 182,5 m^3 per year (Web site: Dardel & Eurostat, 2008). All cases of study were inside this range so the model function properly and the values are not out of reality.

Looking at Figure 14, it could be noticed that processes which consume more water are the bathroom faucet, the shower and the toilet in almost all the cases, but others take more importance in some cases, as bathtub, kitchen faucet and cleaning, due to bad practices in the use of water devices.

In Figure 13, it could be seen that cases I and II, III and IV, V and VI and VII and VIII have similar consumptions, this is due to each couple of cases uses the same technologies and only dishwasher and watering of garden change between them, so one important analysis that could be done at this step is to see how could technology influence consumption and how behavior of people could counteract the fact of having a bad technology. Figure 15 and Figure 16 show these cases

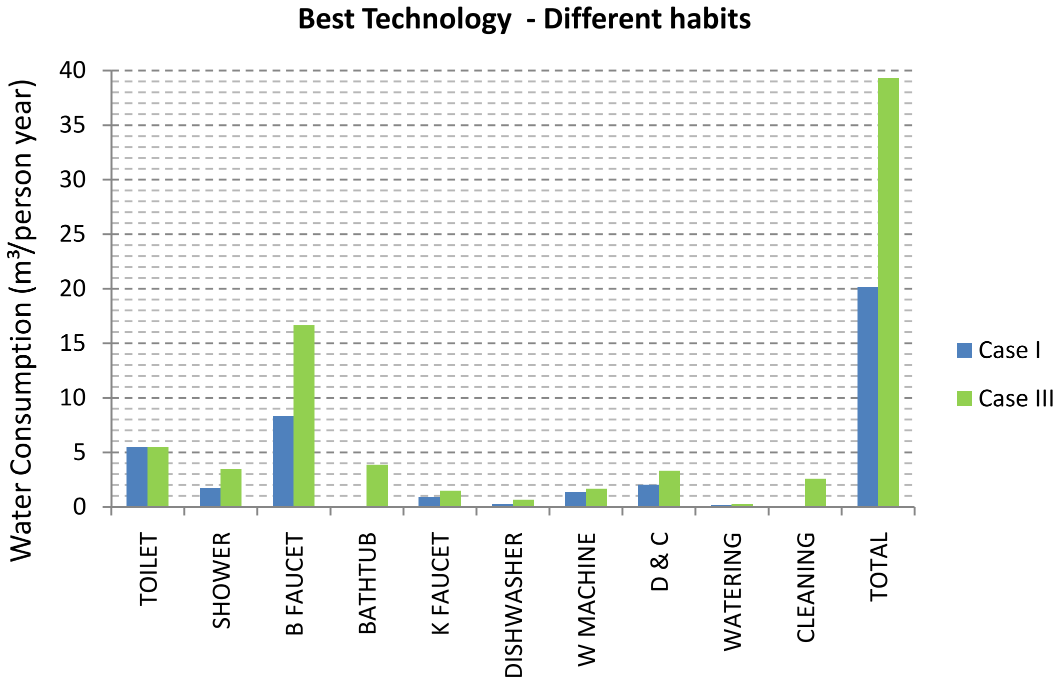


Figure 15: Comparison between cases: Access to the best technology and different habits in water consumption.

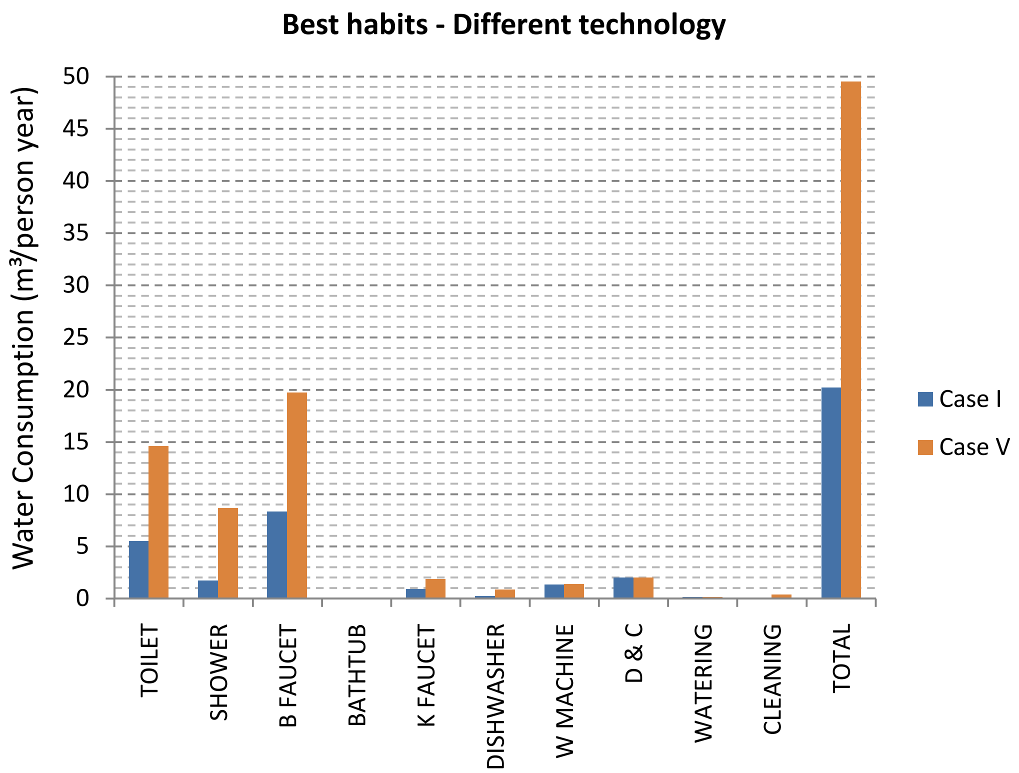


Figure 16: Comparison between cases: Best habits and different technology in water consumption.

Analyzing how the changes of technology and consumption affect water consumption, it could be said that toilet, shower and bathroom faucet consumptions depend more on the technology than on habits; bathtub, washing machine, drinking and cooking and cleaning depends more on how these processes are carried on than in technology. Kitchen faucet, dishwasher and watering have almost the same effect when changing habits or technology. In the total consumption, a change of technology could have a bigger decrement than a change of habits; nevertheless both changes could achieve a reduction of consumption in more than 40%. When both changes are done at the same time, reductions in consumption could achieve up to 80% as shows Figure 17.

The same analysis could be done for energy requirements in the house. These requirements consider the heat needed for elevate temperature from 10 °C to the temperature of use, and electricity needs in appliances, meaning dishwasher, washing machine, and shower if electric devices are installed. All cases were set with the best performance appliances (energetic class A+++), and for heating water in all processes temperature was set in the same value in order to evaluate how energy requirements change only with a change in water consumption. It is important to note that behavior of people could affect enormously energy requirements as regards of water temperature for each use in the house, but in the cases of study this effect is not visible.

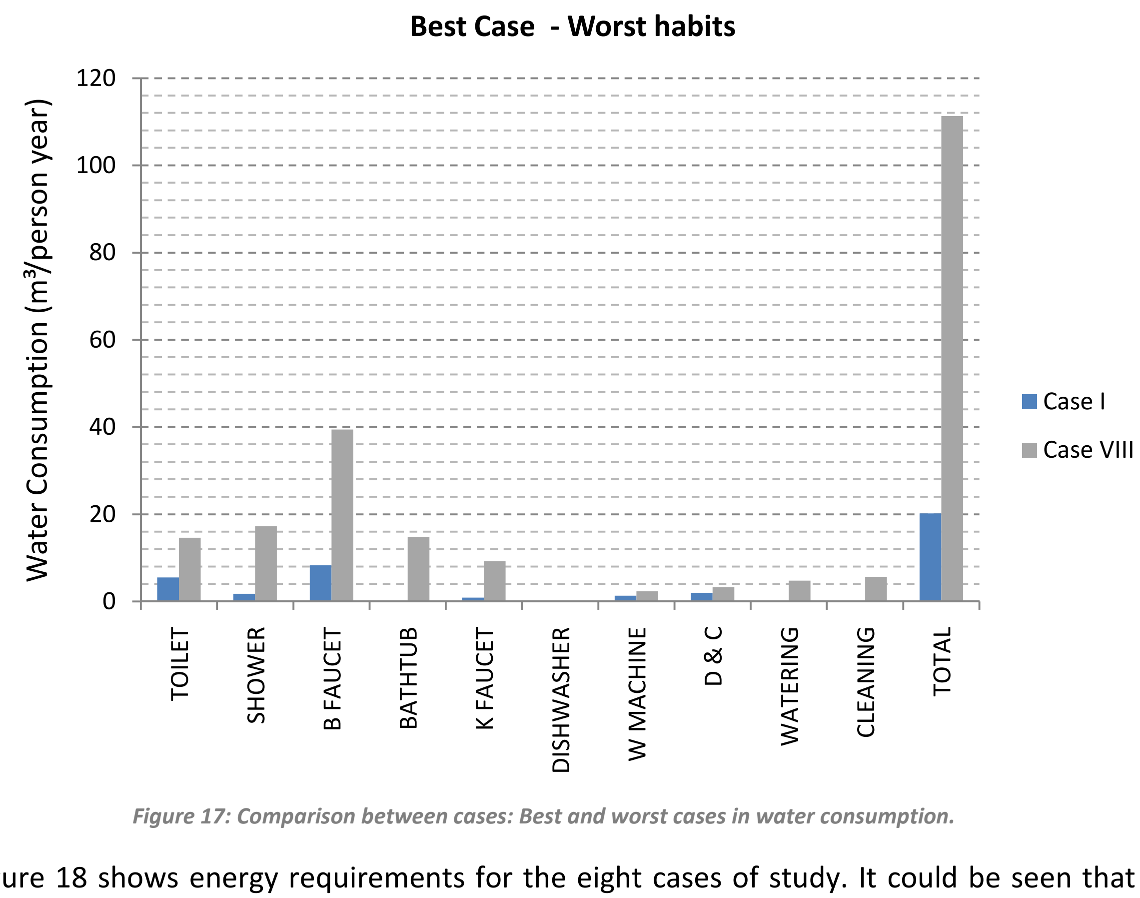


Figure 17: Comparison between cases: Best and worst cases in water consumption.

Figure 18 shows energy requirements for the eight cases of study. It could be seen that processes which require more energy are the bathroom faucet and the washing machine. Dishwasher was the one with fewer requirements in the cases it was used, but when only faucet is used for washing dishes, energy requirement increases considerably, as could be seen comparing cases I and II, III and IV, V and VI; and VII and VIII.

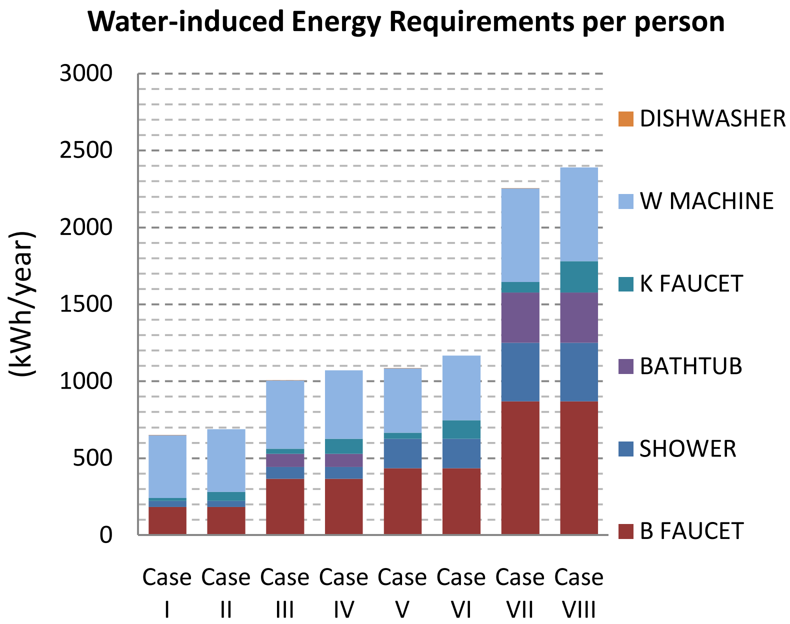


Figure 18: Energy consumption per person (kWh/year,) according to each case of study.

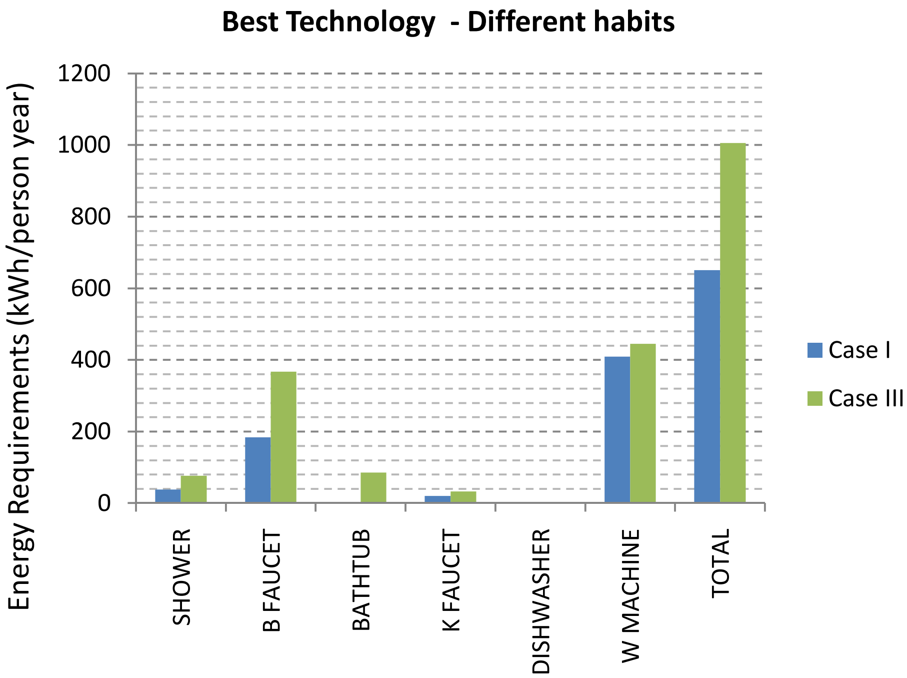


Figure 19: Comparison between cases: Access to the best technology and different habits in energy consumption.

The use of a washing machine could increase energetic requirements more than other processes because is the one that could use water at higher temperatures. Because of this fact is important to select correct temperature cycles, preferable low ones in order to decrease energy consumption.

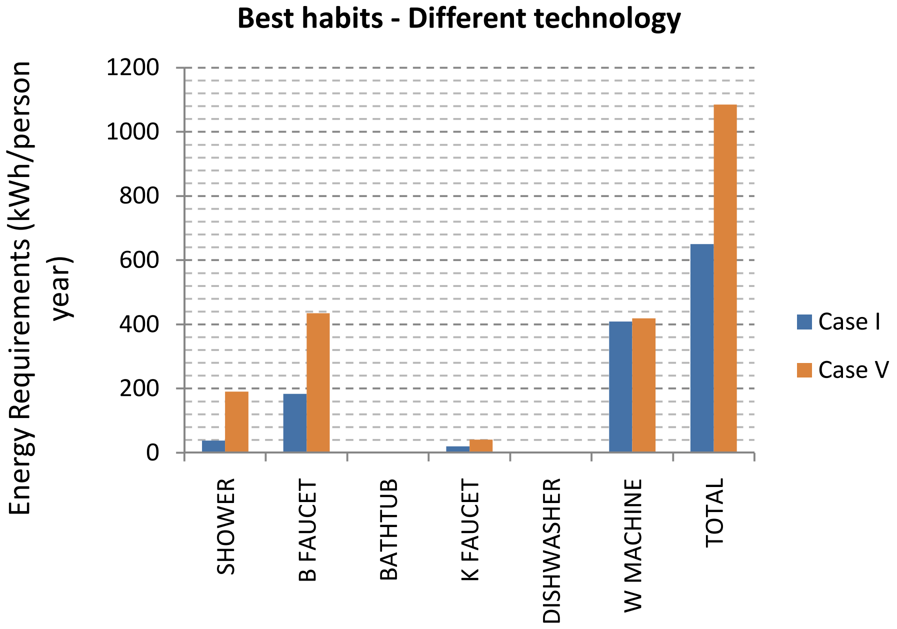


Figure 20: Comparison between cases: Best habits and different technology in energy consumption.

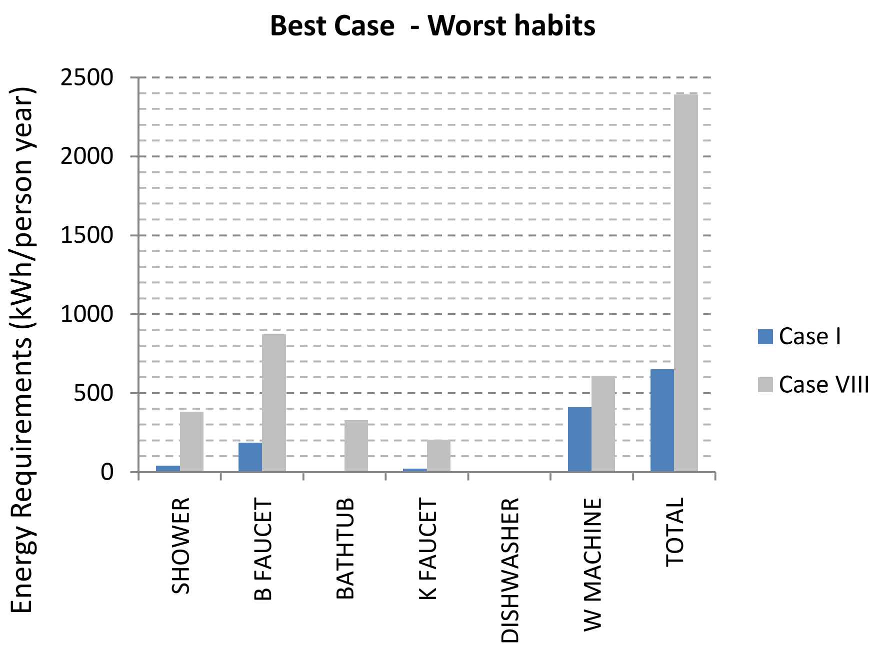


Figure 21: Comparison between cases: Best and worst cases in energy consumption.

Analysis of how energy requirements could change with different habits in water consumption or technologies is shown in Figure 19 and Figure 20. The use of bathtub could change significantly energy requirements. All other processes are affected more by a change of technology than by changes in habits of water consumption. Nevertheless both strategies help appreciably in reduction of energy requirements. Changing habits could reduce energy requirements up to 35 %, while a change in technology could achieve a reduction of 40%. When both changes are doing at the same time, energy requirements could be reduced in more than 70% as shows Figure 21.

5.2 Adaptation of the Model to other cases

The model is also useful for analyzing other types of cases than the ones described in the section before. Some examples of other analysis which could be done with the model are how energy consumption could be affected when pumping is a need for tap water and when electric shower is used instead of water heaters. For these cases, Case I was taken as basis for calculations and comparisons due to its good performance.

Figure 22 shows the performance of these alternative cases.

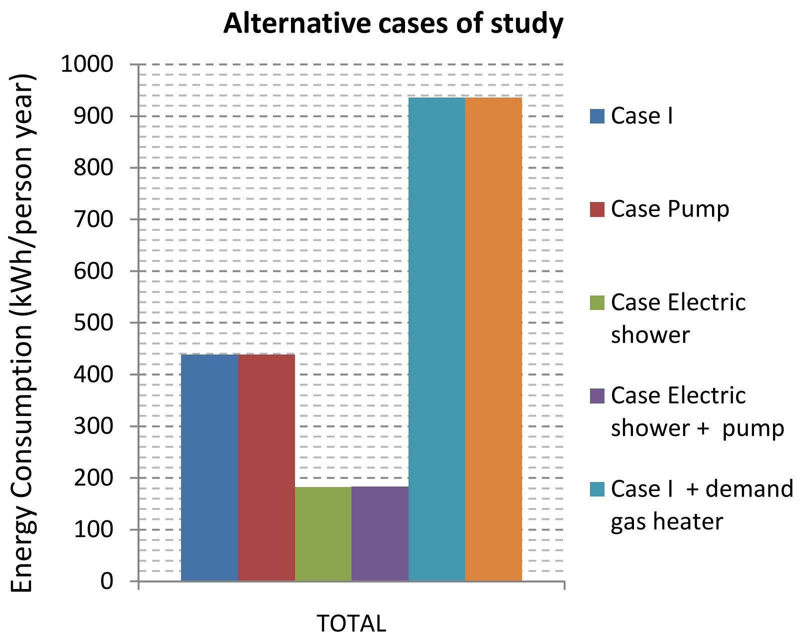


Figure 22: Alternative cases of study: Modifications in energetic systems

As it could be seen in Figure 22, pumping needs are negligible when compared with energy consumption of all other processes in the house, but the use of electric shower shows a large reduction in energy consumption. That is due the fact that when electric showers are installed, no other water heating element is used, so faucets and other processes use water with the same temperature it arrives to house. A study of how pumping needs could increase energy consumption when electric showers are used shows that also in this case, pumping consumption is negligible.

Due to the fact that Case I was simulated selecting an electric heat pump which has an efficiency of more than 100%, and that system of heating is the newest one, so only a few of people have the availability of one of these heaters, another case of study was done, selecting a demand gas heater, which is not the best neither the worst in efficiency but is a very common device in households. As Figure 22 shows, with this new case of study energy consumption is increased in more than 100%, so a change between a demand gas heater and electric showers is more appreciable. Finally, a case with demand gas heater and pumping system was modeled and in this case as in the others, pumping consumption was negligible.

Alternative cases for water consumption could be made analyzing possibilities for decentralized water supply, which means collection, treatment and supply close to the point of use, in this case inside the house. Some alternatives could be rainwater harvesting or gray water and black water recycling (Article: Mankad & Tapsuwan, 2011). As black water treatment systems are not typically done at household level because of its complexity and biological risk when the system is not managed appropriately, this case is not going to be analyzed in this work. Figure 23 have a resume of decentralized water supply cases compared with Case I.

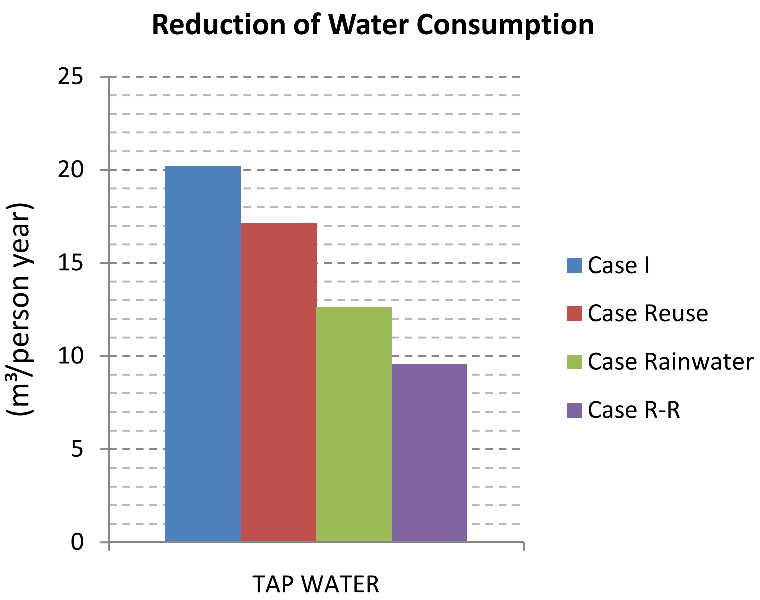


Figure 23: Alternative cases of study: Modifications in water systems

For the case of reuse of grey water, some assumptions were done. First for energetic purposes and due to the results in the alternative cases for energetic systems, pumping needs for recycling water are not taken into. Second assumption is that all grey water, this means waste water from shower, bathroom sink, washing machine and bathtub, is collected and reused (Article: Al-Jayyousi, 2003). As a third assumption is set that grey water could be used for cleaning purposes, toilet flushing, dishwasher and watering (Article: Sutherland, 2008). Fourth assumption is that if water required by processes of third assumption is more than quantity provided by the recycling system, tap water could be used. Finally, if grey water is more than the required in processes of the third assumption, the excess goes out of the house. After those assumptions, it could be seen that a reduction of nearby 15% could be achieved when recycling water. It is important to note that when grey water is used, some treatment is needed, depending on the quality of water involved, in order to avoid biological risks, and possible flow problems. Options for treatment vary widely among physical, chemical and biological treatments (Article: Li, Wichmann, & Otterpohl, 2009)

For rainwater case, it is assumed that all water collected is used in the house, so tap water is going to fit the total requirements which rainwater could not achieve. With precipitation data selected for the model (686 mm/year), and with a covered area of the house of $50m^2$, a reduction of more than 35% is attained.

When recycling and rainwater harvesting systems are implemented in the house, more than 50% of tap water consumption could be reduced.

Disinfection processes were not analyzed till here because they do not consume water for its functioning. Energy requirements for household systems of disinfection are very small, even less than pump requirements, so the use of any of those systems does not affect all analysis made before. Selection of the correct disinfection system must be done according to the quality of water which is going to be treated. For these purposes the quality indicator developed for the model could be used taking into that the better quality of water is achieved with a WQI of 100.

5.3 Construction of an Index based on the Model

After doing the appropriate analysis of the model, is important to simplify the findings in a compact system in order to give to users a way to measure their behavior in terms of water consumption and energy consumption related with water uses.

For achieving this work, an index of concepts is developed taking into the principal results of the model.

The first finding that is going to be described is the consumption of water. For a good behavior of the house this consumption must to be reduced with both improve of technology and good practices of use in all processes in the house. An indicator of how water consumption behaves in a house is shown in Equation 30.

$$\frac{WC_{min}}{WC} \times 100\%$$

$WC_{min}: Minimum\ Water\ Consumption\ possible\ [m^3/(person \times year)]$
$WC: Actual\ Water\ Consumption [m^3/(person \times year)]$

Equation 30: Model of Indicator of Water Consumption

The model showed that a minimum consumption for an urban detached dwelling in order to have comforts but with a good use of them is 20m^3/person year, so Equation 30 could be arranged as follows.

$$\frac{2000\, m^3/(person \times year)}{WC} \%$$

$WC: Actual\ Water\ Consumption [m^3/(person \times year)]$

Equation 31: Final indicator of water consumption

Next concept is the recycling of water. According to the model, water consumption could have a notable reduction with water from some processes is reused for other processes. A model of equation which indicates the conduct of recycling systems is exposed in

$$\frac{R_w}{R_{w\ max}} \times 100\%$$

$R_w: Quantity\ of\ recycled\ water\ [m^3/(person \times year)]$
$R_{w\ max}: Maximum\ Quantity\ of\ recycled\ water [m^3/(person \times year)]$

Equation 32: Model of indicator for recycling of water

Processes from which water could be recycled without major treatment are shower, washing machine and bathtub. A value proposed for these processes is 3m^3/person. This value could vary in accordance with consumption in those processes, but the proposed quantity is going to be used as an example for the best case of house modeled, given as a result Equation 33

$$\frac{R_w}{3\, m^3/(person \times year)} \times 100\%$$

$R_w: Quantity\ of\ recycled\ water\ [m^3/(person \times year)]$

Equation 33: Final indicator for recycling of water

Another important point analyzed was the harvesting of rainwater. In this indicator some additional variables as water values must be considered.

$$\frac{W_c \times 1000}{A_c[(Pp \times C_r) - (12)]} \times 100\%$$

$W_c: Collected\ water\ [m^3]$
$Pp: Total\ annual\ precipitation\ \ [mm]$
$C_r: Run - off\ coefficient$
$A_c: Collection\ area\ \ [m]$

Equation 34: Model of indicator for rainwater harvesting

Run-off coefficients are listed in Table 3. As an example, indicator for rainwater harvesting set with data from case of study would be written as shown in

$$\frac{W_c}{0{,}3027[m^3]}\%$$

$W_c: Collected\ water\ [m^3]$

Equation 35: Example of indicator for rainwater harvesting

Finally, an indicator of water treatment must be arranged to account all the possible methods for achieving a sustainable management of water in the purposed model. This indicator is the one that is most difficult to be calculated, but it is an important measurement for controlling quality of water which enters and go out of the house.

$$\sum_{i=1}^{n}\left[\frac{V_{i\ in} \times WQI_{i\ in}}{V_{i\ out} \times WQI_{i\ out}}\right] \times 100\%$$

$n: Number\ of\ processes\ in\ the\ house$
$V_{i\ in}: Volume\ of\ inlet\ water\ to\ the\ process\ i\ [m^3]$
$V_{i\ out}: Volume\ of\ outlet\ water\ from\ the\ process\ i\ [m^3]$
$WQI_{i\ in}: Water\ Quality\ Indicator\ in\ the\ inlet\ water\ of\ process\ i.$
$WQI_{i\ out}: Water\ Quality\ Indicator\ in\ the\ outlet\ water\ of\ process\ i.$

Equation 36: Model of indicator for water treatment

These indicators must be arranged into an index in order to give them a correlation and a global significance. Nevertheless rainwater harvesting and treatment of water are not feasible in some houses because of required space for those processes for collecting, storage and treating facilities, so the index is going to be organized in two classes: Use of water and self-sufficiency of systems.

INDEX CLASS	INDICATORS	WEIGHT	TOTAL
Use of Water	Water consumption	60%	100%
	Recycling of water	40%	
Self sufficiency of systems	Rainwater harvesting	50%	100%
	Water treatment	50%	

Table 29: Index classes, indicators and their weights

Table 29 shows the weights of each indicator in each class and the total percentage of each class. Water consumption has a larger weight than other indicators because of two facts. First is that reduction of consumption is an easy work to achieve at all houses and second because analysis of the model shows that different behaviors could make a big difference in consumption of water and that almost 80% of reductions could be achieved. Rainwater harvesting and water treatment have the same weight because both systems implies a development of non conventional technologies and both improves self-sufficiency in the topic of water consumption.

	INDEX CLASS	WEIGHT	TOTAL
INDEX OF SUSTAINABILITY OF WATER USAGE	Use of Water	50%	100%
	Self sufficiency of systems	50%	

Table 30: Weights of Index classes

Table 30 lists how index classes are organized to create the index of sustainability of water usage. The highest point achieved with this index is a 100%, which means an excellent development in the use of water and a high self-sufficiency of water systems. In the case that a house do not count with enough space to carry out processes of rainwater harvesting or water treatment, the best way to measure the behavior of the house is to only take into account the class of use of water which could also achieve a 100% of punctuation.

6 RESULTS

After analyzing how the model works, and which important facts are fundamental in households' water consumption and water induced energy consumption, some recommendations can be given. It is also imperative to establish in which cases the model and the index could be applied and how this application could be managed.

The model is designed for accounting water and energy related with water consumption in urban single-detached dwellings, but it could be extended to other types of buildings or zones implementing more variables proper of other systems. It is also possible to include other energy uses and resources but all these changes make the model more complex and dependant of more information.

An important result of the evaluation of the model is that water consumption at domestic spheres depends on how water is used as much as on which technology is used. Both options together could decrease water consumption in a considerable percentage. Nevertheless, real sustainability could be achieved when rainwater is totally used and a treatment of water in the house is made, in order to decrease at a maximum point the dependence on aquifers and network supply and to increase quality of waste water for diminish possible effects in environment and ecosystems and help centralized treatment plants to be more efficient when treating less contaminated or pretreated water.

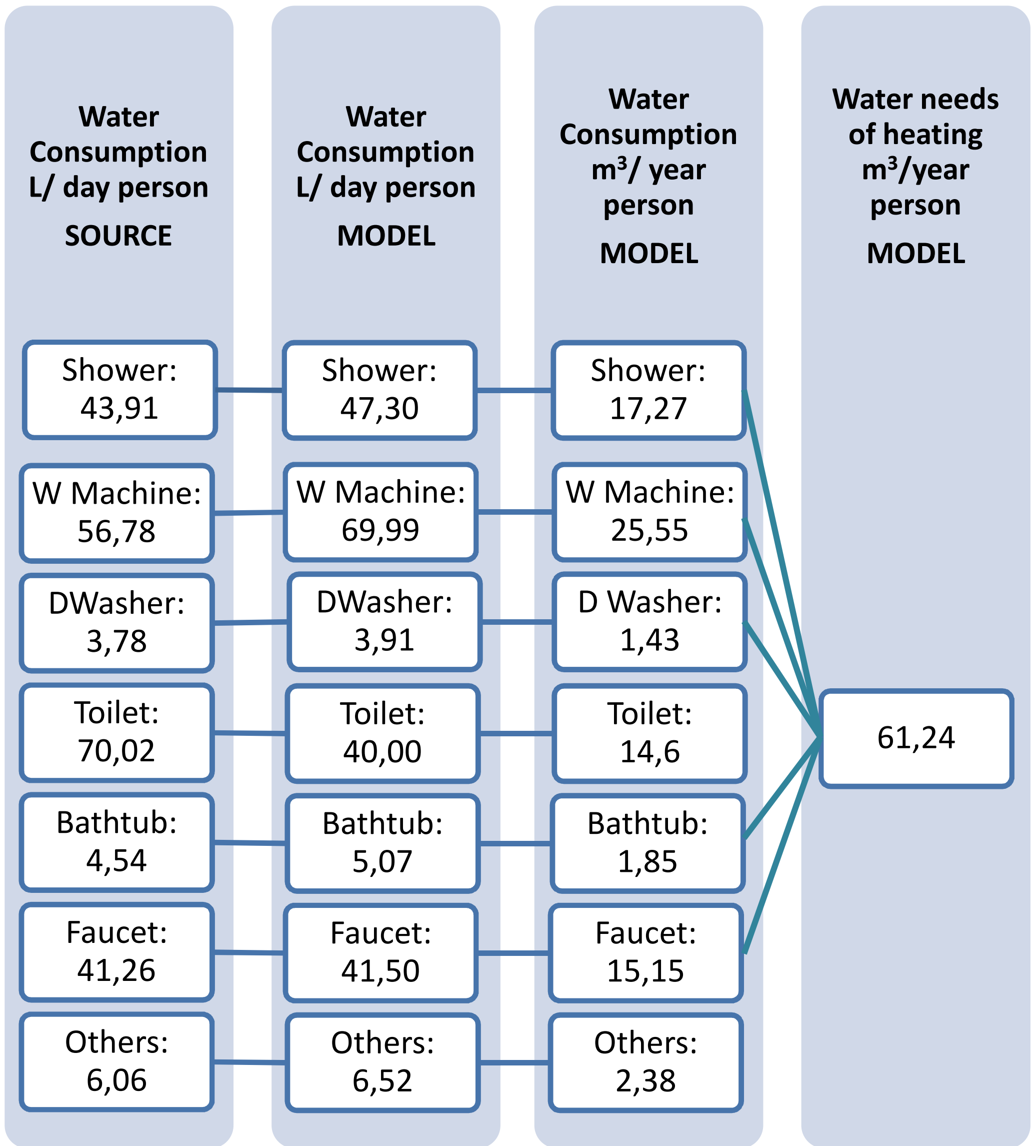
6.1 APPLICABILITY OF THE STUDY

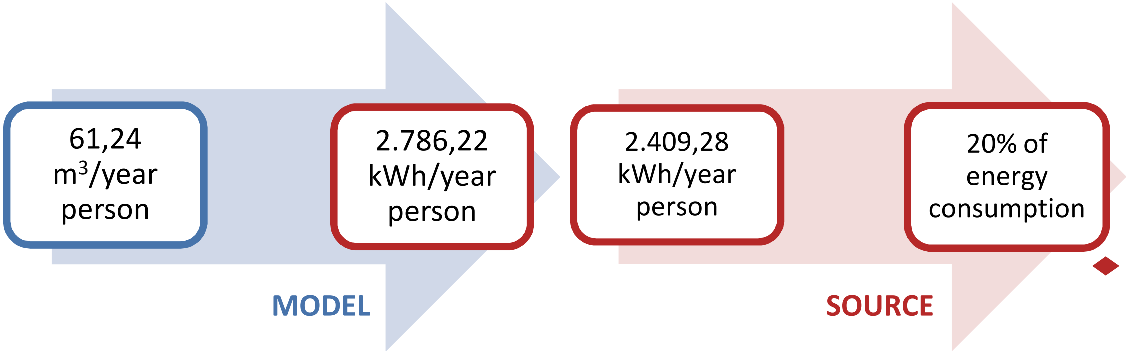
Modeling a house in terms of water and energy consumptions is not an easy work due to the huge quantity of variables included in every process of the house. Even though some assumptions could be made for the generalization of some cases, when a real system is studied the major quantity of variables must be measured and selected according to the specific case. Nevertheless one example of how energy and water could be related with the use of this model is shown in a case example. As reference data were taken from literature and comprise average values, the test for validity not fully reliable. Also some further assumptions were made.

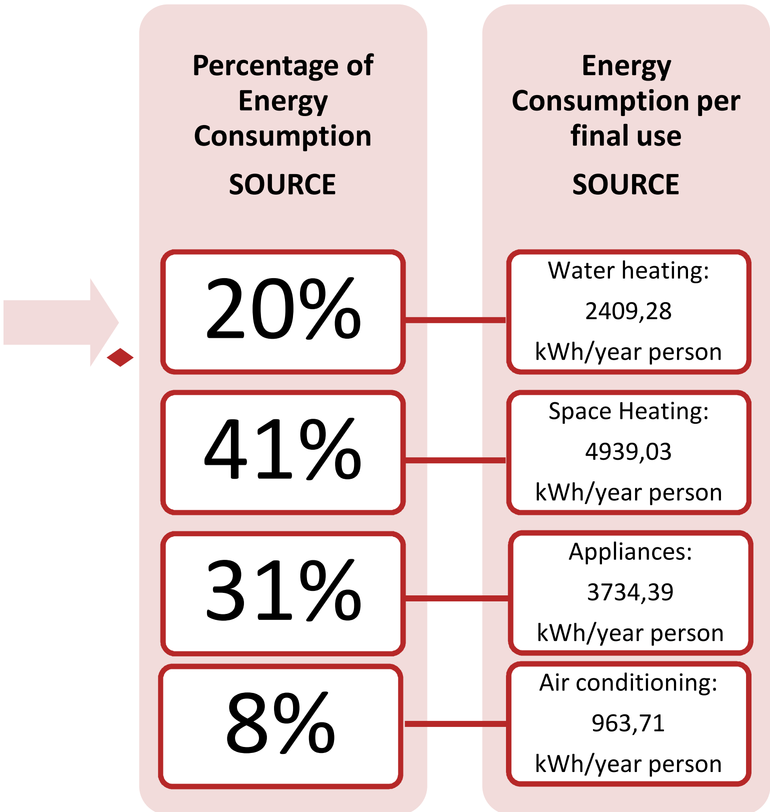
This example is about United States of America households' average water and energy consumption. It is important to mention that using the model with aggregated data would create some mistakes due to differences in specific data, so it will calculate approximate figures. For a detailed modeling, more precise information is required. For developing this study data of water consumption in households in the USA was used (Web site: American Water Works Association, 2011).

The model was run with some specifications known about USA consumers, like the type of washing machines, the use of dishwasher and bathtubs and the average of people living in the household. After some calibrations of the simulation, the model delivered data of water consumption similar to the ones specified by literature and also some information about energy consumption.

The quantity of energy consumption provided by the model was compared with the values provided by literature (Web Site: U.S. Energy Information Administration, 2011), and both values were similar in magnitude, so the model is considerably trustable. Values provided by sources and model are illustrated as follows.







Finally, applicability of the model in different climate zones could be changed with two variables: First precipitation data, which is important when measuring rainwater harvesting possibilities, and second temperature of the tap water which enters into the house. When the model is applied to places in subtropics areas, local average data of temperature and precipitation must be given. Also, the model allows to calculating seasonal differences (e.g. for winter and for summer) giving different input data in order to analyze the possible variations of water and energy consumptions throughout the year.

6.2 FURTHER WORK AND SUGGESTIONS

This model was elaborated with theoretical data, sometimes generalized ones, and many assumptions were made in order to simplify the structure of calculations and of the model itself. An important improvement for this work could be the evaluation of a real house, with detailed information and measurements in order to validate totally the model.

Programming the model in another platform which could be supported in the internet could also be essential for the diffusion and improvement of the work.

This model could also be modified in order to give the option to model other types of households like multi-unit housing or semi-detached dwellings.

Incorporating a data source (such as for Climate consultant) for detailed climate information would be an excellent tool for allowing different analysis of variances of consumption when changing the location of the dwelling.

7 CONCLUSIONS

After analyzing water uses and consumption and the water-induced energy consumption in an urban single-detached dwelling, a theoretical model was created. From that, several alternatives were found to present a potential option for reducing both consumptions in single-detached dwellings in order to develop more sustainable performances.

Furthermore an indicator for evaluating sustainable conditions of a specific dwelling was developed. Water quality and decentralized systems for water supply were also taken into account. The following conclusions can be drawn:

- The relationship between water consumption and its induced energy consumption depends on the specific evaluated house, but it is principally bounded together with energy needs for heating water. Nevertheless pumping needs could become important in some particular cases when water heating is not a priority.

- Water consumption in a single-detached dwelling could be widely reduced by changing equipment technology or habits of consumption achieving up to 80% of reductions when both options are carried out.

- Decentralized water supply systems are an excellent option for reducing tap water consumption when the dwelling allows systems to be installed. A reduction of tap water consumption of more than 50% could be achieved when rainwater harvesting and grey water recycling systems are installed.

- A reduction in water consumption affects directly energy consumption due to a decrease on heating water requirements in a dwelling. A drop of near 70% on energy consumption could be reached by means of decreasing water consumption.

- Including water consumption into energetic balances at a household level is possible but it is not an easy task due to the huge quantity of variables that must be considered in order to build up a detailed analysis.

- The use of indicators of water quality, consumption and self-sufficiency of water supply could give a guideline to users for knowing the alternatives for reducing consumptions.

- Case study of consumption in the United States of America showed that around 2700 kWh/year per person is needed to satisfy water heating requirements. This result was congruent with literature statistics and allowed the model to be calibrated even when aggregated data were used. Nevertheless an improved calibration could be done when measured figures of a real dwelling are used.

- Real sustainability at a household level will only be achieved when all the components of the system work in equilibrium (People, economic and natural resources and environment). Therefore, it is fundamental to include resources consumption into sustainable vision of households. Water and energy must be considered as a priority in that vision because they are main and basic resources in every household and are also necessary to maintain a good quality of life.

After a detailed analysis, a theoretical model was developed and the principal relationships between water and energy in an urban single-detached dwelling were found. Furthermore, the use of this model and the developed indicators together could help to achieve a better understanding of sustainability at a household level. It also could give a guideline for the design of more sustainable dwellings when analyzing consumption figures before building up a specific project.

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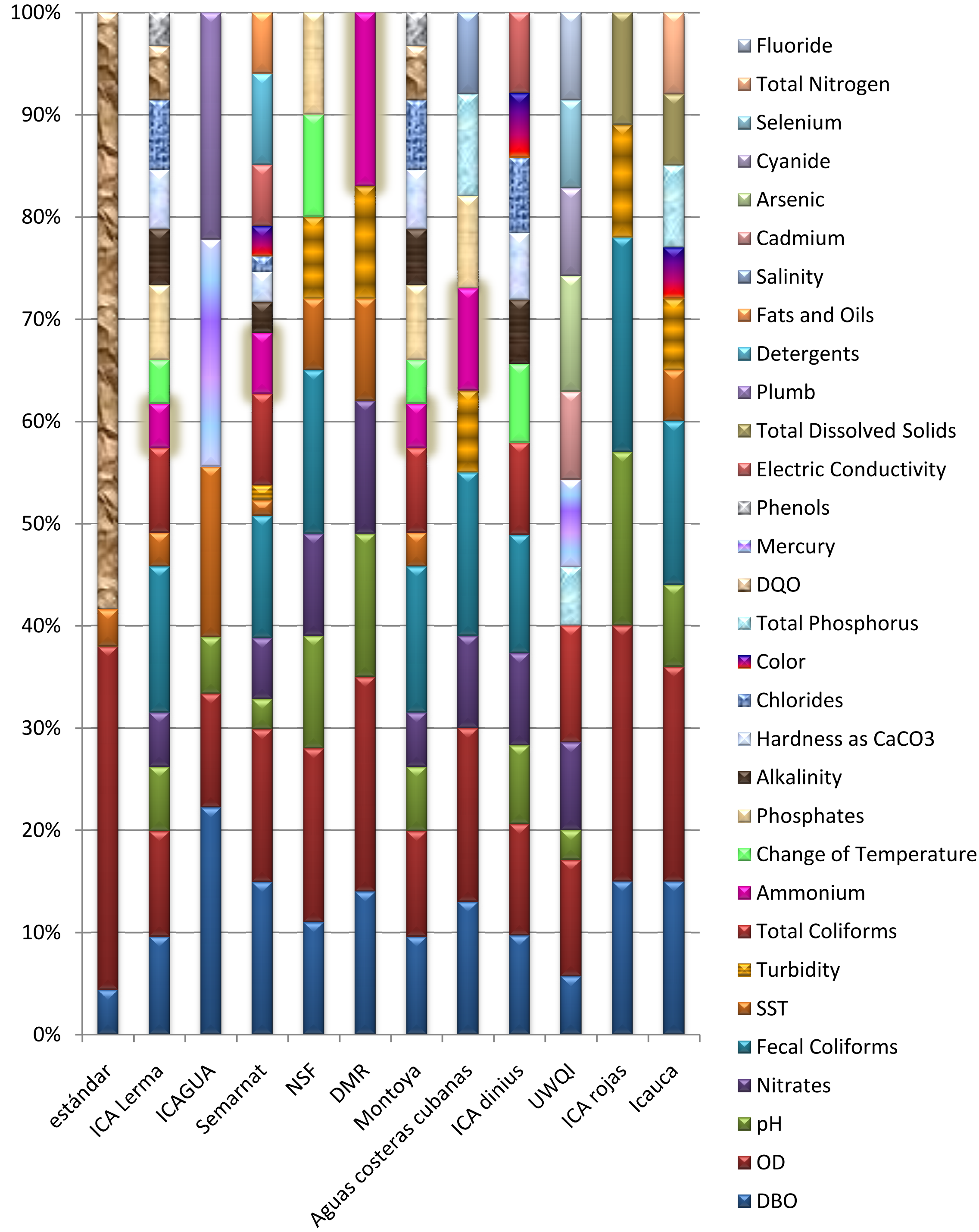
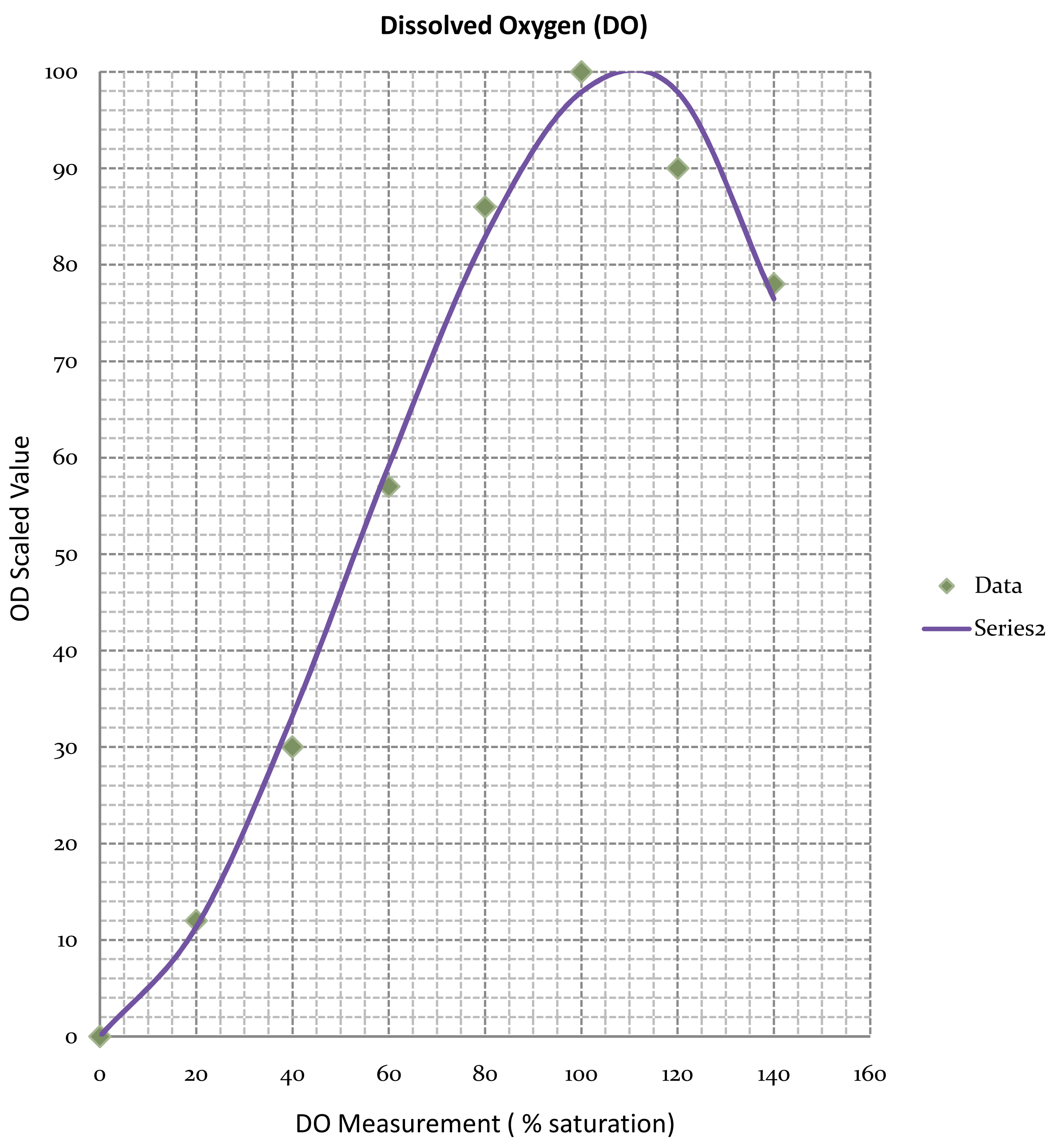
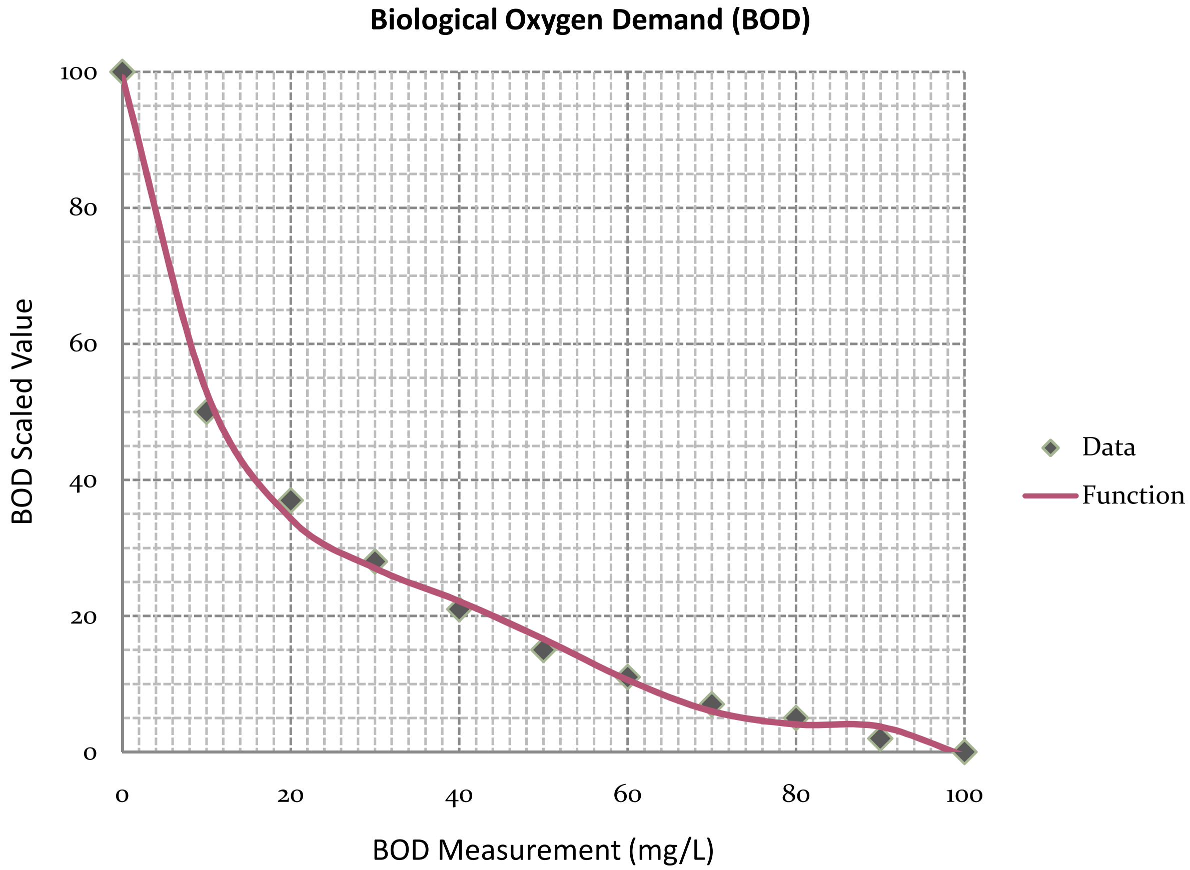
9 ANNEXES

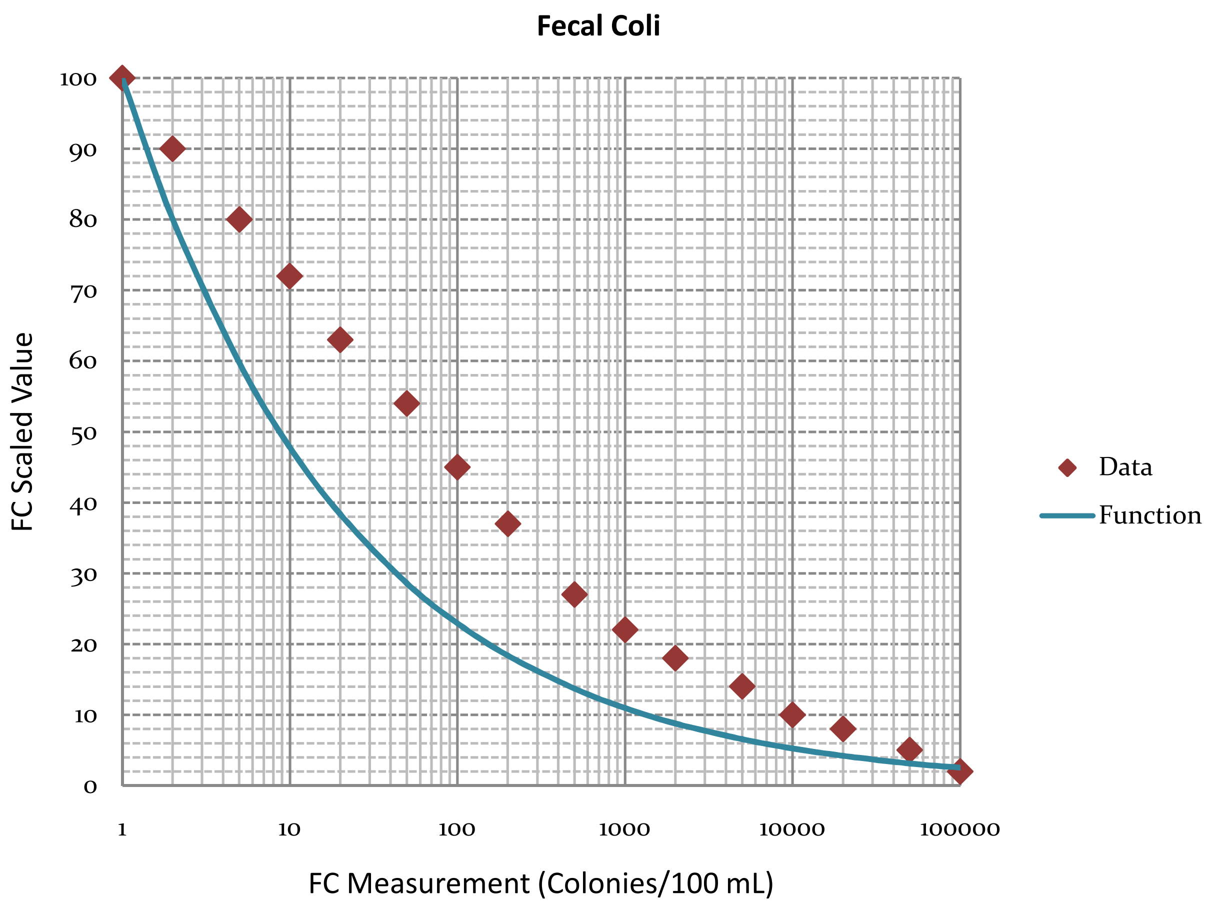
9.1 PERCENTAGES OF USE OF WATER QUALITY INDICATORS IN SELECTED QUALITY INDEXES

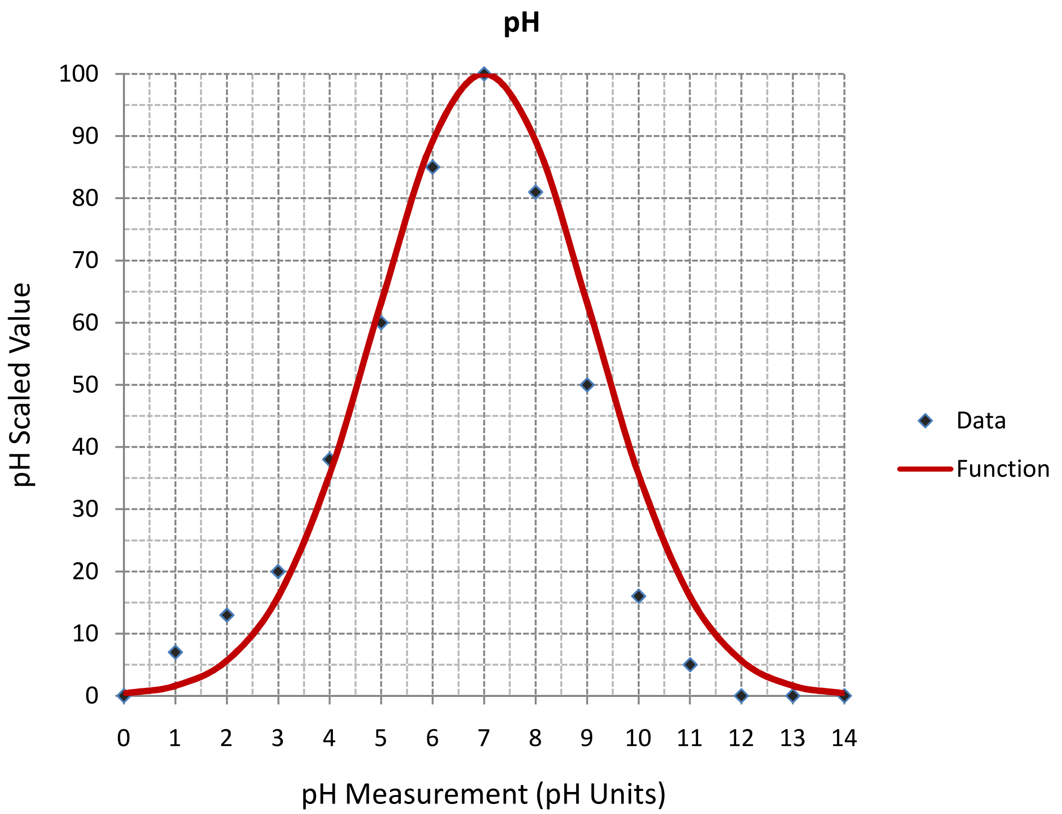


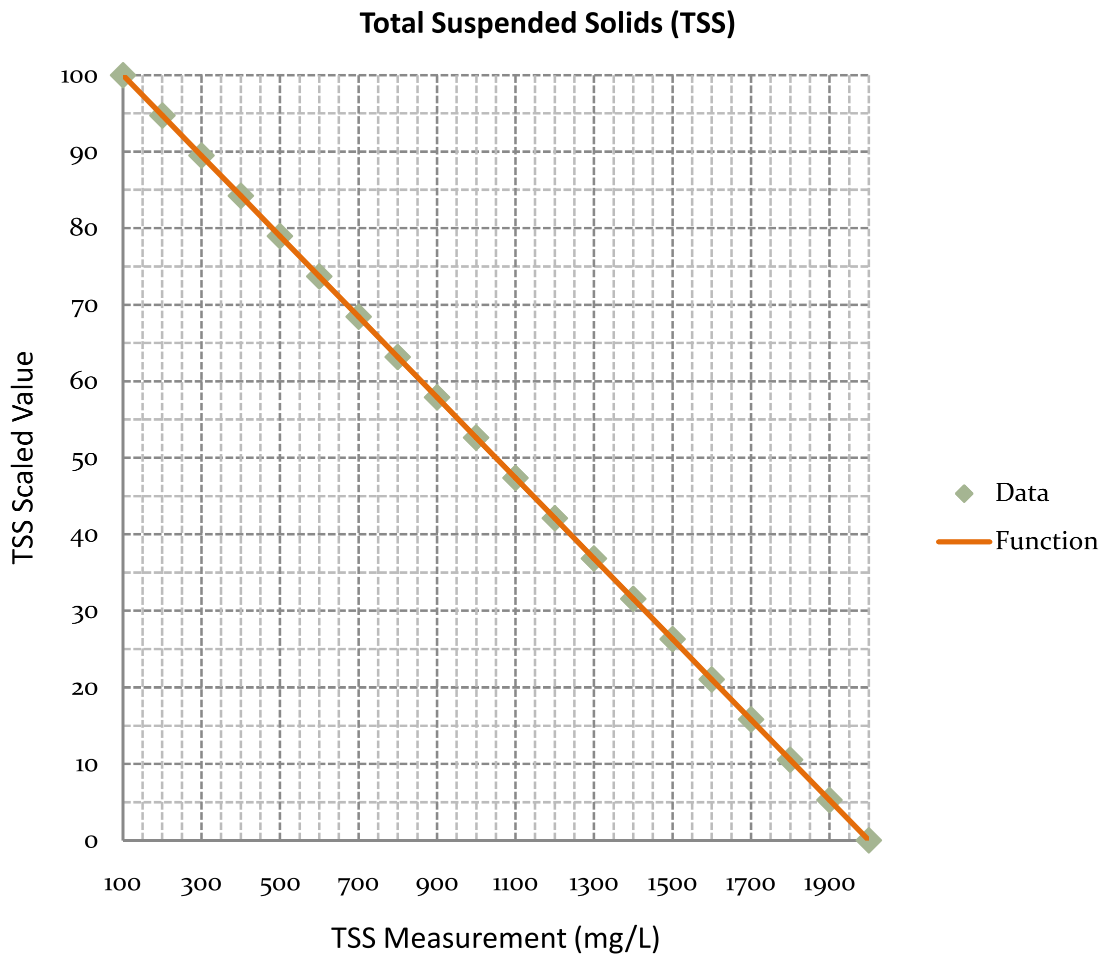
9.2 GRAPHICS OF SCALING FUNCTIONS FOR THE PARAMETERS OF THE WATER QUALITY INDEX.



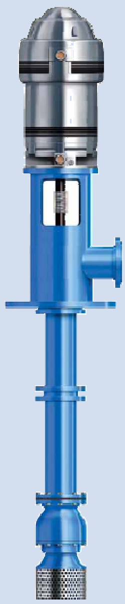

Biological Oxygen Demand (BOD)
BOD Scaled Value
100
80
60
40
20
0
0
20
40
60
80
100
BOD Measurement (mg/L)
Data
Function


Fecal Coli
FC Scaled Value
100
90
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
100000
FC Measurement (Colonies/100 mL)
Data
Function


pH
100
90
80
70
60
50
40
30
20
10
0
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
pH Scaled Value
pH Measurement (pH Units)
Data
Function


Total Suspended Solids (TSS)
100
90
80
70
60
50
40
30
20
10
0
100 300 500 700 900 1100 1300 1500 1700 1900
TSS Scaled Value
TSS Measurement (mg/L)
Data
Function

9.3 Pictures of selected pumps

PUMP TYPE		
Centrifugal	Submersible Booster	Submersible Well
		
(Web site: Shimge, 2010)	(Web site: Wacker Neuson, 2011)	(Web site: Zhejiang Water Pump Co., Ltd., 2010)
Turbine Booster	Turbine Well	
		
(Web site: ITT, 2010)	(Web site: ITT, 2010)	

9.4 PICTURES OF SELECTED TOILETS.

FLUSH TYPE (Actuators could change, but the basis of the classification is the quantity of water for discharge**)**

Economizer	Short Discharge interruption	Large Discharge interruption	Normal
			
(Web site: Become, Inc., 2011)	(Web site: Home to Dreamhome, 2011)	(Web site: IndiaMART InterMESH Limited, 2011)	(Web site: ATG Stores, 2011)

9.5 Pictures of selected shower heads.

SHOWER HEADS		
Rainshower	Rain shower with flow reduction	Sunflower shower
		
(Web site: Grohe Rainshower, 2011)	(Web site: Plumb-Warehouse, 2011)	(Web site: Shower Head Store, 2009)
Water lily shower	Roadrunner shower	Jet Spray shower
		
(Web site: Shower Head Store, 2009)	(Web site: Shower Head Store, 2009)	(Web site: Shower Head Store, 2009)
Efficient shower	Ultra low flow shower	Electric Shower
		
(Web site: Shower Head Store, 2009)	(Web site: Shower Head Store, 2009)	(Web site: Vesta Bathrooms, 2010)

9.6 PICTURES OF SELECTED FAUCET HEADS.

FAUCET HEADS			
Compression valve	Cartridge Type	Ball Type	Electronic sensor and aerator
			
(Web site: Diamond Bailey, 2011)	(Web site: Diamond Bailey, 2011)	(Web site: Plumbing Store, 2011)	(Web site: Sloan Valve Company, 2011)
Disc Valve	Push type	Swan Neck	
			
(Web site: Kohler Co., 2010)	(Web site: The Chicago Faucet Shoppe, 2011)	(Web site: Shopperhive Ltd, 2010)	

9.7 Pictures of selected Bathtubs.

BATHTUB TYPE				
Alcove (Three walls) Tub	Drop-in Tub	Clawfoot Tub	Freestanding Tub	Corner Tub
				
(Web site: Alcôve Style & Design, 2011)	(Web site: Tubz.com, 1999)	(Web site: Nextag Inc., 2011)	(Web site: Vintage Tub & Bath, 2011)	(Web site: Blue Bath, 2011)

9.8 Annual water domestic consumption in different countries of the World (L/capita)

COUNTRY	CONSUMPTION	COUNTRY	CONSUMPTION
United Arab Emirates	500	United Kingdom	153
Canada	326	Austria	153
United States	295	Luxembourg	150
Japan	278	Ireland	142
Australia	268	France	139
Switzerland	252	Germany	129
Finland	213	Netherlands	129
Italy	213	Belgium	112
Spain	200	Hungary	101
Portugal	194	Bulgaria	101
South Korea	183	Poland	98
Greece	175	Czech Republic	95
Sweden	164	India	25
Denmark	159		

Source: (Web site: Dardel & Eurostat, 2008)