Re-bathroom

Thermal and grey water reuse system in a domestic bathroom

POLITECNICO
DI TORINO

Area dell'ARCHITETTURA
Corso di Laurea Magistrale in DESIGN SISTEMICO

Re-bathroom

Thermal and grey water reuse system in a domestic bathroom

Supervisor:
Prof. Fabrizio Valpreda
Co-supervisors:
Prof. Barbero Silvia
Prof. Comino Elena
Prof. Luca Fois (Politecnico di Milano)

Candidate:
Zhao Shuyi

Academic year:
2018-2019

Acknowledgements

I would like to give great thanks to professors who helped me in this thesis: Prof. Valpreda Fabrizio and Prof. Barbero Silvia of DAD at Politecnico di Torino, Prof. Comino Elena of DIATI at Politecnico di Torino, and Prof. Luca Fois from Politecnico di Milano. Without their help, I cannot finish this project. I am very appreciated that they not only help me to keep in the right direction, but also help me with specific details. They gave me the confidence and the encouragement to working on this thesis.

Last but not the least, I want to express my gratitude to my parents and friends for providing me with support and faith throughout the process of finishing my thesis.

Zhao Shuyi

Abstract

The topic chosen for my dissertation deals with the field of sustainable design in the home, which considers the elements of society, environment and economic together, aims to eliminate negative environmental impact completely through skillful, sensitive design (McLennan, J. F.,2004).
The first part of is the understanding of the sustainable design, including the definitions, goals, and principles, etc.
The second section is to clarify the design method and design process of the thesis, providing a guide for the development of the paper.
The next chapter starts from the analysis of a home system to figure out the resource consumption and the opportunity to reuse the output. The analysis is based on a family with 4 people, which is one of the most common families. It is found out that the warm gray water could be an entry point. Thus, a literature review of gray water has been done, involving the domestic water consumption, gray water definition, current gray water treatment principles and methods. Besides, the related design cases of designing a product or a system is also explained in this part.
Finally, the clear-cut plan is defined in the chapter 4. Starting from the design guideline, concept and target users, the structure of gray water treatment system is decided. Combining the research on grey water treatment, it comes out that the method to achieve the function in the home. However, thinking about the difficulty and the cost of treating gray water in home, the equipment dealing with gray water is settled outside the home to save the room and the cost of buying and maintaining. In addition, the user experience and interaction is another aspect of consideration.
Furthermore, the management of economic and business model are been done to verify the feasibility of the project.

Content


Every leaf traps CO_2.
PLANT FOR THE PLANET
Donate trees on www.plant-for-the-planet.org

1

Sustainable design

"Surely we have a responsibility to leave for future generations a planet that is healthy and habitable by all species."

—— David Attenborough

In recent years, sustainable development has become an increasingly prominent issue. Present patterns of development and consumption are unstained in a world of growing population, rising human aspirations and limited carrying capacity. In order to move towards a more sustainable society, fundamental changes are needed to avoid serious risks to human well-being and natural systems. Sustainability is not a distant future issue, but a problem that requires progress and solutions now, if serious problems are to be avoided in the future.

1. Definition

According to Brundtland Report, sustainable development is defined as "··· development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts:

-The concept of 'needs', in particular, the essential needs of the world's poor, to which overriding priority should be given; and

-The idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs." (World Commission on Environment and Development, 1987)

2. Goals

Sustainable Development Goals (SDGs) proposed 17 goals and 169 targets,

Figure 1.1 Sustainable Development Goals (SDGS), (United Nations Member States, 2015)

what are part of the 2030 Agenda, which recognizes" that eradicating poverty in all its forms and dimensions, including extreme poverty, is the greatest global challenge and an indispensable requirement for sustainable development."(UN, 2015)

3. Three Elements

Sustainable development is not simply equivalent to ecological or environmental protection. It is generally considered to consist of three aspects.

-Environmental aspect: means to reduce the environmental impact as much as possible;

-Social aspect: means still meeting the needs of human beings;

-Economic aspect: refers to the economically profitable. There are two meanings: first, only economically profitable development projects are likely to be promoted, which makes it possible to maintain their sustainability. Second, economically loss-making projects are bound to obtain subsidies from other profitable projects in order to achieve a balance of finance, which may result more serious environmental damage.

Sustainable development emphasizes the coordinated development of the three elements, promotes the overall progress of society, and avoids the benefits on the one hand at the expense of other aspects of development

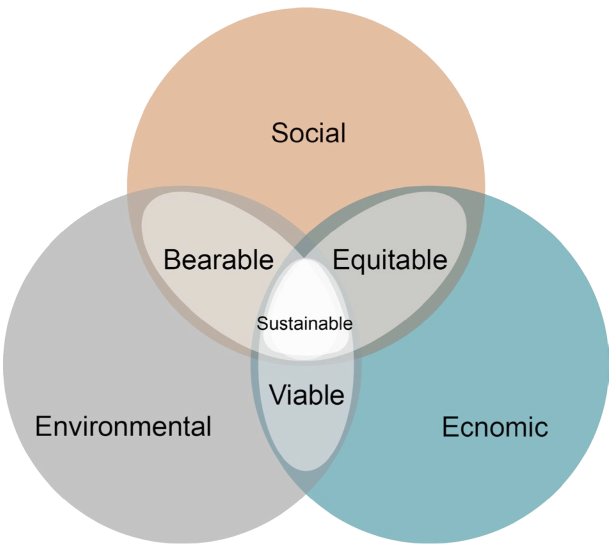


Figure 1.2
Components of sustainable development

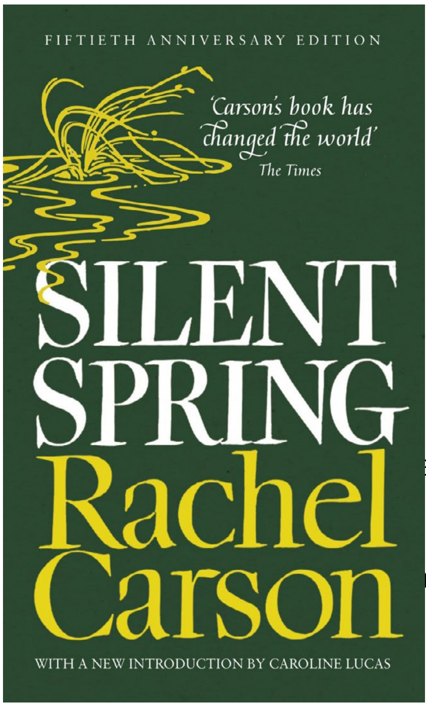
and overall social benefits.

4. Brief history

From about 14th century, with the using coal as the fuel, air pollution became to show up. Till 18th century, with the beginning of the Industrial Revolution, the emission of fuel gas, waste water, and waste residue increased rapidly. From 1950s, several great pollution events happened sometimes and shocked the world, such as Great Smog of 1952 in London, Minamata disease event in Japan in 1956, the photochemical smog episode in Los Angeles, etc..

Sustainable development can date bake to the idea of sustainable forest management which were developed in Europe during the 17th and 18th centuries. (Blewitt, John, 2015)

In 1960s, environmental movement increased the awareness of environmental problems. The publish of silent spring by Rachael Carson in 1962 made the great societal attention to the consequences of industrial pollution, and aroused people's concern about the relationship between economic growth and development and environmental degradation.



In 1969, America founded the United States Environmental Protection Agency (EPA). In the same year, US government's National Environmental Policy Act (NEPA) was made. It came largely in response to the 1969 Santa Barbara oil spill, which had a devastating impact on wildlife and the natural environment in the area (Danny Stofleth, 2015).

esirable "state of global equilibrium" in its clas- 1972, "We are searching for a model output n that is sustainable without sudden and un- e of satisfying the basic material requirements

Figure 1.3 Silent spring

of all of its people." In this report, the word "sustainable" was first time used "in the modern sense" (Danny Stofleth, 2015). In the same year of its publication, United Nations Conferences on the Human Environment was held in Sweden and presented Stockholm Declaration, which is the first document mentioned in the international environmental regulations document that human beings have the right to live in a healthy ecological environment.

In 1980, the International Union for the Conservation of Nature(IUCN) published a world conservation strategy that included one of the first references to sustainable development as a global priority (IUCN,1980) and introduced the term "sustainable development"(Sachs, Jeffrey D. 2015)

Two years later, the United Nations World Natural Charter proposed five principles of protection to guide and judge human behaviors that affect nature. In 1987, the United Nations World Commission on Environment and Development (WCED) published the "Our Common Future" report, often called as the Brundtland Report, which includes one of the most well-known definitions of sustainable development. (Smith Charles, Rees Gareth,1998).
Since the Brundtland report, the concept of sustainable development has transcended the original intergenerational framework and focused more on the goal of "social inclusive and environmentally sustainable economic growth". (Sachs, Jeffrey D. 2015)

In 1992, on the 20th anniversary of the first international Conference on the Human Environment, (Stockholm, 1972), the United Nations Conference on Environment and Development (UNCED), also known as the "Earth Summit", was held was held at Rio de Janeiro, Brazil.
On the conference, several documents were adopted, including Earth Charter, which outlines the establishment of a just, sustainable and peaceful global society in the 21st century, and Agenda 21, which "recognizes the right of

each country to pursue social and economic progress and gives countries the responsibility to adopt a sustainable development model.” (Danny Stofleth, 2015)

In the recent years, in 2013, a study concluded that sustainability reporting should be redefined through four interrelated areas: ecology, economics, political science and culture (Liam Magee, et al.,2013).

In 2015, the United Nations General Assembly formally adopted the 2030 Agenda for Sustainable Development, indicates 17 Sustainable Development Goals (SDGs).

Sustainability is an important topic for all human beings, and designers have the unshakable responsibility. A good design is not only the sustainability of the product itself, but also to promote sustainable development through the use of products, and to make users develop sustainable habits in a subtle way. In every field of the design, sustainability can be the subject of design, or at least one of the factors that should be considered.


1
2
3
4

2

Design method and process

"Methodology should not be a fixed track to a fixed destination but a conversation about everything that chould be made of happen."

——John Chris Jones

2.1 Design Methods

Design methods are procedures, techniques, aids, or tools for designing(Wikipedia, 2018). They offer many different types of activities that designers can use throughout the design process. They are tools that help designers to achicieve an innovate design thinking, and also to externalise the design process(Jones, J. Christopher, 1980).

There are various of design methods. As a designer, it is important to choose the suitable design methods according to the topic.

Generally, the sustainable design approaches can be divided into four levels:
- Product innovation level: Focus on improving the existing products or developing new products.
- Product Service System Innovation Level: The focus here is the integrated combinations of products and services instead of individual products
- Spatio-Social innovation level: the background of innovation here is the space of human settlements and communities. This can be solved in different contexts, from neighborhoods to cities.
- Socio-Technical System innovation level: focuses on how to achieve fundamental changes in social needs (such as nutrition, transportation, mobility) to support the transition to new social technology systems.

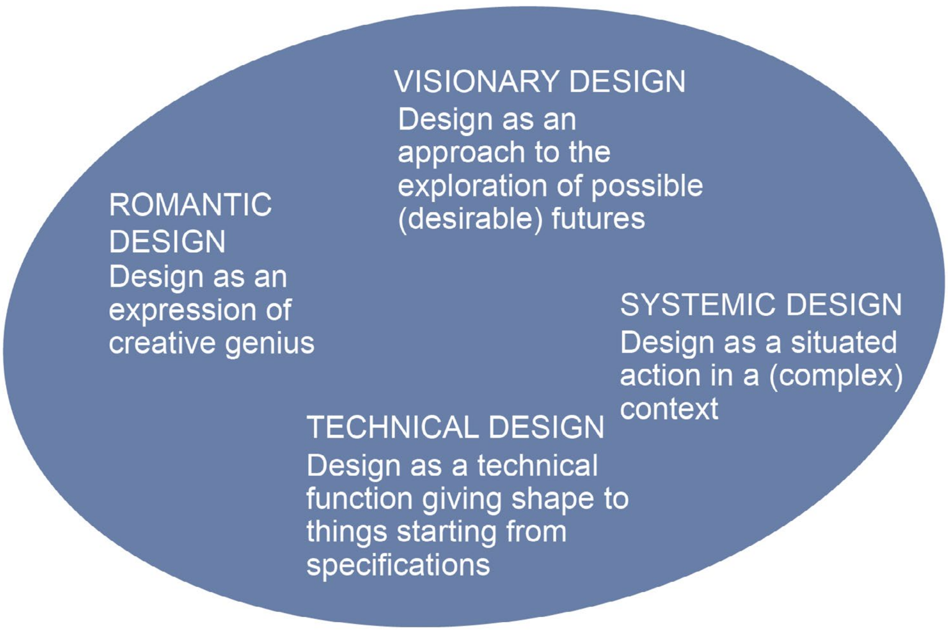


Figure 2.1 Many ideas of design (Alessandro Deserti, 2017)

-Sustainable product design

In product design, sustainability can be defined as the ability of a product to work continuously while ensuring lowest environmental impacts and providing economic and social benefits to the stakeholders. (Shamraiz Ahmad et al., 2018) because Manufactured products impact all three facets of sustainability (economy, environment and society) throughout their entire life cycle (Tarne et al., 2017). It was found that about 80% of sustainability impacts are decided at the product design stage (Keoleian and Menerey, 1993; Kulatunga et al., 2015; Lewis and Gertsakis, 2001). Thus, designing sustainable products was found to be an important strategy to achieve sustainability (Moreno et al., 2011; Ameli et al., 2016).

Sustainable product design plans and emphasizes the importance of the product's entire life cycle, from raw material selection, concept and structure formation, manufacturing and use to its end-of-life, reuse and recycling (Peng et al., 2013; Gagnon et al., 2012). The primary goal of sustainable product design is to reduce a product's resource use and emission to the environment(Shamraiz Ahmad et al., 2018), and to improve its socio-economic performance throughout the lifecycle from cradle to grave (Gagnon et al., 2012).

-Systemic design

System design is a recent design initiative that integrates system thinking and human-centered design to help designers cope with complex design projects.

The design challenges caused by the recent increase in complexity caused by globalization, migration and sustainability have led to inadequate traditional design methods, thus, designers need better ways to design responsibly and avoid unexpected side effects. System Design aims to develop methods and methods that help integrate system thinking and design into environmental, social and economic sustainability. This is a diversified initiative that encourages many different approaches to flourish, with new approaches to dialogue and organic development at the core.

Systems and complexity theories and design thinking redesign a pretty new discipline: the Systemic Design, which is located as a human-centered systems-oriented design practice (Bistagnino, 2011).

It can be defined as Designing locally-based productive systems in which waste from one productive process becomes input to other processes(Fabrizio Ceschin et al., 2016).

The system design uses a territorial approach to study local socio-economic actors, assets and resources with the aim of establishing synergies among the production process (agriculture and industry), natural processes and the surrounding territories (Barbero & Fassio, 2011). This approach can design material and energy flows from one element in the system to another, reducing waste flow elements by converting the output of each system element to the input (opportunity) of another system (Bistagnino, 2009), may lead to a new, local-based value chain (Barbero, 2011).

Systemic design approach was applied into various fields, including agricultural and food networks (Barbero and Toso, 2010, Ceppa, 2010), water treatment (e.g. Toso & Re, 2014), energy systems (Barbero, 2010), etc.

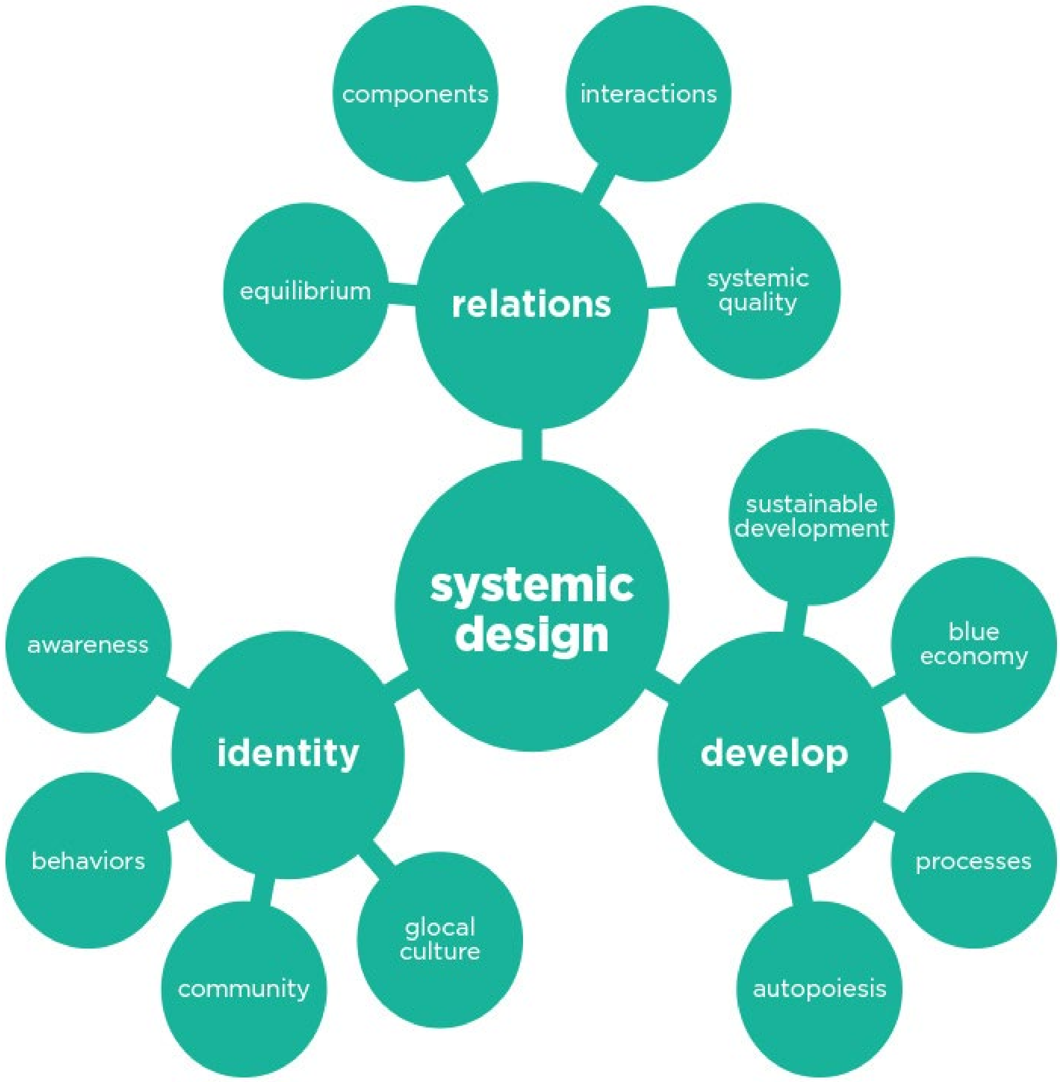


Figure 2.2 Systemic design (Maurizio Vrenna)

2.2 Design Process

The Design Process is a way to break down large projects into manageable blocks, which can make design simplified, clear and easier to control.
Designers use this method to define the steps needed to follow up whole project, and to make the design completed and comprehensive.

Design process varies among different fields, projects, designers. However, the core structure is similar.
-Design task clarification: First, defining the target by clarifying the stakeholder, need, and requirement.
-Problem framing and idea generation: Understanding the key problems and to clear up the problem and to sum up partial ones from the plenty of solutions that produced by brainstorming.
-Ideal selection and concept formulation: Selecting the suitable solution, proposing the guideline and forming the outline and concept of the design.

Every step needs iterate to achieve a better solution. Furthermore, the whole design process is necessary to repeat in order to lead to the final proposal.

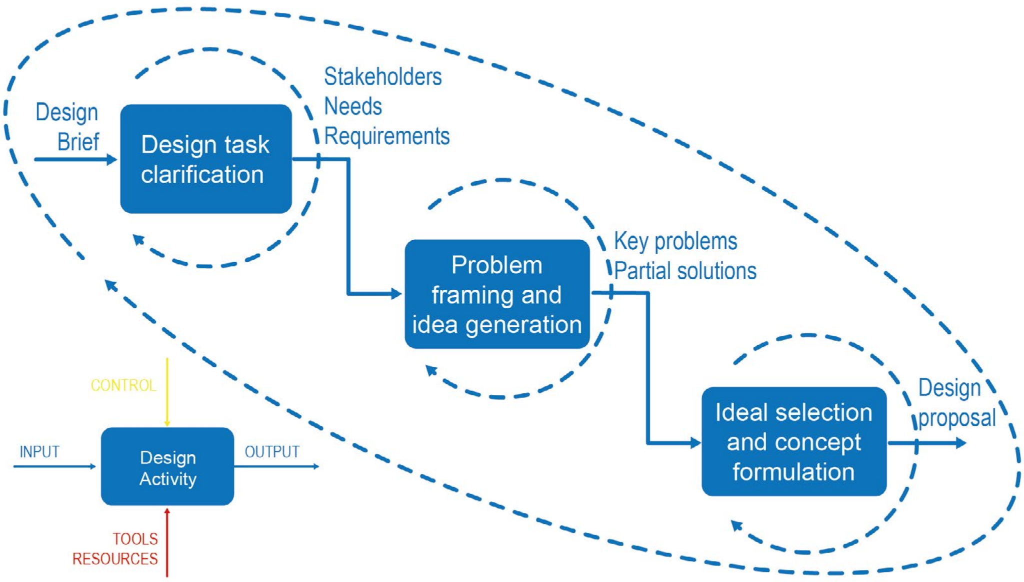


Figure 2.3 Main stages of design process (Gaetano Cascini, 2017)

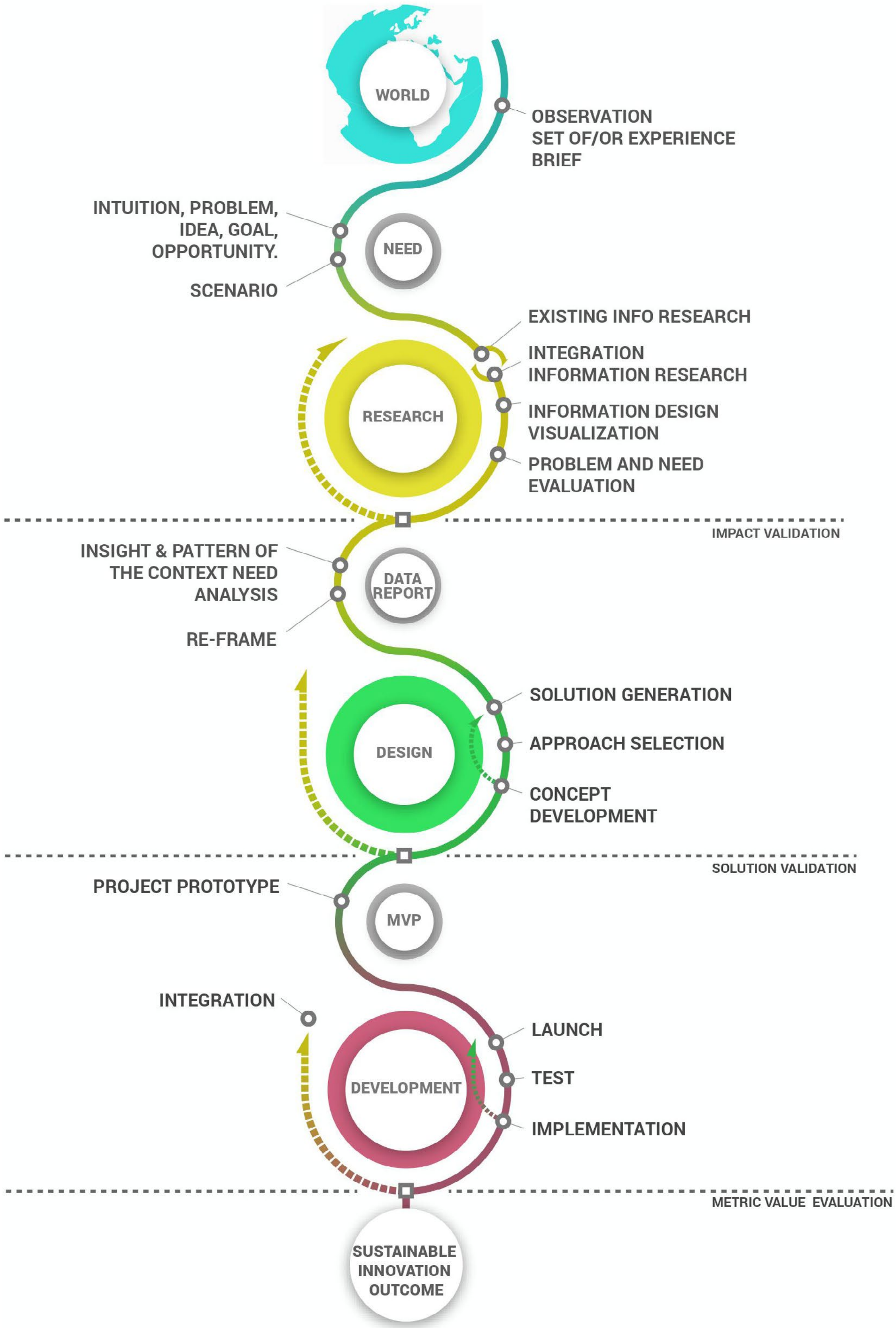


Figure 2.3 Design process (Paolo Tamborrini, 2016)

Some design flow charts explain the design process more detailed.
The flow chart in figure 2.3 shows the specific design process, including observation, finding out the need, research, data report, design, prototype, development, and final outcome. Each single step is supposed to repeat to reach a better result. The overall process before getting the outcome can be divided into 3 phases: impact validation, solution validation, and metric value evaluation.

In conclusion, the exact design process for each project depends on the circumstances.

Design process that used in this thesis presents as follow:
1.Knowing the sustainable design and relevant methods;
2.Analyzing the untilization and consumption of resource in home, finding out the input and outout, deceiding the focus, doing the literaure review to understand the stat of the art, and searching some example cases;
3.Defining the guideline, concept, target and coming up the ideas;
4.Developing the details including the systemic structure, implementation methods, etc.;
5.Evaluating the feasibility by magement cost and bussiness model.


17.2.9.

3

Home System

"A house is made of walls and beams, a home is made of love and dreams."

——Anonymity

3.1 Home system analysis

It is essential to start with the understanding the resource utilization in the home system in order to find out the opportunities to promote the enjoyment of personal life by optimizing the resource consumption, including reducing the input, recycling and reusing the output.

The analysis takes the family with 4 people as an example, aims to figure out the structure and percentage of the resource consumption in common families.

1. Personas

Figure3.1 Family portrait

Elena
35 years old
company employee
lives with her family

A family with 4 people-parents, a 7-year-old girl and a 5-year-old boy.
Under the education from the father of a university professor, they have developed a good habit of saving, such as turning off unneeded lights, buying the household electrical appliances with a higher energy consumption level.
In one word, it can be summaried as they eliminate waste while ensuring quality of life.

Figure3.2 Family activites

The figure above shows the daily activites in their family.
The breakfast usually makes up by a cup of coffee, a glass of juice and some croissants, which means they use coffee pot, jucer, and toaster everyday.
Family dinner, generally with the 4-people-family, with a big family including cousions and grandparents twice a week indicates that the oven is needed. Besides, sometimes the baking with children make the additional consumption of the oven.
Every member of the family takes shower everyday. And children are old enough to use the shower instead of a bathtub.
They always have the family activity, for example, watching a family film together once a week. In addition, children watch cartoons and parents watch TV shows everyday.
The 7-year-old daughter is already in school and she needs to do the homework and reading every week day. However, the reading before sleeping for 5-year-old son is also needed.
The husband generally needs to use the computer in home to deal with the work stuff.
The list of the daily activities can help us to image that what kind of life stytle they usually have.

Figure 3.3 Floor plan of the house

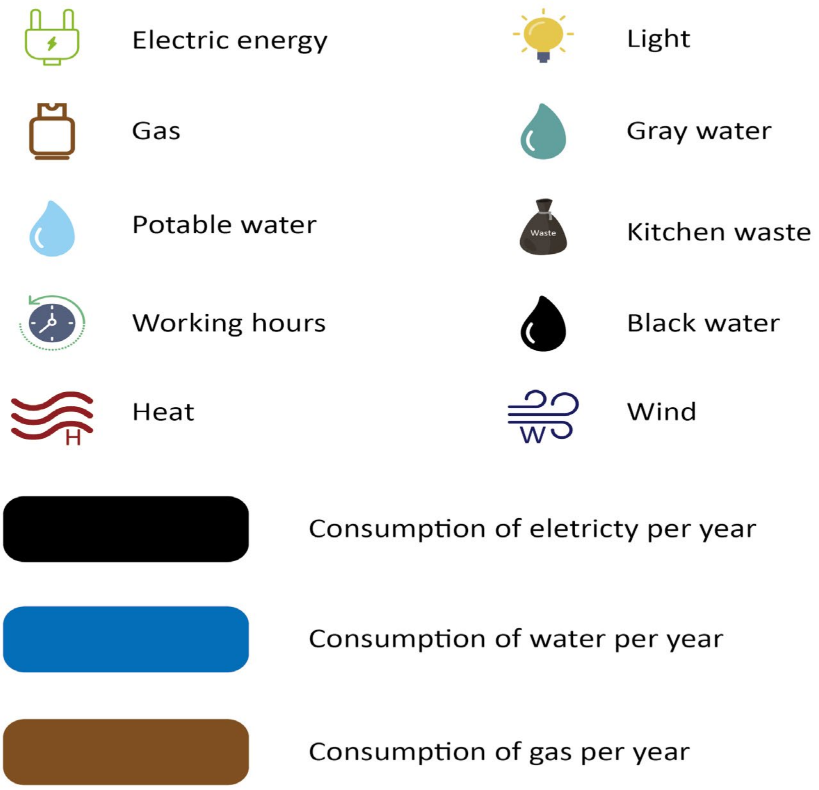
The figure 3.3 shows one of the most common layouts of a house that suitable for a 4-people family. It is consisted of a kitchen, a dining room, a living room, two bathrooms and three bedrooms. The total area of the house is 118 square meter.
3 bedrooms is the suitable number so that children don't need to share the bedroom, and 2 bathrooms can reduce conflicts effectively.

As for the consumption of the resource, according to the average number of italian family, a 4-people family consumes 3300 kilowatt hour of eletricity per year(Dati dell'Autorità,2018) and 256 cubic meter of water per year(ISTAT,2012).

2. Resource Consumption

Based on the personas, from figure 3.4 to figure 3.8 show the detailed resource consumption in the home, including electric energy, water and gas. Every equipment has a specific example with the concumption in every year, product model, energy efficiency level, and working time. The waste of each appliance is signed too.
For example, the refrigerator in the kitchen uses eletricity with the amount of 255 kwh per year, and has the out put of the heat.

Icons used in the schemas:



The resource that labeled on the top of appliances is the input(the consumption), while the one on the bottom is the output (the waste).
Eletric energy, potable water and gas illustrate the resource that the equipment consumes, annotated with working hours so that it is easy to know the consumption of resourece per year.
Gray water, heat, light, kitchen waste, black water and wind are the output of appliances.

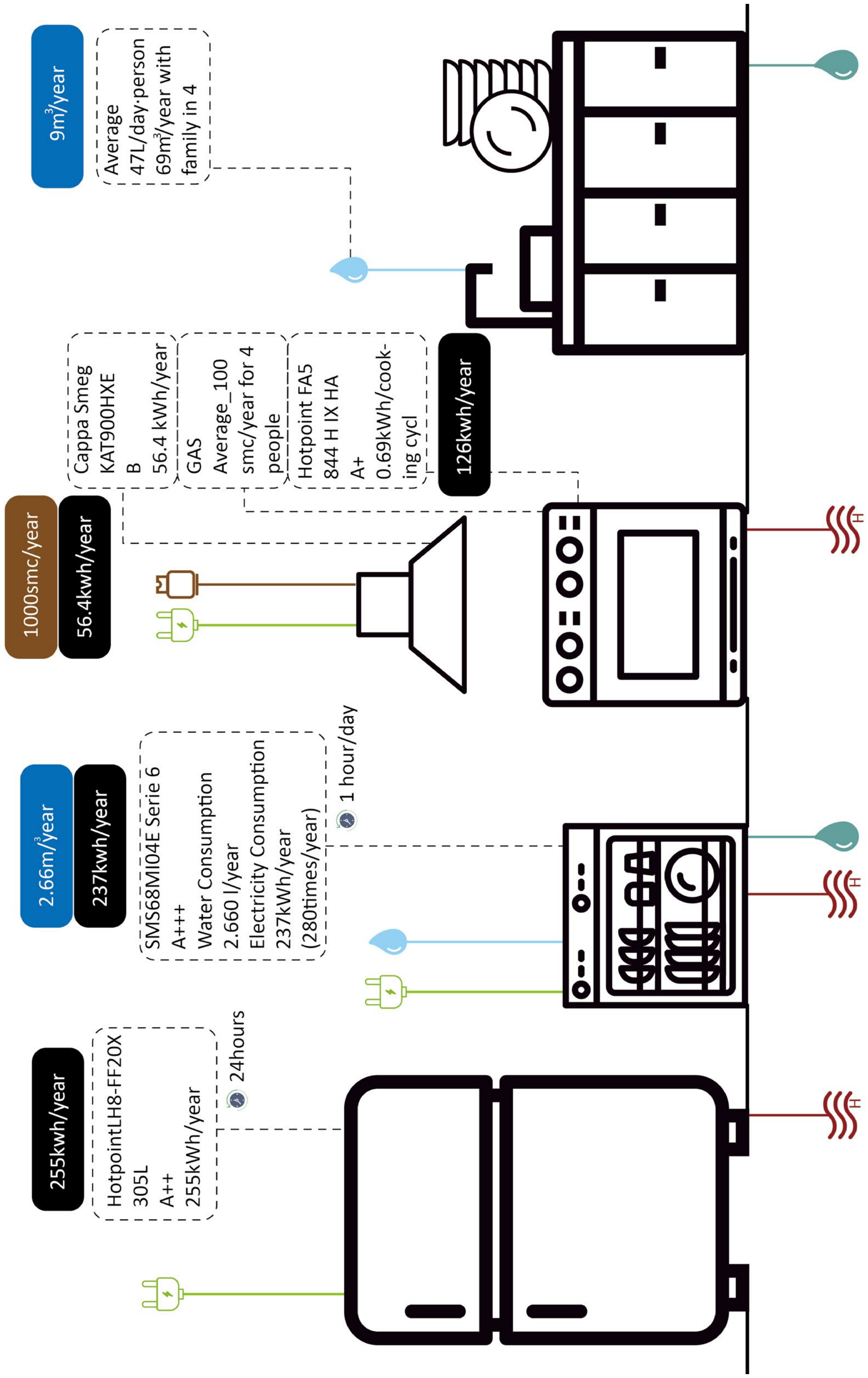


Figure3.4 Resource consumption in kitchen(1)

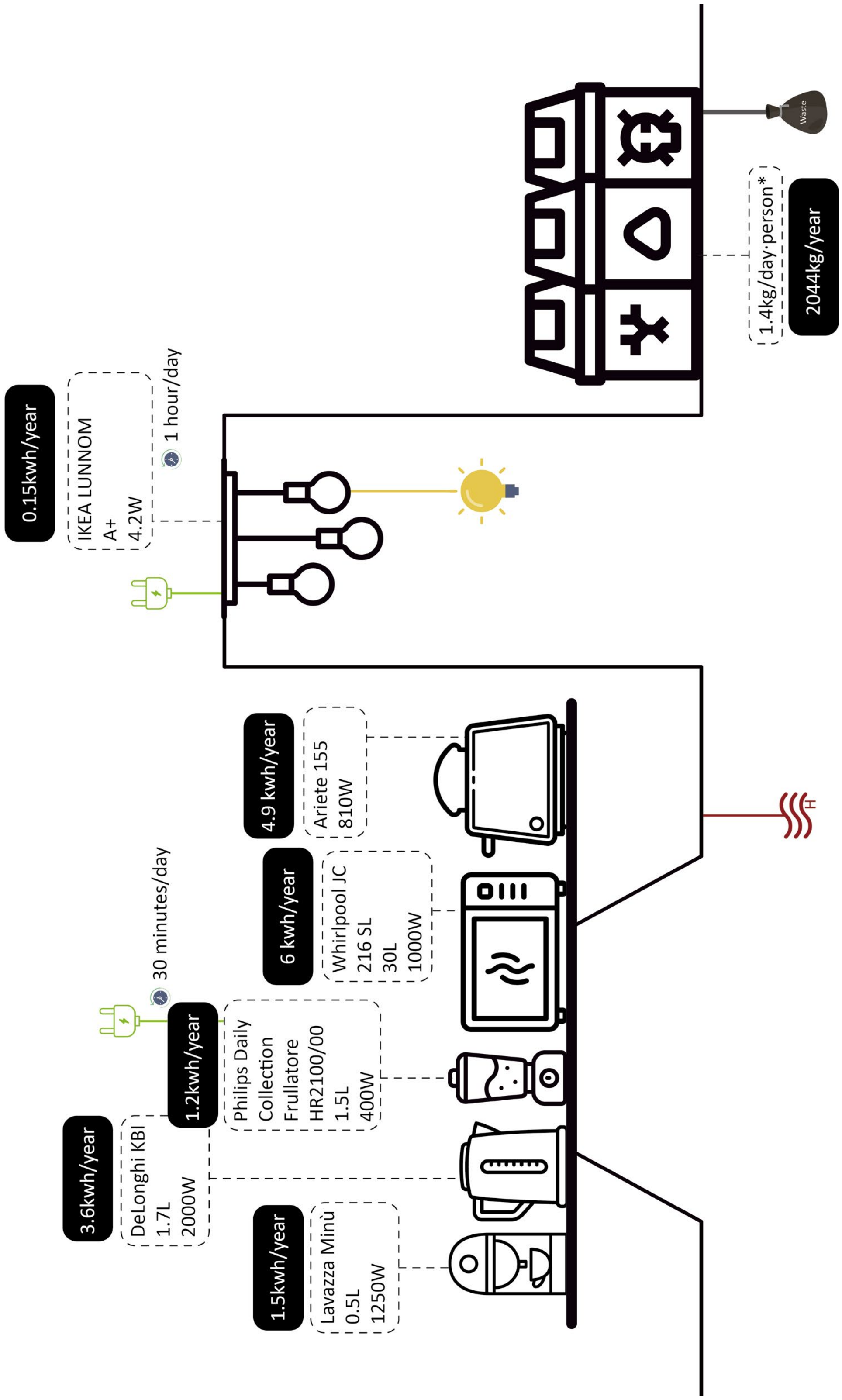


Figure3.5 Resource consumption in kitchen(2)

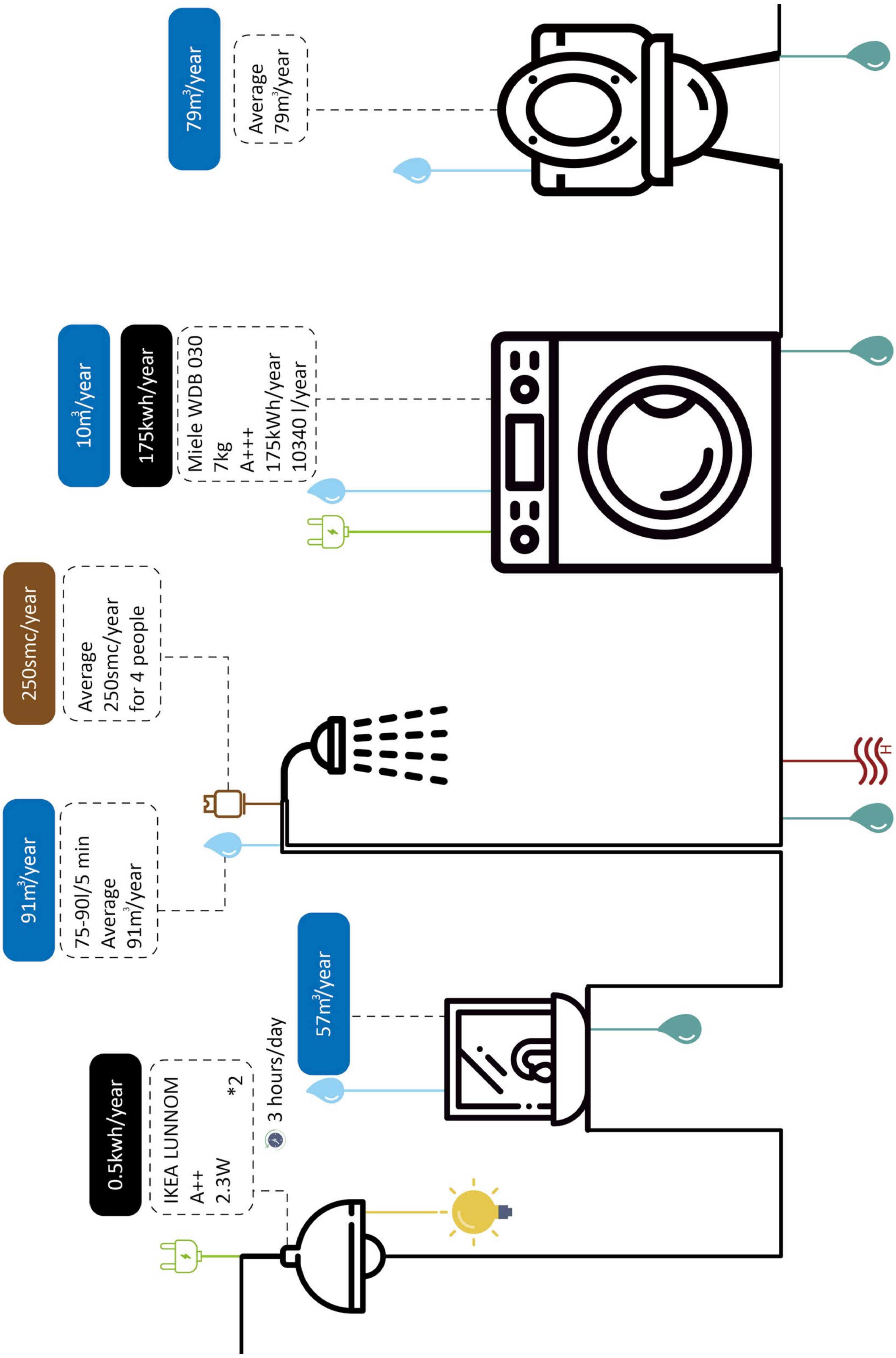


Figure3.6 Resource consumption in bathroom

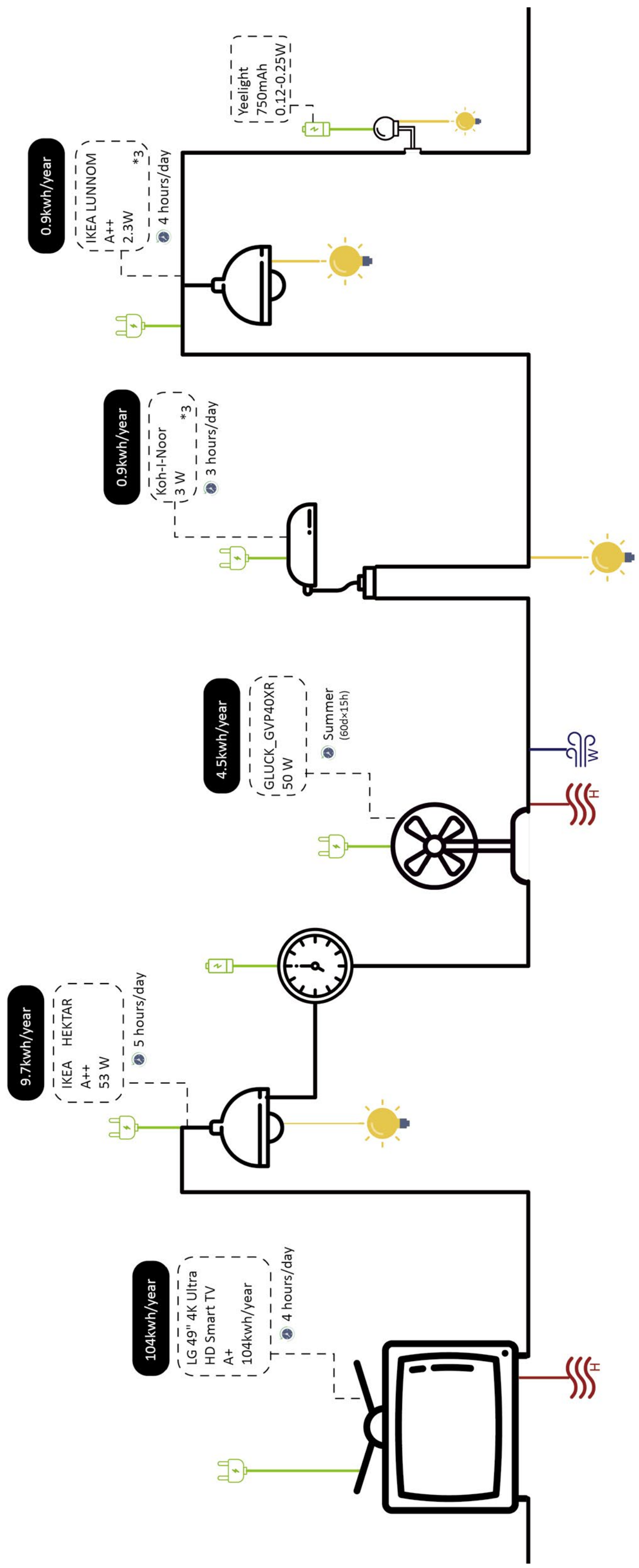


Figure3.7 Resource consumption in living room and bedroom

It can be concluded from the schemas that, the consumption of electricity is the most comprehensive one, which is used in every room. The water cosumes mainly in the bathroom, also another part in the kitchen. The waste that produced by potable water is principally gray water while the black water is only produced by toilet.
The output is mostly consisted by the light, heat and gray water.

Furthermore, to find out opportuinties to reuse the waste and reduce the consumption, figure 3.9 to figure 3.11 arrange and divide all the appliance by types of the consumption, so that it is easy to understand the situation of input and output in home system.

Figure 3.9 shows the appliances that consumes electricity. The out put of these appliances comes out into light and heat.
In figure 3.10, there are equipments that uses potable water and produces gray and black water, while the equipments in figure 3.11 consumes gas and generates heat.

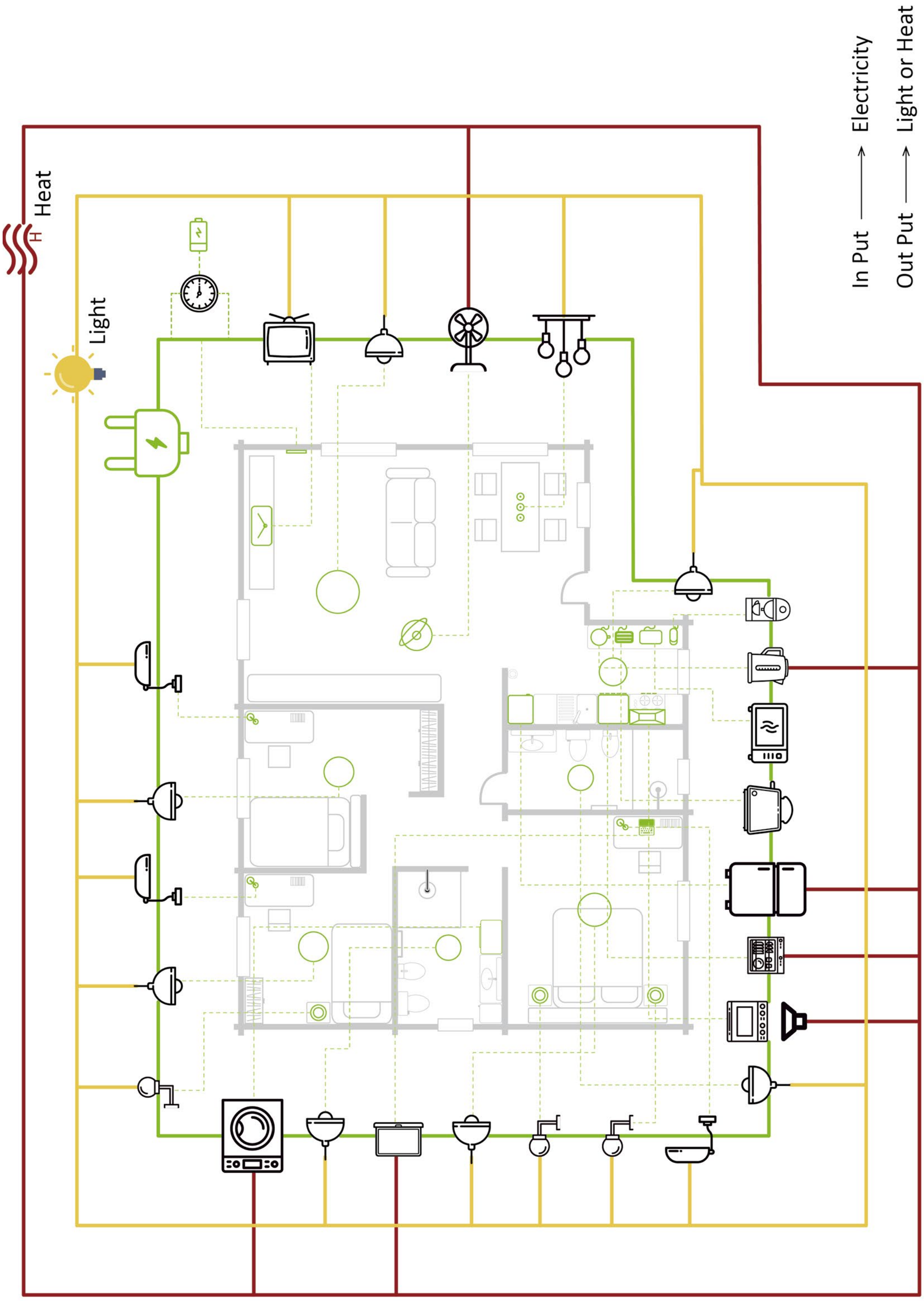


Figure3.8 Electricity consumption

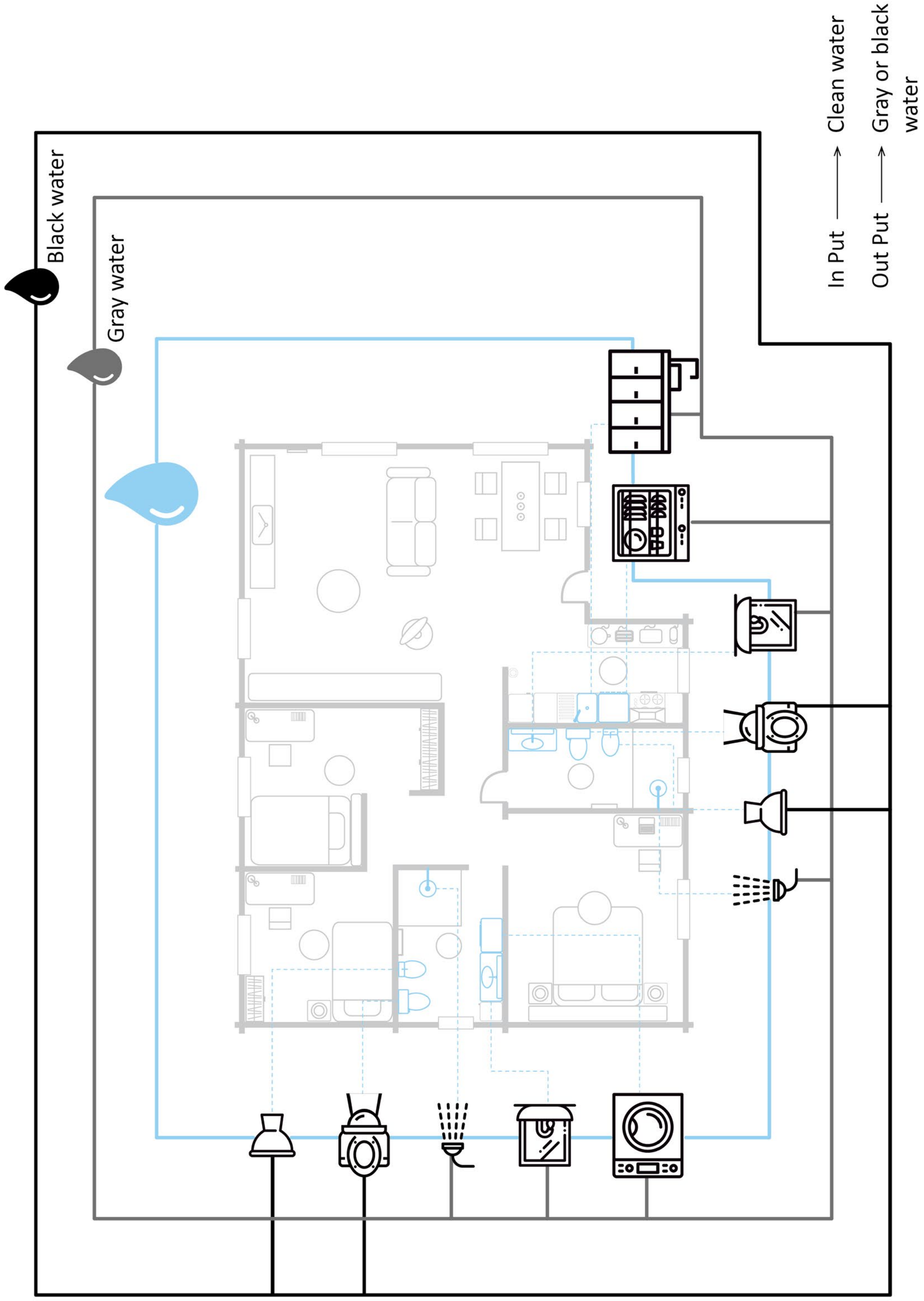


Figure3.9 Water consumption

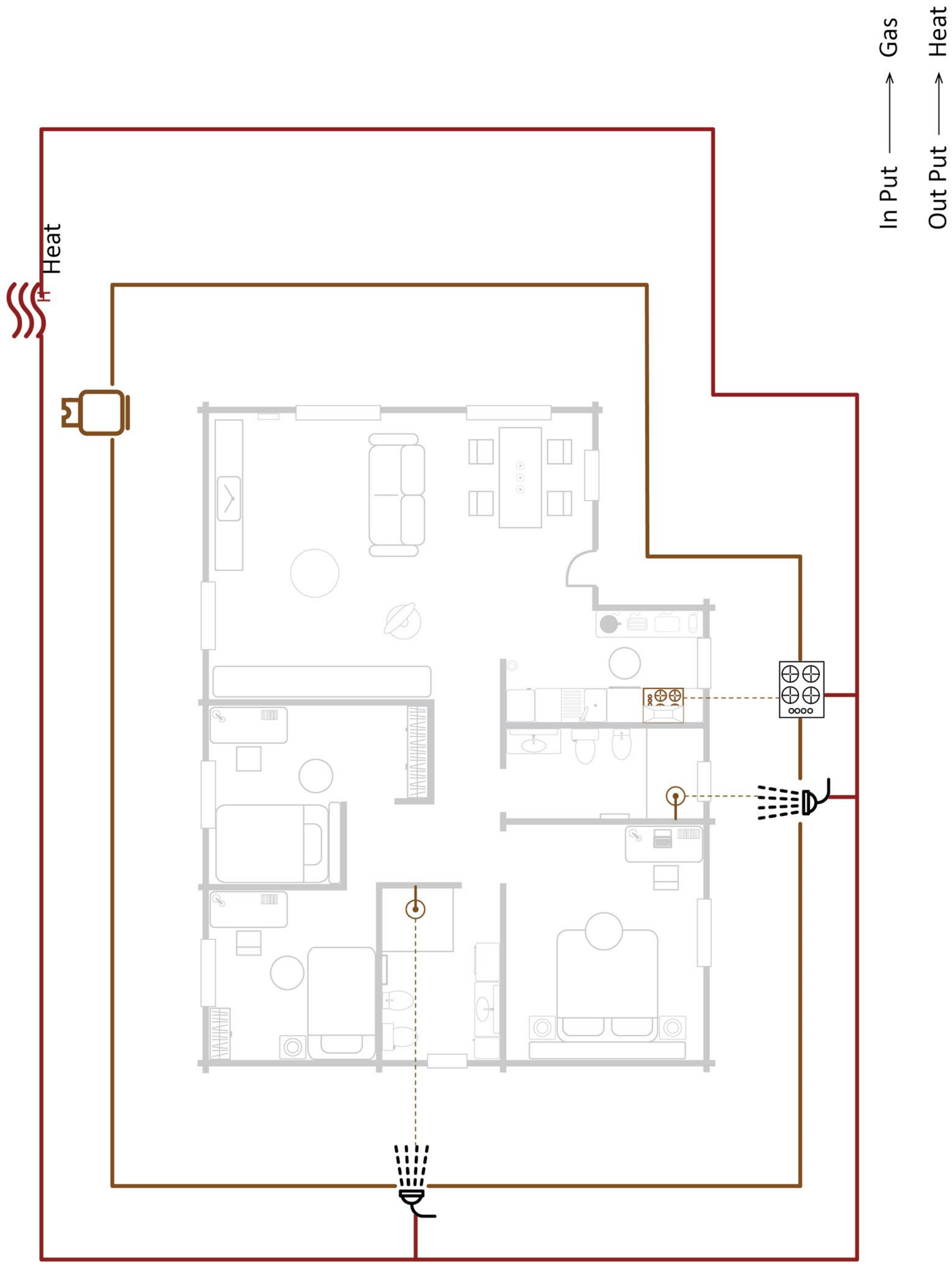


Figure3.10 Gas consumption

In addition, there are equipments that showed up in 2 schemas, which means they use 2 different types of resource together. From the perspective of the output, it can be orgianzed in heated gray water and heated air, showing in figure 3.12 and figure 3.13.

The dish-washing machine, washing machine and shower produce the heated gray water. And we can know from the analysis above that, the warm gray water produced by shower is much more than the others, with the number of $91m^3$ per year comparing with the sum number of $12.6m^3$ per year. Besides, the position of washing machine is various depending on each family, however, it is mostly placed in the bathroom.
The data leads us to the conclusion that the warm gray water is produced mostly in the bathroom.

As for the heated air, it is produced mainly in the kitchen by oven, frige, cooking and boiling the water. The heated air partly comes from heat dissipation, which is little and diffcult to calculate andcollect. One the other hand, the heat produced by cooking and electric kettle is mixed with odour or water vapor.

Moreover, it can be easily found out that this kind of equipment distribute mainly in the kitchen and bathroom.

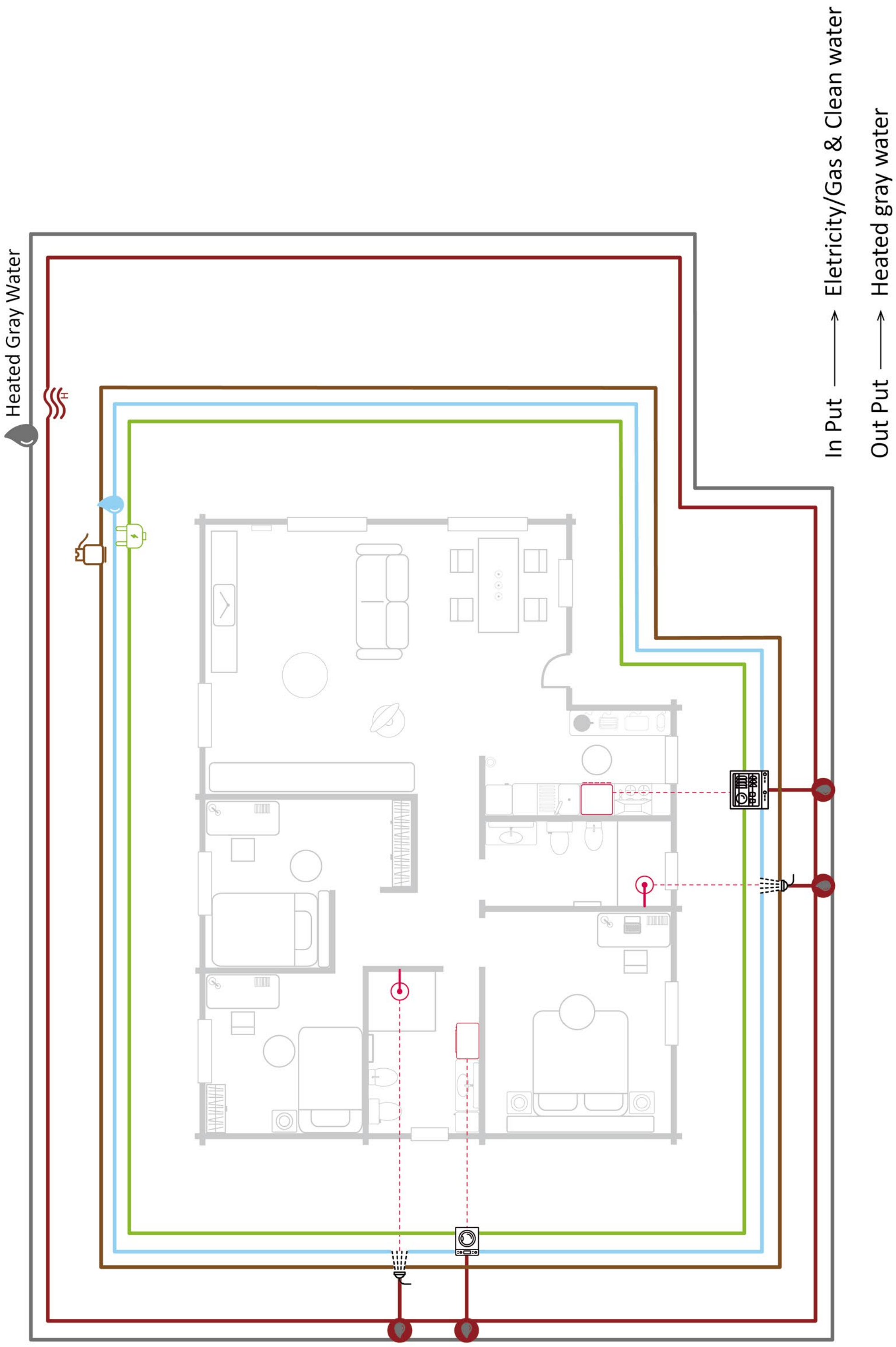


Figure3.11 Out put of heated gray water

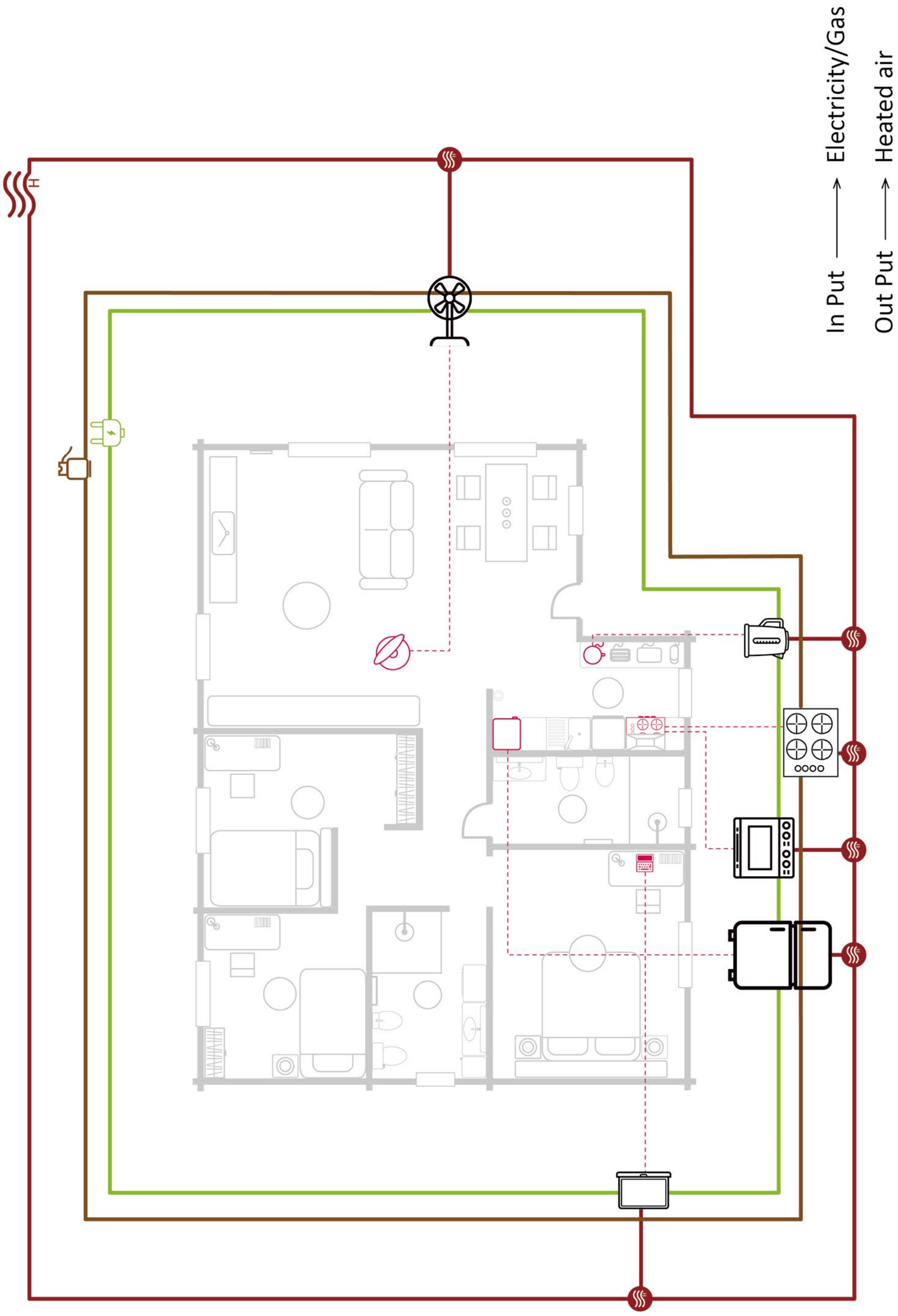


Figure3.12 Out put of heated air

The method of systemic design is to find out the way to reuse the output. In other word, is to change the output into another input instead of ignoring.

Figures3.14 shows the opportunities to reuse the resource:

-The heat that carried by heated gray water and heated air can be reused by heat exchange, and the cooling gray water can continue to be reused again;

-Gray water can used to water plants and to flush the toilet, fianlly becomes to black water;

-The light can be used to grow plants;

-Black water cannot be used any more in domestic system.

It can be observed that the reuse of output becomes a flow chart:

Firstly, heated gray water turns into cooling gray water and heated air turns into room temperature after heat exchange to reuse the heat. Next, the gray water is recollected and reused by watering the flower and flushing the toilet. Finally, the flow chart ends up with the balck water that cannot be reused anymore.

The flow chart leads us to the conclusion that, heated gray water and heated air are the starting point of the whole circulation. However, it is diffcult fo recycle the heated air in the most situation, thus, the thesis will focus on working with **heated gray water**. Furthermore, the bathroom is the place where the water cunsumes the most and produces the most heated gray water, so that building a heated gray water in **bathroom system** will be the target of the thesis.

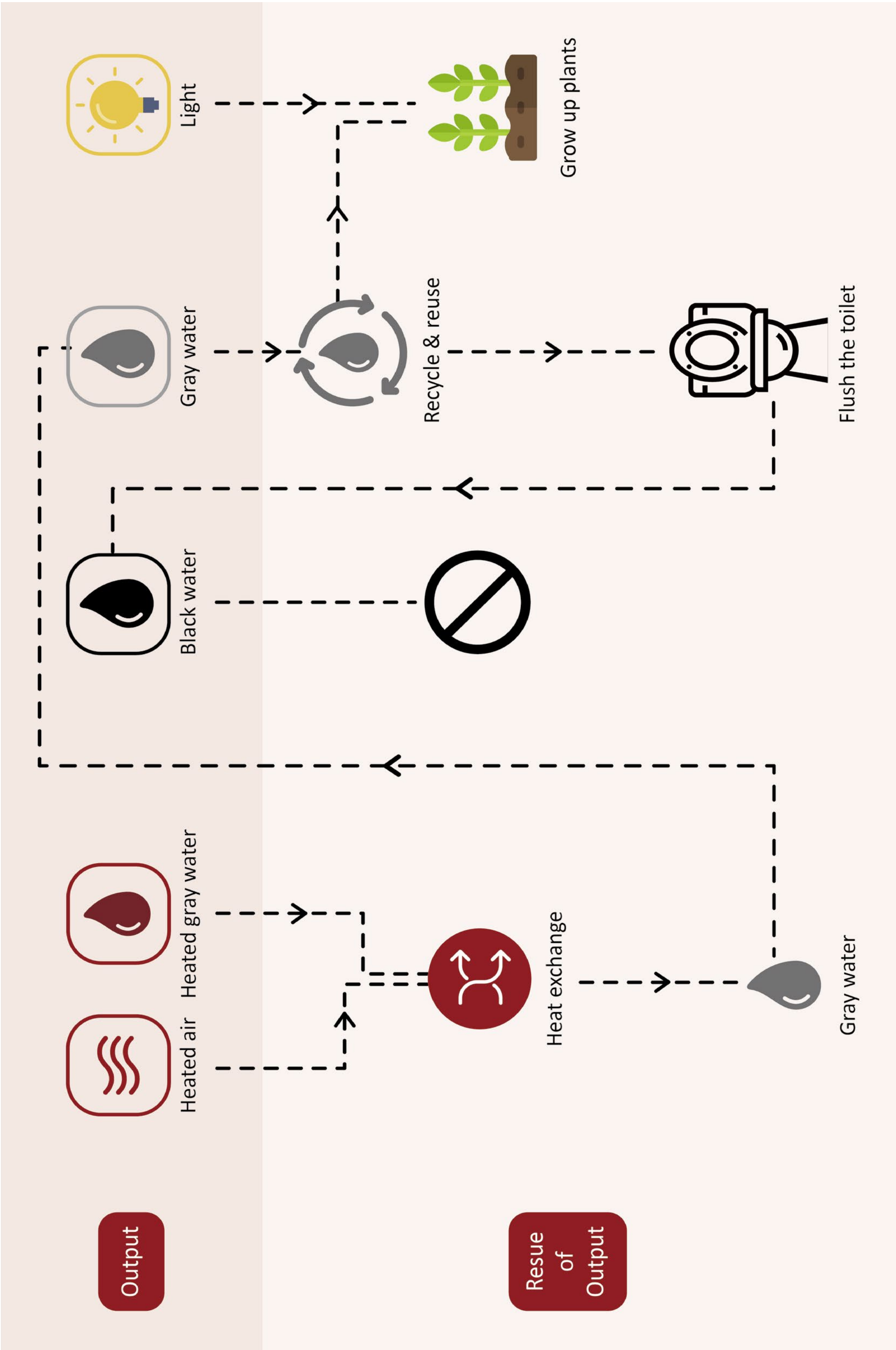


Figure3.13 Reuse methods of out put

3.2 Domestic waste water

According to the analysis before, the system will centre on the gray water. Thus, a research of domestic water consumption and gray water treatment and reusage is needed.
This part will show the general situation of the domestic water utilization, the importance of water reuse, the definition and the amount of gray water, treatment and assessment method of the gray water. Moreover, a literature review of gray water handling approaches is summarized.

1.Domestic water consumption

Water is one of the most essential resource that people use in their daily lives. Taking Italy of an example, the quantity of water consumption for one person per day is 250L.

Water abstractions refer to freshwater taken from ground or surface water sources, either permanently or temporarily, and conveyed to the place of use (OCED, 2005).
The total amount of freshwater abstraction in Italy is 56 200 m3, 980m3 per capita per year (OCED, 2005), and the freshwater abstraction by public water supply in Italy is 159.1m3 per inhabitant per year (EU, 2012).

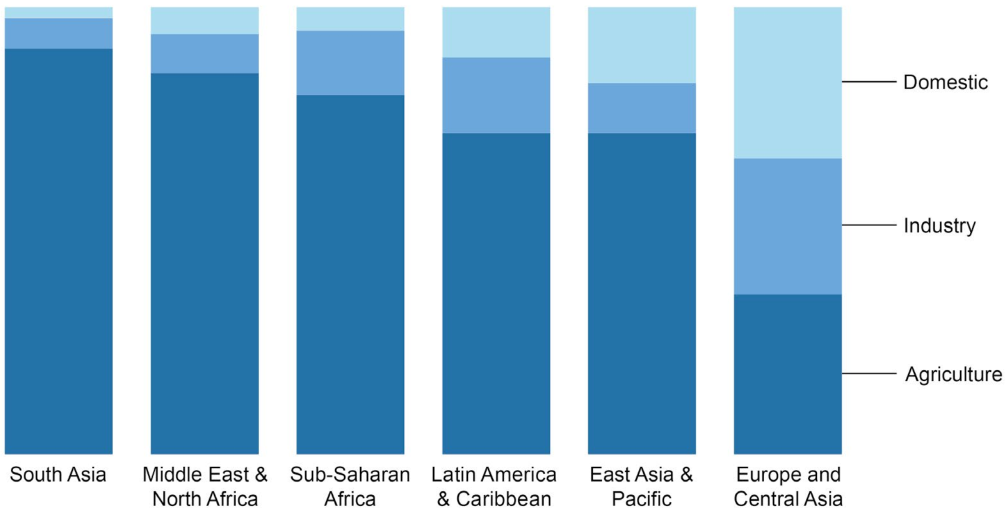


Figure3.14 Worldwide water consumption structure (Food and Agriculture Organization,2014)

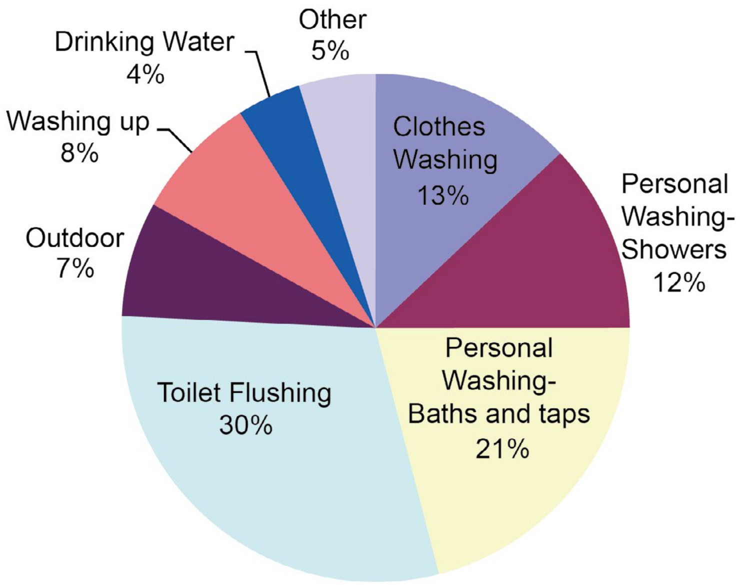


Figure3.15 Water use in home(Water wise, 2007)

The domestic water consumption takes the percentage of 33.5 of total amount in Europe (Food and Agriculture Organization, 2014), and the water is used to different uses. Except the toilet flushing, which produces black water, the personal washing (including baths and taps) takes the maximum ratio, which is 21%.

2.Water stress and importance

Water resource is considered as one of the most critical issues in many countries. Even three-quarters of the world is covered by water with the total volume of 1.386 billion cubic kilometers, the fresh water accounts only 2.5% of the total amount, of which less than 1% is usable fresh water, mainly sourced from rainwater, groundwater, snowfall and other surface fresh water (Rozin et al., 2015). Because of the population growth, resource consumption and the pollution problems, water supply is difficult to keep up with the pace of demand. The global demand for has doubled roughly every 21 years (Zhe Li et al., 2010). By 2050, insecurity of these resources will mostly be felt in urban areas resulting from urban population increasing by up to 70% of the total population (Evan Wanjiru & Xiaohua Xia, 2017).

In this content, the most important uses of water has been identified as urban (i.e., households and industry connected to the public water supply system), industry, agriculture, and energy (i.e., cooling in power plants) (Giulia Romano et al., 2015). Cities and urban areas are large consumers of water in many countries (Ren et al., 2016). For instance, they accounted for 95% of water consumption growth in United States between 1985 and 2005 (Jeong, Gulbinas, Jain, & Taylor, 2014).

According to statistics, Italy has the highest water use per capita in Europe (EU,2012), and is one of the highest users among OECD countries (OECD, 2009). However, Italy is actually a water-stressed country and has one of the least available water per capita of the 25 EU countries (EAA, 2008).

3. Grey water and black water

The recycle and reuse of grey water is one of the effective ways to solve the problem of water stress.

Grey water is defined as the urban wastewater that includes water from baths, showers, hand basins, washing machines, dishwashers and kitchen sinks, but excludes streams from toilets (Jefferson et al., 1999; Otterpohl et al., 1999; Eriksson et al., 2002; Ottoson and Stenström, 2003). Some authors exclude kitchen wastewater from the other grey water streams (Al-Jayyousi, 2003; Christova-Boal et al., 1996; Little, 2002; Wilderer, 2004)

Grey water accounts for 50-80% of total domestic water consumption. In dwellings and residential buildings, treated grey water reuse might represent 40–47% reduction of total water consumption (Santos et al., 2012).

The published literatures indicate that the typical volume of grey water varies from 90 to 120 l/p/d depending on lifestyles, living standards, population structures (age, gender), customs and habits, water installations and the

degree of water abundance (Morel and Diener, 2006). And because of the characteristic of it, grey water is considered particularly suitable for on-site (i.e. decentralized) treatment and reuse (Revitt et al., 2011).

The guidelines for safe use of wastewater, excreta and greywater provided by the World Health Organization (WHO) accentuate on the prominence of grey water as an alternative water resource (World Health Organization, 2006). According to WHO, grey water can contribute to this as it is: (a) still water; (b) makes up the largest volume of the waste flow from households (c) has nutrient content that, although low, can be beneficially used for crop irrigation; (d) has low pathogen content; and, (e) can be used to reduce the demand for first use water (Mandal et al., 2011; WHO, 2006).

4. State of art

Generally, the treatment system of grey water depends on the quantity to be treated and the reuse applications (Mandal et al., 2011), and is also based on the site conditions and grey water characteristics (Carme Santasmasas et al., 2013). The major difficulty for the grey water treatment its various composition. There are 4 criteria for grey water treatment: hygienic safety, aesthetics, environmental tolerance, and technical and economic feasibility (Al-Hamaiedeh and Bino, 2010; DHWA, 2002).

Followings are some common parameters that are used to assess the quality of grey water.

1) PH: is a logarithmic scale used to specify the acidity or basicity of an aqueous solution. It reflects the activity of hydrogen ions;
2) TSS (total suspended solids): is the dry-weight of suspended particles, that are not dissolved, in a sample of water that can be trapped by a filter that is analyzed using a filtration apparatus. It is a common water quality parameter;
3) Turbidity(NTU): refers to the turbidity caused by a large amount of suspended matter in the water sample, it is the degree of light scattered by the particles suspended in the liquid. Turbidity measurement is one of the important test items for water pollution;
4) BOD (mg/l): biological oxygen demand, is the amount of dissolved oxygen required for the oxidation process during a certain period of time during which the aerobic microorganisms in the water decompose the organic matter in the water into inorganic matter at a certain temperature. It takes 20 days to determine the BOD in the first stage, which is difficult to achieve in practical work. Thus generally takes 5 days as the standard time for determining BOD, expressed as BOD5. BOD5 is about 70% of BOD20.
5) COD (mg/l): chemical oxygen demand, is an indicative measure of the

amount of oxygen that can be consumed by reactions in a measured solution. It reflects the amount of organics in water. The ratio of BOD and CON accounts for the proportion of organic matter that is difficult to biodegrade in water. Organic pollutants that are difficult to decompose by microorganisms are more harmful to the environment.

6) TN (mg/l): total nitrogen
7) TP (mg/l): total phosphorus
8) Total coliforms (CFU/100ml): is the total coliform group includes bacteria found in the soil, in water affected by surface water, and in human or animal waste. It is the most basic test for bacterial contamination of a water supply for testing total coliform bacteria. The total coliform count gives a general indication of the sanitary conditions of the water supply.
9) Fecal coliform (CFU/100ml): is the total coliforms that are thought to be particularly present in the intestines and feces of warm-blooded animals. Since the source of the fecal coliform is more specific than the origin of the more general total coliform, fecal coliform is considered to be a more accurate indicator of animal or human waste than the coliform.

The general methods used to treat grey water including physical treatments, chemical treatments, and biological treatments. (Fangyue Li et al.,)
-physical treatments include coarse sand and soil filtration and membrane filtration. physical processes physical processes alone are insufficient to guarantee an adequate reduction of the organics, nutrients and surfactants except in situations where the organic strength is extremely low (Fangyue Li et al.,).
-chemical treatments involve coagulation, photo-catalytic oxidation, ion exchange and granular activated carbon
-biological treatments include rotating biological contactor (RBC) (Nolde, 1999; Friedler et al., 2005; Eriksson et al., 2007), sequencing batch reactor (SBR) (Shin et al., 1998; Hernandez et al., 2008), anaerobic sludge blanket (UASB) (Elmitwalli and Otterpohl, 2007; Hernandez et al., 2008), constructed wetland (CW) (Li et al., 2003; Gross et al., 2007) and membrane bioreactors (MBR) (Lesjean and Gnirss, 2006; Liu et al., 2005; Merz et al., 2007), etc. And most of them have been applied for grey water treatment.
Before biological treatments, there is the physical pre-treatment step such as sedimentation, usage of septic tanks (Nolde, 1999; Li et al., 2003) or screening (Friedler et al., 2005).
And after biological treatments, besides MBR process, usually follows by a filtration step (for example sand filtration) and /or a disinfection step to meet the non-potable reuse standards (Fangyue Li et al.,).

The recycled water can be used for direct potable, indirect potable and non-potable reuse. In the case of Windhoek, Namibia, the low precipitation and high evaporation necessitate augmentation of direct potable water supply with reclaimed water (Du Pisani, 2006). Indirect potable reuse can either be planned or unplanned (Fangyue Li et al.,). For example, in California and Florida, US, environmental buffers are utilized to provide further processing and retention times. Unplanned potable reuse takes place through discharging treated waste water into the environment which is subsequently abstracted for potable use (Wilcox et al., 2016). Non-potable reuse is the most commonly applied decentralized water recycling system in urban areas. (Fangyue Li et al.,) There are several well-established examples such as Tokyo and Fukuoka in Japan (Asano, Maeda, & Takaki, 1996), as well as Queensland in Australia (Mankad, 2012).

5. Literature Review

author	title	abstract	notes
Zhe Li et al.	Rainwater harvesting and greywater treatment systems for domestic	A domestic rainwater harvesting and greywater treatment system that can be applied in Ireland.	Introduced two of the most common household grey water treatment systems: basic two-stage system and physical process system
C. Santos et al.	Development of an experimental system for greywater reuse	Paper introduces a low-cost, easy-to-maintain experimental system for grey water reuse. The system has a collection tank and a treatment system consisting of a pump, a filter and UV disinfection. The raw grey water collected in the sink and shower was processed and analyzed. The system significantly reduces SS, COD and BOD and does not detect total fecal or fecal coliforms in all treated grey water samples.	It is a simple and feasible bathroom gray water treatment structure.
Carme Santasmasas et al. 2013	Grey water reclamation by decentralized MBR prototype	The study designed and installed a decentralized automatic MBR prototype in the REMOSA facility to handle low-load grey water for recirculation in flush-to-toilet applications. The recycling of grey water consists of four stages: screening, biological oxidation, filtration and final disinfection by chlorination.	A Comprehensive treatment method of grey water using biological, physical, and chemical methods together
Evan Wanjiru, Xiaohua Xia	Optimal energy-water management in urban residential buildings through grey water recycling	This paper introduces open-loop optimization control and closed-loop model predictive control (MPC) strategies to ensure safe and reliable operation of building grey water recovery systems. The 2 optimal controllers optimize the management and control of grey water recovery and treatment to reduce potable water, energy and waste flow requirements.	Proposed a management control method for grey water treatment system.

Surjit Singh et al.	Grey water treatment and its application in cultivation of plants	Paper studies the phytotoxicity analysis of treated and untreated grey water after biological, physical and chemical treatment of grey water. Study determines the results of raw grey water and treated water samples, compares and analyzes the toxicity of plants, including the seeds of V. radiata and V. mungo that were grown for 30 days and its lengths of root and shoot. Germination rate was found to be 100% in treated grey water in comparison with untreated where only 70% germination rate was observed. Significant changes in root and shoot length was also observed in both treated and untreated grey water. Significant changes in root and stem length were also observed in treated and untreated grey water. The conclusion is that grey water can be used for irrigation in the arid areas.	It verified that the treated grey water can be used for plant irrigation
Fangyue Li et al.	Review of the technological approaches for grey water treatment and reuses	Based on the literature review, a non-drinking urban grey water reuse standard was proposed, and the treatment scheme and reuse scheme of grey water reuse were evaluated according to the grey water characteristics and proposed standards. Literature review shows that separate physical processes are not sufficient to ensure adequate reduction of organic matter, nutrients and surfactants. The chemical process effectively removes suspended solids, organic materials and surfactants from low-intensity grey water. The combination of aerobic biological processes with physical filtration and disinfection is considered to be the most economically viable solution for grey water recovery. MBR seems to be a very attractive solution for collective urban residential buildings.	A detailed analysis of existing grey water treatment methods and an alternative is to indicate the applicable grey water treatment method in each case.

3.3 Case Study

There are some excellect examples that worked in the home system, mainly kitchen and bathroom system.
Some of them focus of one sigle product, others works on a room system. However, the core point is to make the output of one product into the input of another, which is the approach of Systemic design.

Figure3.16 Andrea - Plant-Powered Air Purifier

Andre-Plant air purifier can improve the air quality in home without additional planting space and care time. It encloses a small indoor plant and draws in toxins from the ambient air through its specially designed fan. These toxins circulate around the leaves and roots of the plant to produce clean, purified air that is then recycled to the home, which requires only a removable tray that used to water plant on the base, and a dial that regulates the speed of the fan .
Besides common household volatile organic compounds, it can purifier other toxins that from carpets, paints and adhesives. This is the only plant air purifier that has been proven to be effective in reducing formaldehyde concentrations (reduced by 50% in 30 minutes,10 times faster than traditional air filtration systems).

It is a good example that one product can be used for multi-purpose.

Figure3.17 Ecofrigo

The heat dissipation that produced by the frige is collected and reused to help grow the plants.

It is an example way to reuse the warm air, which changes the output into an input of another product.

Figure3.18 Lavatrice "BioLogic" di Whirlpool

The design consists of three areas: a holding tank for water, a series of washpods, and a plant container.
Product uses plants to update the “grey water” produced in the wash because the plants use some of the pollution (phosphorus and nitrogen) as nutrients.
The whole appliance runs on fuel cell technology, which uses the electrochemical attraction between hydrogen and oxidant to generate energy. No waste will be produced.
The wash cycle itself is carried out in several wash tubs, freeing users from rigid, routines. .

It is an case that applies the green principle, product systems can regenerate itself, while keeping output to a minimum.

The innovative Eco Bath system is a double tank designed to recover water that from the sink. It consists of two key parts: circulating water in the left part and tap water in the right .
When the left part is filled, the LED turns green, so that user can use circulating water to flush the toilet.

Figure3.19 Eco bath system

It provides a common way to use gray water in dometic system. However, the system lack the treatment of gray water which may lead risk in healthy and sanitation.

Ecooking Kitchen combines a lot of different furniture and fixtures, including fridge, dishwasher, oven, induction oven, sink, seating for six, an espresso machine and mini-wall garden for herbs.
The structure of Close-packed makes kitchen environmentally friendly, including solar panels, water filtered and reused (from sink to dishwasher to plant water), the exchange of heat and moisture, etc.

Figure3.20 Ecooking columnar kitchen

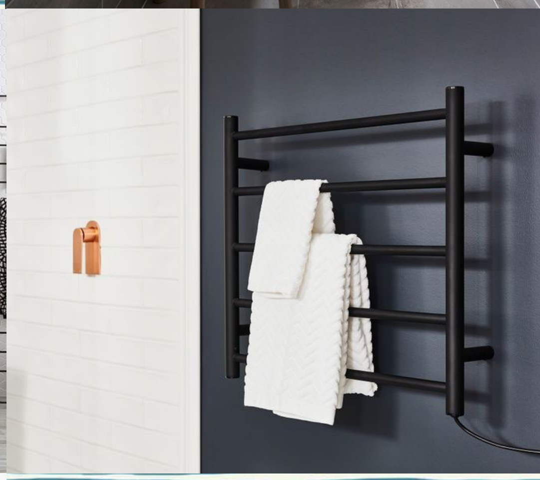
Figure3.21 Whirlpool's Green Kitchen Concept

Whirlpool's concept of a future kitchen integrates all parts of the kitchen into one, including the oven, hob, herbarium, refrigerator, dishwasher, and sink.
In an efficient system, 60% of water and heat are transferred to other household appliances, which is expected to reduce waste (including energy, water and heat) to increase energy efficiency up to 70%.
The heat generated by the oven is used for the growth of plants. The heat dissipation from the refrigerator is used to heat the collected clean water from the sink and then used in the dishwasher.
However, this is just a concept up to now.










4

Re-bathroom

"Innovation is seeing what everybody has seen and thinking what nobody has thought."

——Albert Szent-Györgyi

4.1 Concept

This process comes up the outline of the project, including setting up guidelines, proposing design concept.

Since the system starts from the warm gray water, it is necessary that to find out the approaches to reuse the heat.

There are lots of appliances in home that need to use the heat.
Figure 4.1 shows some examples:

-Heating the mirror during taking shower, to avoid mirror filling with the steam;
-Drying the wet towel;
-Warming the bed with a electric blanket;
-Hot-water bag;
-Warming the room with central heating system;
-Washing machine;
-...

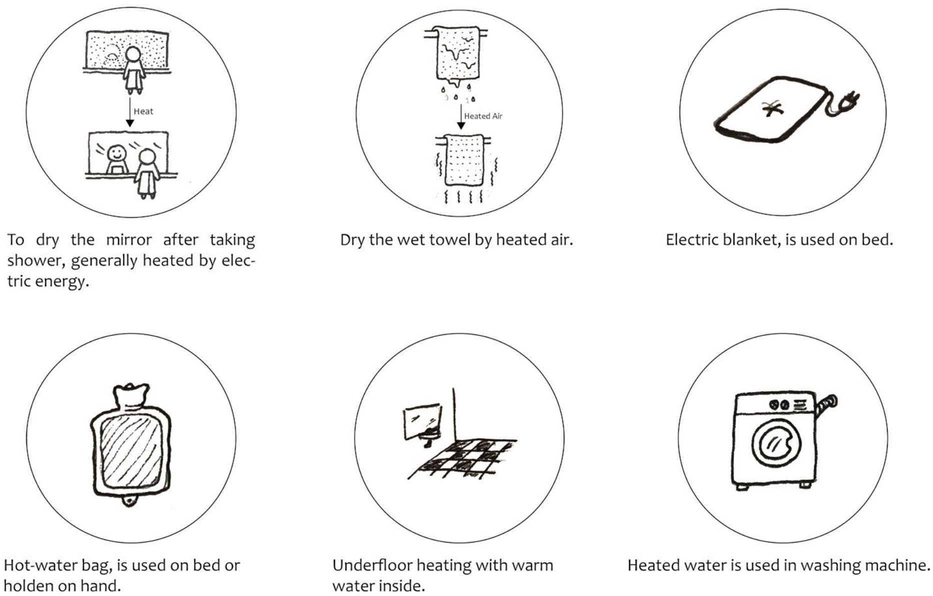


Figure4.1 Appliances requiring heat

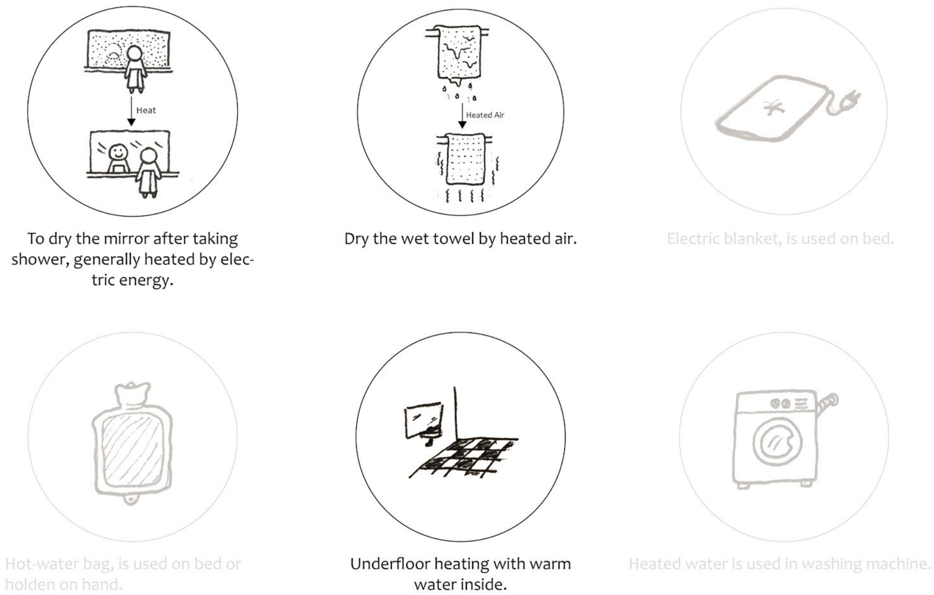


Figure4.2 Selected appliances

Part of appliances that may reuse the heat from warm gray water are selected:

-The reason why there is steam on the mirror after shower is that vapour condenses on the cold surface of the mirror. The warm water goes through the back of the mirror during the shower to make the surface warm so that the steam will not form;

-The bathroom usually gets damp, where the towel are not easy to dry. In some families a electric towel rack is needed. The electricity can be replaced by the warm gray water that coming from the shower and lasts for about 30 minutes, which is enough for drying the wet towels;

-It is cold after the shower during the winter even if there is a central heating in home because the evaporation of water on the body takes away the heat. Usually an extra heating such as fan heater is used in winter. A floor heating powered by gray water can service as the extra heating.

The appliances above illustrate the opportunities that reuse the heat brought by warm gray water, which constitute the first step of the flow chart of the system.

In addition, according to the research and literatrue review, the reuse of gray water is one of an effective method for water shortage problem, and the treated gray water is safe to reuse again. Even if it still has the difficulty to make it drinkable, it is adequate for toilets and plants.

So far, combining with the principles of sustainable development and systemic design, the guideline can be defined:

-Try to make the output from some products into the input of the others;

-The system should use as less extra energy as possible;

-It's better that don't produce extra waste;

-It will save money for users to make it feasible;

-It is easy to use and control;

-The system will promote the enjoyment of personal life;

-The system won't have any negative effects for the basic function of products;

-It is a diffusion of the idea of sustainability itself.

Moreover, taking the specialized functions into account, the design concept can be proposed:

With the aim of reducing resources consumption, design a bathroom system that can reuse both the heat and the water of warm gray water that comes from shower. The heat is used to warm up the mirror to prevent the steam form on it during taking shower, to dry the wet towel and to make bathroom warmer by heating the floor when the weather is cold. After reuse the heat, the cooling-off gray water will be collected and treated to flush the toilet and water the plant.

4.2 Gray water treatment system

The gray water needs to treat before reuse for avoiding the microbiological and chemical damage. Thus, a treatment part is needed for the whole system. This part will discuss about the suitable treatment method for the system, both for the room and for the building.

The water consumption of bathroom per day showing in figure 4.3 indicates the fact that, shower is the biggest water consumption, with the average amount of 249L comparing with the total number of 542L per day, accounting for 46 percent. Besides, the utilization of flushing toliet is second largest consumption with the number of 216L per day.

Thus, the starting point of the system is the shower, which shows in the figure4.5.

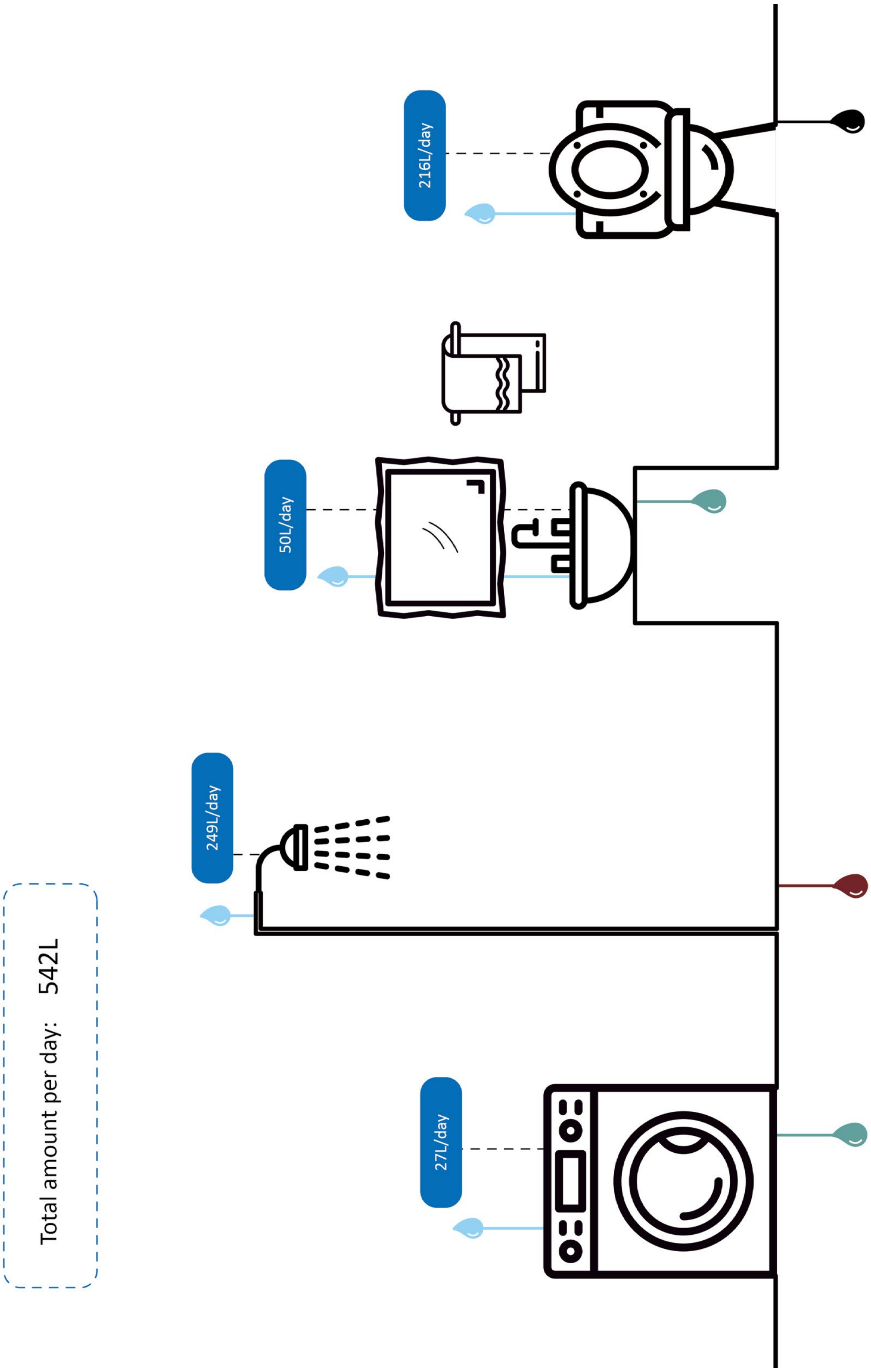


Figure4.3 Bathroom water consumption

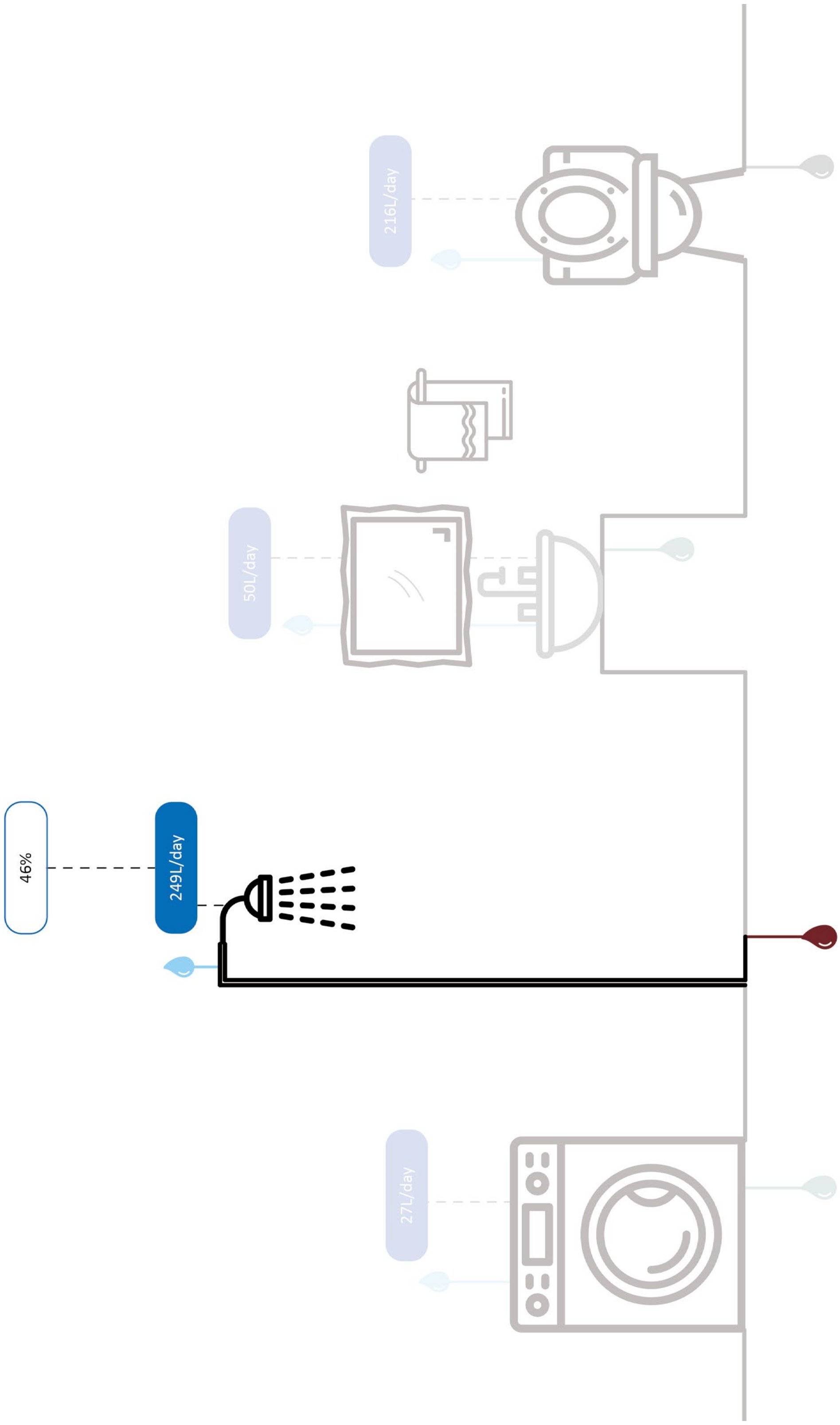


Figure4.4 Biggest water consumption

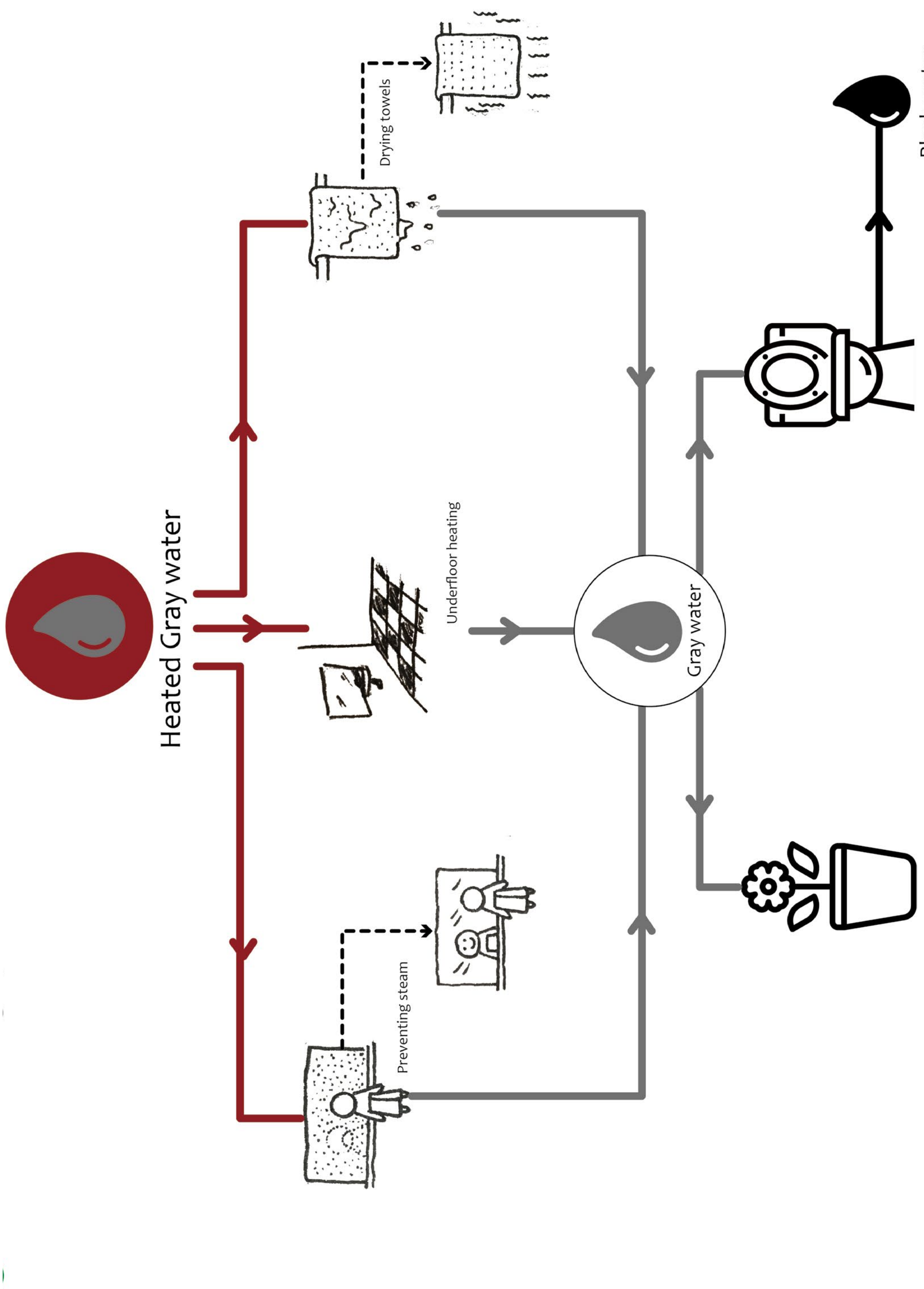


Figure4.5 Basic structure

The next step, there are 3 approaches to reuse the heat that carried by warm gray water:

-The water goes through the back of the mirror so that heats the mirror during users taking a shower to aviod the steam forming on the surface of mirror;

-The water goes under the floor to warm bathroom during the winter, taking the role of floor heating;

-The water goes through the pipes that used to hung the towels to dry the wet towel.

After that, warm gray water comes into cool gray water after the heat that brought by it is reused and cooling, thus, the second part of the structure is to reuse the gray water:

-To water plants;

-To flush the toilet, and finally becomes to black water that cannot be used anymore.

Figure 4.5 depicts the water flows that generated in accordance with system structuer:

-Light blue in this schema means the potable water.

-Warm gray water is labeled by pink color. The system strats from the bottom of the shower. Heated gray goes into 3 different ways, showing by pink pipes: the back of the mirror, the pipes under the floor which can be turned off in summer, and the tubular shelf for towels. However, a small pump is needed to raise water. Finally, goes out of the bathroom to collection and treatment.

-On the oter hand, the nomal gray water, showing in gray color, is collected to reuse to as well. It comes from washing machine and the sink.

-After cooling and treated, the gray water becomes available for flushing toilets and watering flowers (color in dark blue). Treated gray water is introduced in bathroom agai.

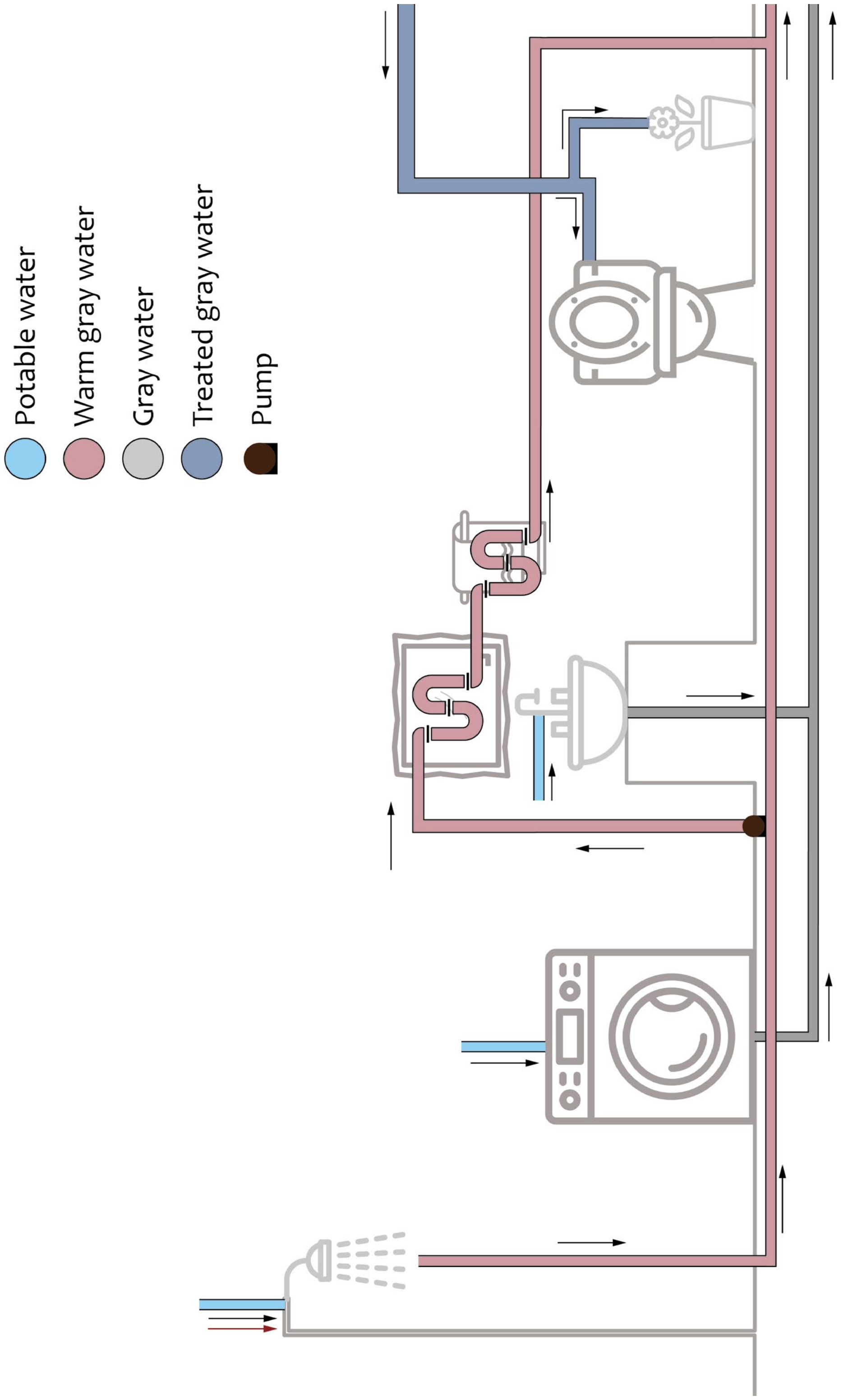


Figure4.6 Water flows

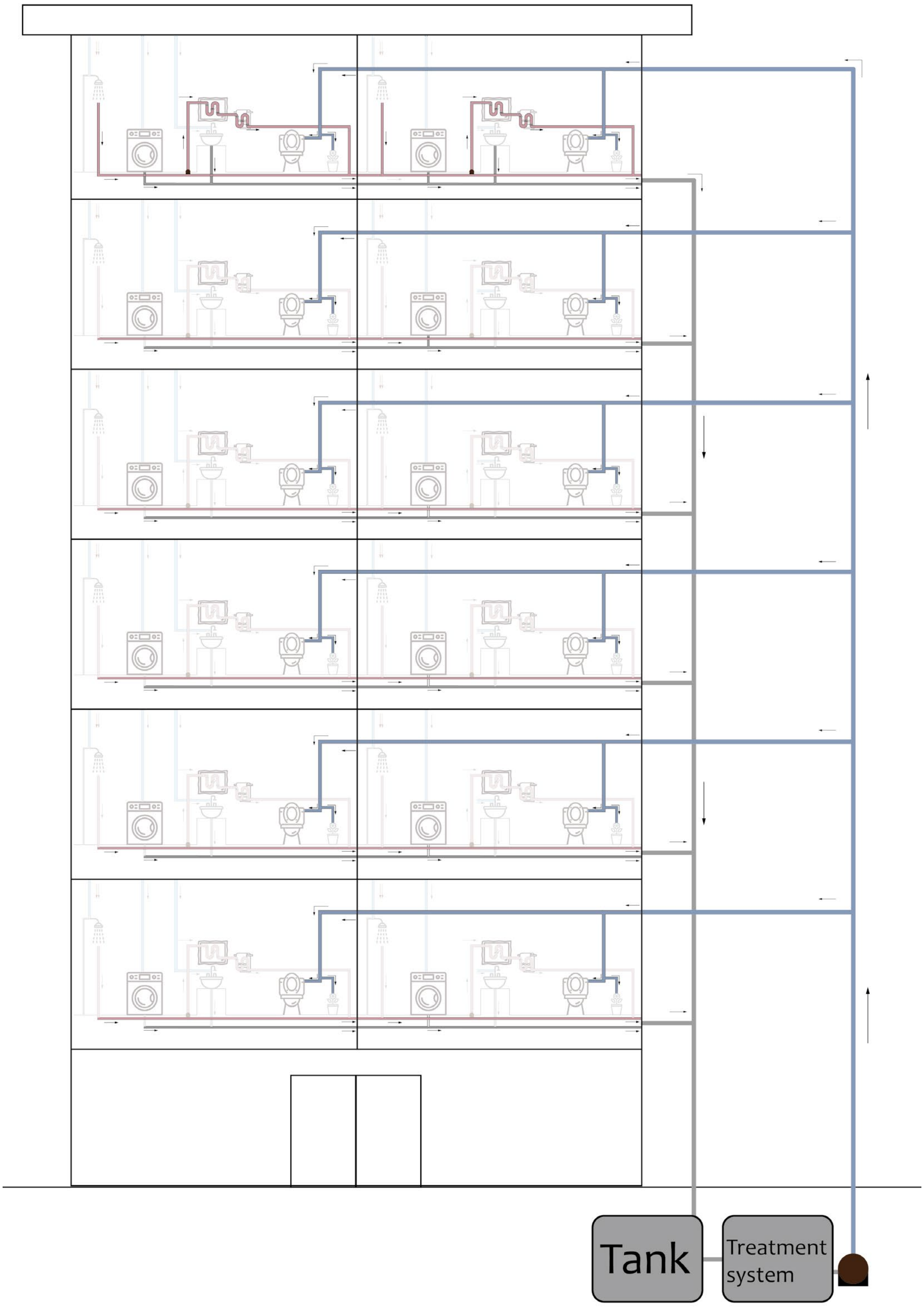


Figure4.7 Water flows in building

The appliance to treat the gray water is suppossed to set outside the room, services for the whole building. On the one hand, it is a waste of the room that putting the tank indoor. On the other hand, the bigger the tank is, the lower cost of running the treatment is.

Figure 4.7 shows an example that how the pipes distribute in the building with 7 floors and 12 households.

There are 2 outlets of flow in each household, however, they will become into one pipe to connect with the treatment tank under the building, which shows in figure 4.8. Besides, a pump is needed to raise the treated water from the treatment tank to the house. The gray color shows the flow of gray water while the dark bule illustrates the treated one.

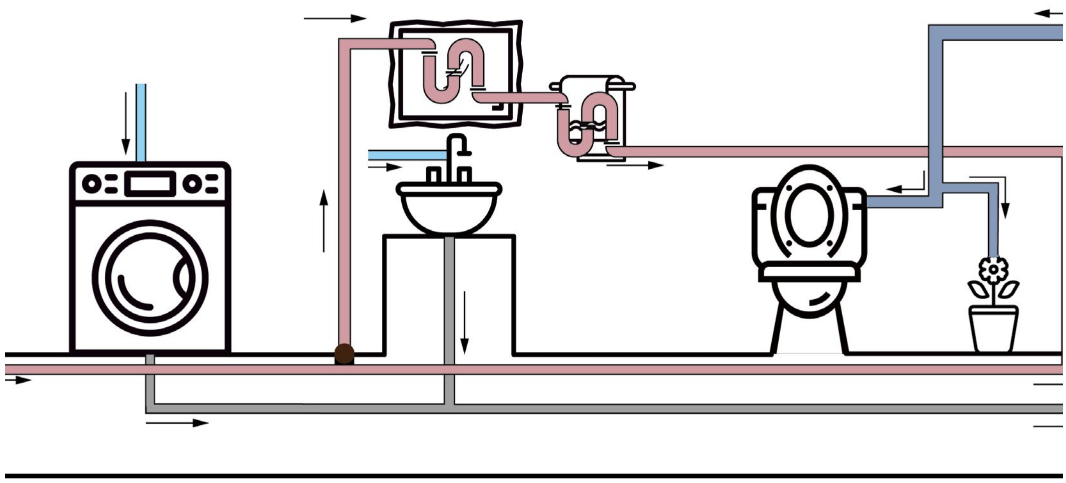


Figure4.8 Inlet and Outlet

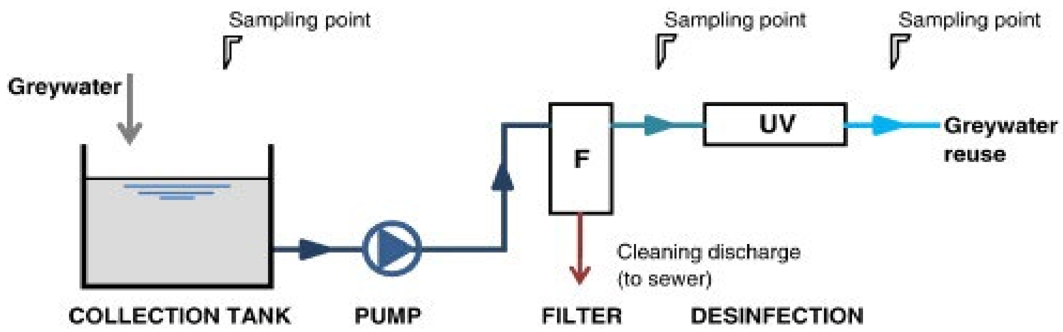


Figure4.9 Gray water treatment method(C. Santos et al., 2012)

The water treatment system applies the research from C.Santos et al. in paper ***Development of an experimental system for greywater reuse*** in 2012.

The system for grey water treatment includes a collection tank, a pumping device, a filtration system and an ultraviolet disinfection device. The system was designed to provide a shorter residence time for the collected grey water and to disinfect it immediately prior to reuse to minimize the possibility of microbial regeneration.

The water inlet passes through the top of the tank and the pump is drawn in at the bottom to minimize solids accumulation because no mixing device is installed. The centrifuge horizontal shaft pump is sized to deliver 2,7 m^3/h at a pressure of 3 bar. The filter is a hydraulically activated self-cleaning mesh filter with a stainless steel screen and a 465 cm2 filter area set to start the self-cleaning process every time the differential pressure on the screen reaches 0,5 bar. One advantage of this type of filter is that the cleaning process is automatic and fast, and it takes only 8 to 12 seconds to clean the screen surface. The cleaning effect is discharged to the wastewater network system. The mesh of the filter is 0.025 mm.

The disinfection unit (Micropal UV40) consists of a 40 watt UV lamp and a 60 mm diameter stainless steel chamber 970 mm long. The low pressure mercury lamp emits UV-C radiation at 254 nm with an illumination>30 $mJ.cm^{-2}$. The operating temperature is 2 to 40 degree centigrade and the lamp life is approximately 7500 hours.

In this treatment unit, the pipes and accessories are made of stainless steel AISI 316, and all systems (including collection tanks) can be easily transported and installed, requiring only power and sewage to be connected to the filter cleaning vents. Filtration and disinfection equipment, the investment amount is about 2350 euro (in 2009), to facilitate maintenance and reduce costs.

This study shows that the proposed experimental unit can obtain relatively good grey water treatment results, in particular by UV radiation, using conventional processing methods constructed using the prior art. In terms of settings, the device is considered economical, reliable and safe for field applications.

The reason for choosing this approach for gray water is that, comparing with chlorination, UV is the new and environmental friendly treatment method. Even if chlorination is the most common and effective way to clean the water, its harm for both people and environment is unavoidable.

With the system, it it possible to reduce the water consumption in the bathroom of a 4-people-family from 542L to 326L, about 40%.

There are 3 appliances that need potable water anyway: washing machine, shower, and sink, with the number of 326L per day. However, the consumption of flushing the toilet is the second biggest consumption of water in the bathroom, which uses treated gray water instead of potable so that the total amount of water use reduces notably.

Furthermore, the need of water in the purpose of watering plants is very different from every family, which is diffcult to calculate and is the reason why that it shows "indetermination". The percentage of water reduce will higher if taking this part of water use into account, since the number of water consumption in general bathroom will bigger than 542 liter per day while the amount of 326 liter will be constant.

Additionally, the water demand for toilet every day is about only 216L per day, which means about more than 100L of treated gray water remains. Except watering plants,it can be used to supplyt the water consumption of other households in the building.

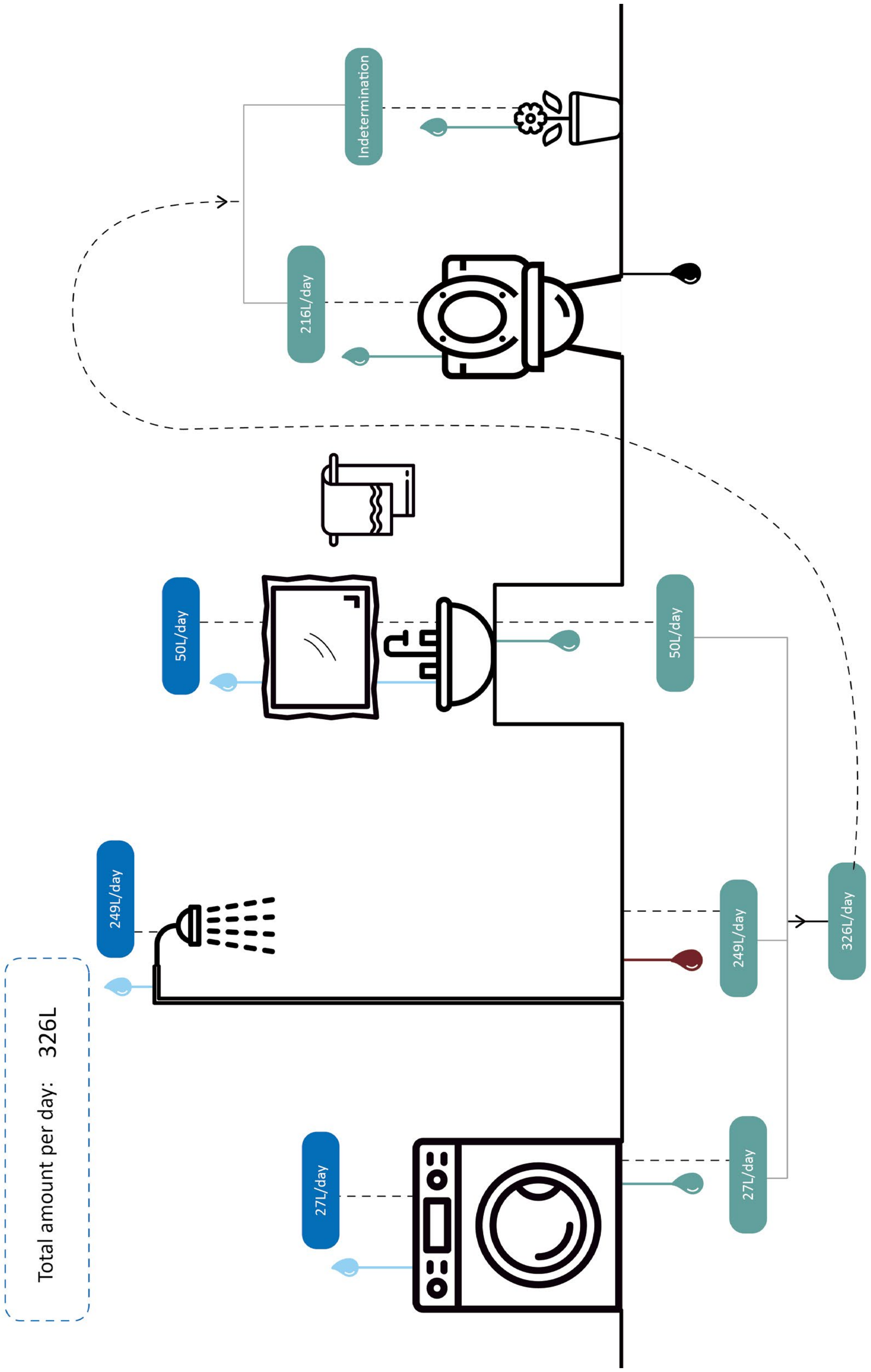


Figure4.9 Systemic water consumption in bathroom

4.3 Economic management

An economic management is necessary to verify the feasibility of the system. The calculation based on the cost and the expenditures cut down, and has the positive result.

Figure 4.10 indicates the cost of installation the system.
The cost is constituted by 2 parts, the cost for whole building and the cost in every household.
Cost of pipes and pumps is based on quotation from website ***www.alibaba.com.*** The price of gray treatment system is shown in the paper. In addition, 350 kwh of eletricity is needed per year to keep it work, which cost 84 eour basing on the electricity fee after tax in Turin.
The cost for installing the system of building is divided by household, which is 12 in this example.

As a result, for each house hold, the cost of installation is 241.5 euro, and the operating charge is 7 eour each year.

As for the expenditures cut down, according the price and product parameters that searched from Amazon, the cost of buying appliances that can be saved is 162 eour, and the energy fee that using appliances per year that can be saved is 65 eour per year. Further more, the water that saved by the system for a 4-people family will reduce the money of 135 euro per year basing on the unit price of water in Turin.

In conclusion, in the first year, because of the fee for installion, users can reduce the cost of 113.5 euro. From the second year, users will cut down the payment of 193 euro per year. Thus, the system is feasible from the view of economic part.

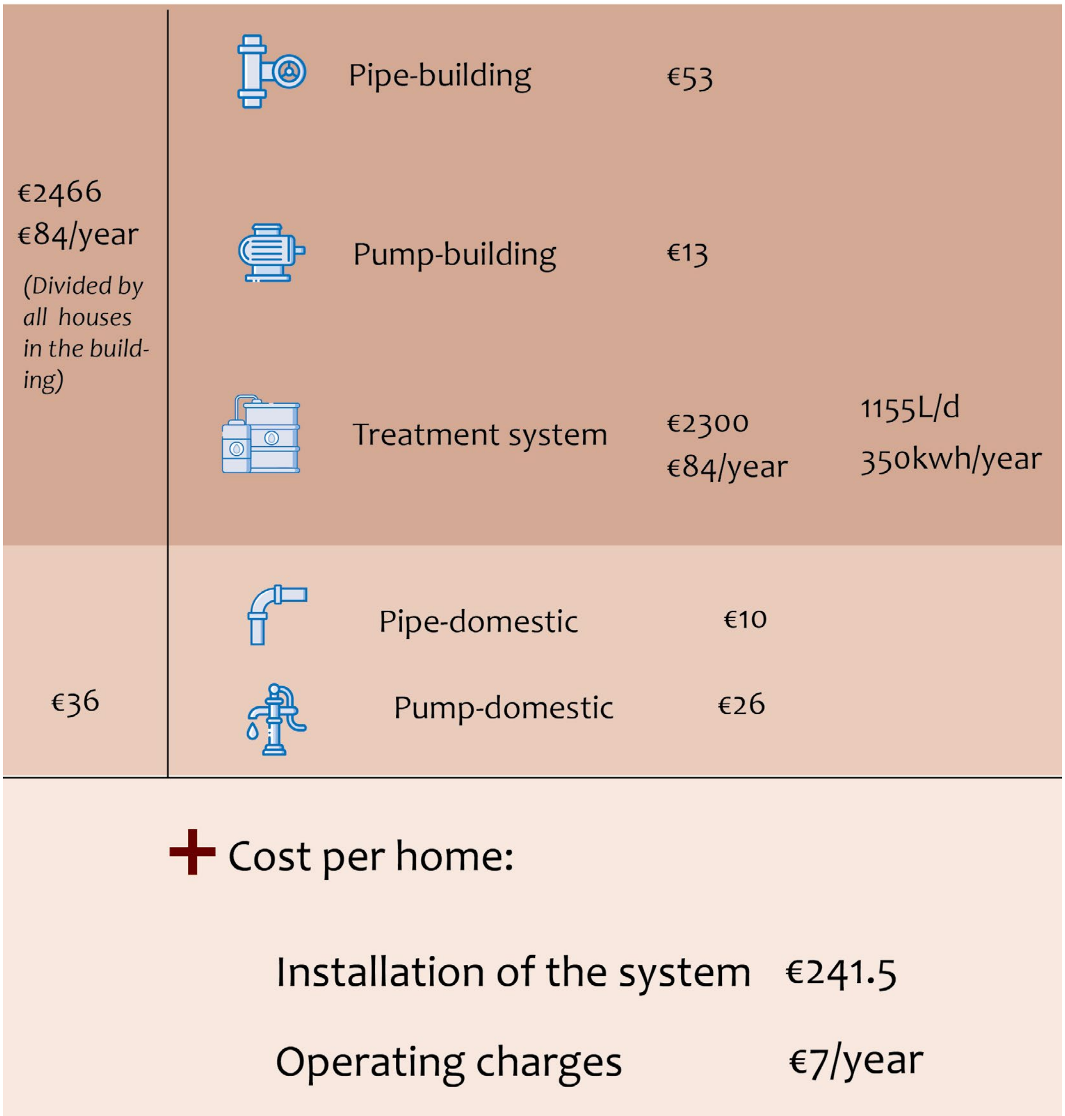


Figure4.10 Cost

Smart mirror	€50	
Heating	€52 €58/year	Power: 2000w 240 kwh/year (1h/d · 120d)
Towel rack	€60 €7/year	Power: 150w 27.5 kwh/year (30min/d · 365d)
Water	€135/year	

- Cost per home:

Installation of the system	€162
Operating charges	€200/year

Figure4.10 Reduction

Economic in the first year:	€113.5
Economic in second year and the years after:	€193

Figure4.10 Reduction

Conclusion

This paper aims to apply sustainable development and system design methods to the home environment and to find practical solutions.
The analysis and summarization of the family resource consumption is crucial to the development of the paper and the discovery of the problem, as well as the proposal of the project. Through this process, the article discovered the opportunity to reuse heated grey water, which improved the quality of life of users while greatly reducing the domestic water utilization. This is also in line with the three elements of sustainable development: economy, environment and society. The saving of water resources meets the requirements for the environment, and the final economic management proves that the economic result is positive, and the human living experience is a social factor that project reached.
In addition, in order to realize the function of grey water reuse, author did the research and literature review, and tried to apply the experimental and latest gray water treatment technology into the actual specific project.

However, this project can be said as a preliminary concept, and for future development. Because the system is very complex and involves many aspects, such as construction, water supply and drainage, environmental engineering, user experience design, etc., the realization of the project needs the participations that coming from multidisciplinary and various fields.

References

Bibliography

Agnieszka Stec, Sabina Kordana, 2015, *Analysis of profitability of rainwater harvesting, gray water recycling and drain water heat recovery systems*, Resources, Conservation and Recycling, 105 (2015): 84–94

Alessandro Deserti, 2017, *Design and innovation: approaches, processes and examples*, lecture for ASP 13th cycle spring school

Arturo Ojeda de la Cruz, Clara Rosalia Alvarez-Chavez, Marco A. Ramos-Corella, Fernando Soto-Hernandez, 2017, *Determinants of domestic water consumption in Hermosillo, Sonora, Mexico*, Journal of Cleaner Production, 142 (2017): 1901-1910

Aspen Pumps, 2014, *Turning grey water into a vital resource,* WORLD PUMPS, April 2014

Aurore Lomet, Frédéric Suard, David Chèze, 2015, *Statistical modeling for real domestic hot water consumption forecasting,* Energy Procedia, 70 (2015): 379 – 387

Blewitt John (2015), *Understanding Sustainable Development (2nd ed.)* London: Routledge

C. Santos a, F. Taveira-Pinto, C.Y. Cheng, D. Leite, 2012, *Development of an experimental system for greywater reuse,* Desalination, 285 (2012): 301–305

Carme Santasmasas, Miquel Rovira, Frederic Clarens, César Valderrama, 2013, *Grey water reclamation by decentralized MBR prototype, Resources,* Conservation and Recycling, 72 (2013): 102– 107

Evan Wanjiru, Xiaohua Xia, 2017, *Optimal energy-water management in urban residential buildings through grey water recycling, Sustainable Cities and Society,* 32 (2017): 654–668

Fabrizio Ceschin, Idil Gaziulusoy, 2016, *Evolution of design for sustainbil-*

ity: from product design to design for system innovations andtransitions, Design Studies, Volume 47, November 2016, Pages 118-163

Fangyue Li, Knut Wichmann, Ralf Otterpohl, 2009, *Review of the technological approaches for grey water treatment and reuses,* Science of the Total Environment, 407 (2009): 3439–3449

Food and Agriculture Organization, *AQUASTAT data*, 2014

Gaetano Cascini, 2017, *Design methods and process*, lecture for ASP 13th cycle spring school

Giulia Romano a, Nicola Salvati, Andrea Guerrini, 2016, A*n empirical analysis of the determinants of water demand in Italy,* Journal of Cleaner Production, 130 (2016): 74-81

Istituto Nazionazle di statistica (ISTAT), 2017, *Annuario Statistico Italiano 2017*, Roma: Tribunale di Roma

Jones, J. Christopher (1980). *Design Methods*. UK: Wiley

Liam Magee, Andy Scerri, Paul James, James A. Thom, Lin Padgham, Sarah Hickmott, Hepu Deng, Felicity Cahill, 2013 *Reframing social sustainability reporting: Towards an engaged approach.* Environment, Development and Sustainability. University of Melbourne. 15: 225–243.

OECD (2014), *Water consumption, OECD Factbook 2014: Economic, Environmental and Social Statistics*, Paris: OECD Publishing

Paolo Tamborrini, 2016, *Metodologia*, lecture for Innovazione, Politecnico di Torino

Rachael Carson (1962), *silent spring,* United States: Houghton Mifflin

Sachs, Jeffrey D. (2015). *The Age of Sustainable Development.* New York: Columbia University Press

Shamraiz Ahmad, Kuan Yew Wong, Ming Lang Tseng, Wai Peng Wong, 2018, *Sustainable product design and development: A review of tools, applications and research prospects,* Resources, Conservation & Recycling, 132(2018) 49-61

Smith Charles, Rees Gareth (1998), *Economic Development, (2nd edi-*

tion). Basingstoke: Macmillan

Sujana Adapa, 2018, *Factors influencing consumption and anti-consumption of recycled*

Surjit Singh, Neha Pradhan, Nupur Ojha, Bodhisattva Roy, Sutapa Bose, 2016, *Grey water treatment and its application in cultivation of plants,* Asian Journal of Microbiology, Biotechnology and Environmental Sciences, 18(4): 1043-1053 · December 2016

The 2030 Agenda for Sustainable Development, United Nations, Member States, *United Nations Sustainable Development Summit 2015,* New York, 2015

Ulrich Grober: Deep roots — A *conceptual history of "sustainable development" (Nachhaltigkeit),* Wissenschaftszentrum Berlin für Sozialforschung, 2007

United Nations Member States (2015), *The 2030 Agenda for Sustainable Development*

Factors influencing consumption and anti-consumption of recycled water: Evidence from Australia, Journal of Cleaner Production, 201 (2018): 624-635

World Charter for Nature, United Nations, General Assembly, 48th Plenary Meeting, 28 October 1982

World Commission on Environment and Development (1987), *Our Common Future*, New York: Oxford University Press

Zhe Li, Fergal Boyle, Anthony Reynolds, 2010, *Rainwater harvesting and greywater treatment systems for domestic application in Ireland*, Desalination, 260 (2010): 1–8https://zh.wikipedia.org/wiki/%E5%8F%AF%E6%8C%81%E7%BB%AD%E5%8F%91%E5%B1%95
https://www.slidegeeks.com/success/product/three-inter-related-components-of-sustainable-development-ppt-powerpoint-show
https://en.wikipedia.org/wiki/Sustainable_development#cite_note-7
http://rethinkingprosperity.org/a-short-history-of-sustainable-development/
https://zh.wikipedia.org/wiki/%E4%BA%BA%E7%B1%BB%E7%8E%AF%E5%A2%83%E5%AE%A3%E8%A8%80
https://www.unsystem.org/content/united-nations-conference-environment-and-development-unced-1992

Sitography

https://en.wikipedia.org/wiki/Sustainable_development#cite_note-Grober2-6

https://en.wikipedia.org/wiki/Design_methods#cite_note-Jones_Design_Methods-1

http://www.discoverdesign.org/handbook

http://www.mauriziovrenna.com/whatssystemicdesign.html

https://ec.europa.eu/eurostat/statistics-explained/index.php/Water_statistics

https://www.safewater.org/fact-sheets-1/2017/1/23/water-consumption

https://www.statista.com/statistics/263156/water-consumption-in-selected-countries/

http://wikiprogress.org/articles/environment/water-consumption/

http://www.rinnovabili.it/ambiente/lasostenibilita-%E2%80%98abita-tiva%E2%80%99dell%E2%80%99acqua/

https://en.wikipedia.org/wiki/Systemic_design

https://www.casaeclima.com/ar_3530__ITALIA-DA-NON-PERDERE-istat--pm10--rifiuti--ac-qua--trasporti--ambiente--indicatori-ambientali-urbani-Istat-le-citt-italiane-diventano-poco-pi-verdi.html

https://www.istat.it/it/archivio/207497

https://data.worldbank.org/indicator/er.h2o.fwag.zs

https://www.markstechnologynews.com/2010/01/only-botanical-air-purifier-supercharg-es-houseplant-filtering-power.html

https://www.whirlpoolcorp.com/project-f-our-designers-featured-on-the-world-stage/

http://blogosfera.varesenews.it/ambiente/whirlpool/index.php-post=43.html

https://www.custommade.com/blog/sustainable-kitchen/

http://www.goodshomedesign.com/innovative-eco-bath-system-jang-woo-seok/

http://inventorspot.com/articles/environmentally_friendly_toilet_inspired_by_japanese_design_18701

https://www.flickr.com/photos/netlawyer/4895560607/in/album-72157608186978006/

https://www.trendhunter.com/trends/ecooking-kitchen

https://mocoloco.com/ecooking-vertical-kitchen-by-massimo-facchinetti/

https://www.treehugger.com/kitchen-design/can-clie-really-pack-whole-kitchen-27-inch-square.html

https://freshome.com/2008/03/17/green-eco-friendly-kitchen-concept-from-whirlpool/

https://www.youtube.com/watch?v=auJolfab5RY

http://www.mauriziovrenna.com/whatssystemicdesign.html

https://zhuanlan.zhihu.com/p/27315842

https://www.alibaba.com/product-detail/China-supplier-plastic-200mm-hdpe-pipe_60737849716.html?spm=a2700.7724857.normalList.6.568e3b96S1F00r&s=p

https://www.alibaba.com/product-detail/30m-head-1-2-hp-0_60766912667.html?spm=a2700.7724857.normalList.1.35282ee6fa8vhT&s=p