Identifying opportunities to improve the sustainability of water resource use at Wageningen Campus by applying the Urban Harvest Approach (UHA)

MSc Thesis in Environmental Science

Environmental Systems Analysis Group

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Preface

The idea behind this thesis was to work on a practical theme that could be useful for Wageningen University and Research – WUR besides being related to sustainability. My background as environmental engineer and my previous work experience in the environmental department of a chemical company made me curious about applying a scientific research with a practical approach in a university context.

Through the first meeting with a member of ESA department, I was advised to talk to someone from Green Office at WUR – GOW in order to identify which projects could be useful to work on. After a few meetings, the topic was defined. Evaluating potential improvements on water use within WUR Campus showed up as an interesting topic due to the lack of previous studies related to water resource use.

The proposal was developed towards identifying the potential improvements on water resource use by applying the Urban Harvest Approach (UHA). The defined program included two months of fieldwork where input data for the UHA was intended to be gathered through interviews. Building managers, technical team, people in charge of energy management, kitchen, cleaning services, wastewater, and laboratory were the interviewees and all of them were willing to support me on gathering the necessary data. Their contribution was precious and I am grateful for being able to conduct these interviews and I would like to express my appreciation to all of the interviewees.

After the fieldwork phase, a challenge phase of compiling and writing the findings took place. Fortunately, I had the support of my supervisors, Karen Fortuin from ESA department and Joeri Willet from ETE department. They both provided me with relevant comments, technical support, and advice besides being patient with someone who needed time to assimilate this new reality of conducting a scientific research. I will be always grateful for the transparent and precise feedback.

I could not forget to express my gratitude also to Erna Maters from WUR facilities department who always supported me on clarifying doubts and providing me with useful insights and tips.

Last, but not least, I am happy of having such an amazing family and friends that support me with all kinds of needs, from philosophical to technical tips. They are what really matter in my life.

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Acronyms

DM	Demand minimization
DMI	Demand Minimization Index
Ei	External inputs
Er	Exported resources
M	Multi-sourcing
OM	Output minimization
REI	Resource Export Index
Rh	Resource harvested
RQ	Research question
SSI	Self-Sufficiency Index
UHA	Urban harvest approach
We	Waste exported
WUR	Wageningen University & Research

Summary

If business-as-usual in water use is not changed, ensuring water access to increasing population and sectors is challenging when a global water-demand deficit of 40% is projected by 2030. Not only water-scarce regions should improve their water-resource use but also countries with and water-surplus and well-recognized water management, such as the Netherlands, must face this challenge.

Improving local water management can reduce on this projected deficit. Therefore, my research investigates opportunities to improve water-resource use at the Wageningen University & Research (WUR) Campus. To achieve this aim, research questions on baseline-water use of each WUR building, the potential building improvements related to demand and output minimization, and multi-sourcing were addressed.

The three steps 'Urban Harvest Approach (UHA)' was applied. The required data and information was obtained through literature review of research papers and technical reports and interviews with WUR employees, who are involved with water management. In total, 16 people were interviewed and these interviews covered all 18 WUR buildings that are all located at the WUR Campus in Wageningen.

The current baseline water-use situation was assessed. This indicated that half or more of WUR's water use is related to toilet flushing (48% to 90%), followed by kitchen use (10% to 34%) and cleaning (4% to 21%). The UHA indicated that reducing water demand potentially ranges from 15% to 31%. This can be achieved by installing water-saving systems and better urinals. This can certainly be applied in half of all buildings. The output minimization step could additionally reduce this by 2% to 19% by cascading water used for washing hands to flush toilets. Finally, the multi-sourcing step considered the potential on rainwater harvesting for each building. The results showed that all water demand related to administrative activities could potentially be satisfied by this approach. Ten WUR buildings could also supply excess rainwater to other buildings.

This thesis not only contributes to other UHA studies, but also provides the main improvements that could be implemented at the WUR Campus to improve water-resource use.

1 Introduction

1.1 Background Information

Sustainable development was formally defined in 1987, in Our Common Future report commissioned by Brundtland Commission and, since then, the definition has been scattered around the world. 'Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (Brundtland, 1987). The concept of sustainable development supported the increasing of awareness, in early 1980, about the fact that population growth, poverty, environmental degradation and resource shortages could not continue at the same rate (Keiner, 2006).

Among all the resources supplied by Earth in order to support humans, water, according to World Water Development Report, is a primary resource which all social and economic activities besides the ecosystem functions depend on and, therefore an adequate management of water resources is necessary if a sustainable management is a goal to be achieved (Connor, 2015).

In fact, improving water usage helps to combat the projection that, by 2030, a deficit of 40% on global water demand will be faced with the business-as-usual (BAU) scenario (Group, 2009). Naturally, the threats regarding water scarcity will vary in different regions since water is not equally distributed over the globe (Connor, 2015). One of the four main threats the Netherlands is expecting to face for future water management is related to climate change and its related impacts such as flood risk, urban drainage and water scarcity (Leterme, 2014).

In this sense, even though the Netherlands has been well recognized by keeping an efficient water management especially when related to flooding control and freshwater supply (Leterme, 2014) there will be always an opportunity to evaluate potential improvements in water management.

According to United Nations Environmental Programme (UNEP) in its Global Environmental Outlook (GEO-5) (UNEP, 2012) increasing water-use efficiency in all sectors is vital to ensure sustainable water resources for all uses. In line with that, university segment is also an important sector not only to support a better resource usage itself but also to dissimulate the acquired knowledge for other sectors of society and consequently spread out best practices (Fischer et al., 2015; Viebahn, 2002) besides being a sector that influences the policy making process (Probert, 1995).

Wageningen University & Research (WUR), which is a well-recognized university in the life sciences and which achieved an expressed position to evaluate the sustainability performance, is a good example of an university that considers water management as an important strategic research theme (Wageningen UR, 2016a).

WUR Corporate Brochure stated its mission as - "To explore the potential of nature to improve the quality of life"- This shows the importance that sustainability has for the organization that recognizes sustainability is an important theme for education and research but also claims to be forefront in the Netherlands when considering its operation and, therefore, establishes an integrated approach to promote sustainability internally and externally (Wageningen UR, 2016a).

During the period from 2010 to 2012, WUR implemented an action plan to move towards a more sustainable operational management. The so-called Green-office Wageningen, in 2012, was implemented (Wageningen UR) because this Green-office is an organization composed of students whose minds are oriented to sustainability and supported by WUR Facilities and Services department.

The aim of Green-office is to move towards a more sustainable mind-set and practice at WUR through facilitating the initiatives that have a connection to sustainability topics (Wageningen UR). Based on this, Green-office has supported and been involved in many projects related to sustainability and with WUR's mission.

Recently, WUR has set a Strategic Plan 2015-2018 (Wageningen UR). One of the five strategic investment themes is "Resource Use Efficiency" where it is proposed to develop knowledge and technology in order to get a more efficient use of raw materials. Here the linkage between a society's need – improve water management system – and WUR target – improve resource use efficiency – was matched.

To get a better efficiency of water use is necessary first to know the overview of its use to evaluate where and how it could be improved. Among other tools that could be applied in this case, the UHA is suitable because it is aligned to the idea of managing the resources in a more sustainable way (Vera, 2012).

UHA is a methodology that has been developed recently, and it is linked to the urban metabolism (UM) approach where a city is compared to a living organism and therefore all the flows of energy and materials are considered (Zhang, 2013). UHA is also connected to the sustainability concept because it claims to achieve a better use of the resources available within a specific area (normally based on a household or a building) (Leusbrock et al., 2015).

The main principle of the UHA approach is that an urban system could be self-sufficient of resources such as water, energy, and nutrients that are available in its surroundings by applying three steps: minimizing demand, minimizing outputs and Multi-sourcing. It is a bottom-up approach that starts at the building/house units but could be built up towards a more complex system such as blocks and even whole cities (Vera, 2012).

Results from UHA have shown that resource reduction of consumption is possible. For instance, 40% of water demand could be reduced if water-saving technologies are implemented; or 10 to 15% of energy consumption from household could be minimized if a system of energy recovery was installed (Vera, 2012; Willet, 2015).

Based on this, improving the use of water resources within Wageningen Campus is likely possible. The application of UHA will demonstrate whether it is a suitable approach to be applied to university buildings.

1.2 Study area

The study area of this research is Wageningen Campus (WUR Campus) with all its 19 buildings that are under WUR responsibility. There are eight more buildings that are located within WUR Campus but these buildings do not belong to WUR and therefore are excluded in this research.

Figure 1 provides an overview of the geographical area of WUR Campus.

Figure 1: WUR Campus

The Table 1 named the buildings located in WUR Campus with their respective codes.

Table 1: WUR building's name and codes

Number	Building's name	Building's code
1	Lumen	100
2	Gaia	101
3	Forum	102
4	Orion	103
5	Atlas	104
6	Radix	107
7	Radix Serre, Klima, Agros	109
8	Impulse	115
9	Actio	116
10	Nexus	117
11	Axis	118
12	Triton	119
13	Carus	120

Number	Building's name	Building's code
14	Innovatron	121
15	Zodiac	122
16	Vitae	123
17	Helix	124
18	Sports Centre De Bongerd	130
19	De Leeuwenborch	201

Data available in the "Wageningen UR 2015 Annual environmental report" shows water consumption within WUR Campus as a whole. This information is showed in Table 2.

Table 2: Wageningen water consumption

		Total water consumption (m^3)
Mains water (supplied by water company)	2013	75,905
	2014	81,048
	2015	90,589
Well water (supplied by groundwater wells)	2013	34,372
	2014	35,865
	2015	28,738

Based on the information above and considering the results obtained in previous studies, a reduction in water demand is expected when UHA is applied (Agudelo-Vera et al., 2012). The application of UHA in WUR Campus provides insight on how to improve water use within this area and moreover, supports WUR goals on moving towards more sustainable water use.

1.3 Problem Statement

Being well recognized for its sustainability performance, WUR is always searching for improvements that support its mission *"To explore the potential of nature to improve the quality of life"*. Nowadays, exploring the potential of nature has to consider, for instance, exploiting resources in a sustainable manner (Leduc & Van Kann, 2013) and therefore improving water use in order to provide a more sustainable management of this resource is covered by this context.

The UHA is a methodology to improve the management of resources such as water, energy, and nutrients available within an urban area (Vera, 2012). WUR Campus resembles an urban area because it presents several buildings in which water is used. Therefore it could be considered as an interesting area for applying UHA.

Water is one of the resources used within WUR Campus managed by its technical team. One of the eight sustainability goals defined by WUR for 2015 was to achieve a reduction in water consumption related to 2014 (Wageningen UR, 2016c). However, instead, an increase of 5% was registered. Water was the only sustainability goal which target set for 2015 was not achieved.

One study related to the UHA has been conducted in Wageningen city (Voogt, 2011) and demonstrated a reduction of 40% of water demand by applying UHA. None study was related to a building that belongs to WUR. In this research, WUR Campus is considered as an urban area and its potential of being a provider of its own water resource was investigated by applying the UHA.

1.4 Research objective and questions

This research aims to identify the potential opportunities to improve water resource use at WUR Campus by applying the UHA.

To achieve this aim, the following research questions (RQs) were formulated:

RQ-1) What is the baseline water use of each WUR building?

RQ-2) What are the potential improvements related to demand minimization for each building?

RQ-3) What are the potential improvements related to output minimization for each building?

RQ-4) What are the potential improvements related to Multi-sourcing for each building?

1.5 Outline of this thesis

This thesis is organized in 5 chapters. Chapter 1, as mention previously, presents the background information regarding concerns about water use. Additionally, this chapter includes information of study area, the problem statement and the research questions addressed to this thesis. Chapter 2 presents the methodology adopted and explain how theoretical values about water consumption were calculated. Besides that, it also presents the conceptual framework chosen to answer each of the defined research questions. Chapter 3 brings the main results of this thesis by describing the findings related to baseline assessment, demand minimization, output minimization and multi-sourcing for each building as well as the whole WUR Campus. Chapter 4 presents the discussion of main results and the difficulties faced in this thesis. Ultimately, Chapter 5 shows the conclusion regarding the potential improvements that could be implemented by WUR Campus towards being a more sustainable university relate to water use.

2 Methodology

The following subchapters describe the conceptual framework and the methods to answer the research questions proposed in this thesis.

2.1 Conceptual framework

2.1.1 Conceptual framework for the thesis

The conceptual framework applied for this thesis was based on the UHA and its steps. The UHA starts with a baseline assessment followed by three steps: demand minimization, output minimization and Multi-sourcing (Vera, 2012). Figure 2 below indicates the steps carried out in this thesis and the respective research questions. The geographic limit of this thesis is the WUR Campus and the smallest unit considered was a building unit.

First, all the input and output of water use within a building was assessed to determine the baseline assessment for each building RQ1. The next step was to evaluate whether there is potential to reduce water demand, answering RQ2. The next step was the evaluation of minimizing the outputs indicated by the baseline assessment and answer RQ3. Any water demand still remaining after evaluating the first and second UHA steps was considered by applying Multi-sourcing options and by doing this RQ4 was answered.

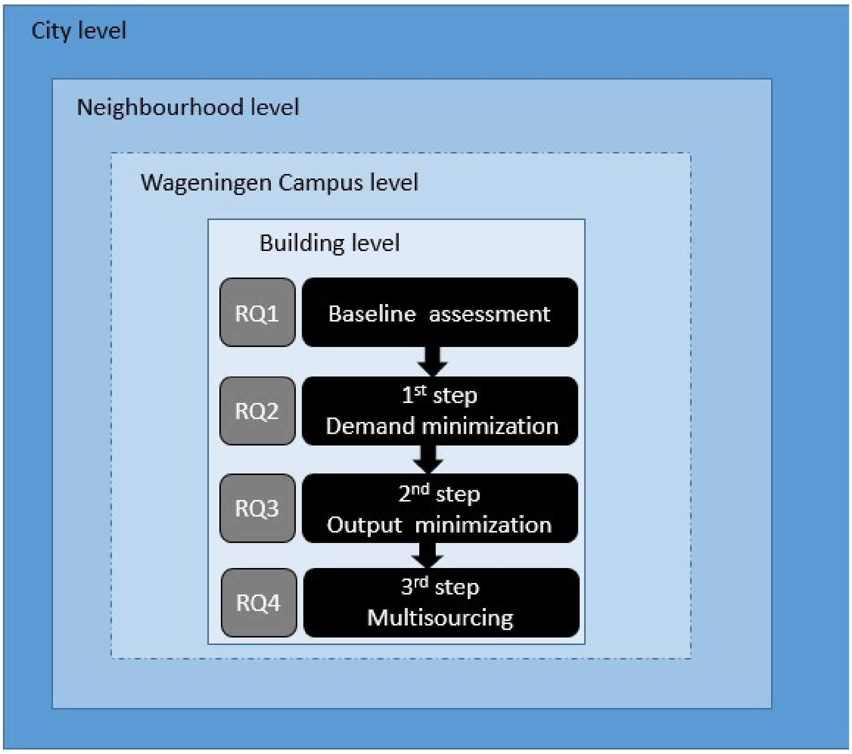


Figure 2: Conceptual framework of the thesis based on (Vera, 2012).

2.1.2 Urban harvest approach concept

UHA is aligned to sustainability because it aims to promote an improvement of resources (energy, water, nutrients) usage within an urban area in order to make this area as self-sufficient as possible. This is done by closing urban cycles, applying technologies that reduce demand for a specific resource and by harvesting resources available within this area (Agudelo-Vera et al., 2012).

The search for this self-sufficiency of an urban area makes this area less dependent on external resources, in order to achieve this goal, the resources have to be strategically managed through the three steps suggested by UHA: demand minimization, output minimization and Multi-sourcing (Vera, 2012).

UHA starts on a small scale of an urban area (building unit) where actually the majority of resources are consumed, therefore it is a bottom-up approach that can sequentially be applied in a bigger urban area, such as block, neighborhood, and city level (Agudelo-Vera et al., 2012; Vera, 2012).

Before applying the three steps, a baseline assessment is performed consisting of preparing a mass flow analysis of the existing situation (Vera, 2012). Ideally, all inputs and outputs related to resource usage in a building are quantified.

Demand minimization is the first step in the UHA and it claims to; firstly, reduce the demand needed of resources such as water, energy, and nutrients. This can be achieved by stimulating changes in human behavior or by technology implementation but UHA does not consider human behavior in its approach but only the implementation of technological improvements. After the baseline assessment, those activities that consume more than 10% of the total resource demand are selected and the possible technologies that could be implemented to achieve a reduction in the demand of this resource are evaluated (Vera, 2012).

Output minimization is the second step on the UHA and englobes three strategies: cascading, recycling or recovering the outputs (Vera, 2012).

'Cascading' supports the idea of reusing an output that presents a lower quality (because it has already been used previously) for lower quality demand. The baseline will provide the information needed to identify the outputs and their remaining qualities. For instance, water used to wash hands could be cascaded to flush toilets because the remaining quality from the first use is enough to the second purpose.

'Recycling' is also related to a reuse of a resource but only after improving its quality and reintroducing it into the system. The feasibility of applying the recycling option is pointed by the baseline assessment and the choice of the appropriate technology is defined considering the local context. The idea is to produce the same or similar product used before recycling process.

'Recovering' is related to the use of interesting substances present in waste flows. The purpose is to harvest the remaining quality present in the waste and obtain a product that belongs to another flow.

Multi-sourcing has the objective to determine the options for supplying the remaining demand (if needed) by local renewable sources, which also reduces the cost of transportation because the resource is harvested locally, for instance, the reuse of rainwater (Vera, 2012).

Figure 3 summarizes the steps described above and the components that were considered in each step. It is based on the urban metabolic profile (UMP) which provides information about the availability of resources and the production of waste or secondary resources and can be combined with UHA (Vera, 2012). In this research, Figure 3 was applied for water resource use within WUR Campus.

In an urban system, there is the input of External inputs (*Ei*) that will provide the Demand (*D*) needed by a building. The resource initially supplied as an External input could be reused through Cascade (*C*) that refers to the direct reuse of this resource within the building and Recycle (*R*) where the resource is treated previously before being reintroduced into the urban system. Multisource (*M*) refers to the local sources used by the urban system. The resource could also be Storage (*S*) within the urban area for further inside usage or exported to be used by another urban area. Waste exported (*We*) is related to the waste that is produced within the urban area and is exported. There is also the possibility of harvesting a resource that could be exported afterward if the Demand is lower than the Total input (*Ti*), *Ti* = *Ei*+*C*+*R*+*M*. Therefore, Exported resources (*Er*) refers to Resource harvested (*Rh*) in the building unit and exported afterward. The main objective of UHA is to minimize *D*, *Ei* and *We* and maximize *C*, *R* and *M* within an urban area and its neighborhood.

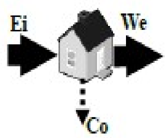
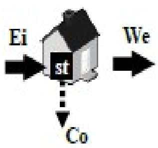
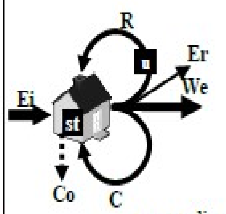
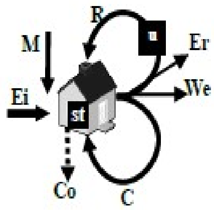
	Step 0	Step 1	Step 2	Step 3
	Baseline	Demand minimization	Output minimization	Multisourcing
		 st=saving technologies	 u=upgrading	
Strategies		Implementation of saving technologies (st)	Cascading: Direct reuse of resources Recycling : Reuse after upgrading (u)	Multisource by using local and renewable sources
Total Inputs (Ti)	*Ei*	*Ei*	*Ei*, *C*, *R*	*Ei*, *C*, *R*, *M*
Total Output (To)	*We*	*We*	*C*, *R*, *We*, *Er*	*C*, *R*, *We*, *Er*
Consumption	*Co*	*Co*	*Co*	*Co*
Resources harvested	$Rh = 0$	$Rh = 0$	$Rh = C + R$	$Rh = C + R + M$

Figure 3: UHA step by step adapted from (Vera, 2012).

Information provided in Figure 3 is used to evaluate the different measures applied by UHA by calculating four indicators:

- Demand Minimization Index (DMI)
- Waste Output Index (WOI)
- Self-Sufficiency Index (SSI) and
- Resource Export Index (REI)

Figure 4 below show the expressions related to these indicators. The indicator WOI was not applied in this research because waste output was not considered.

$$DMI = \frac{Conventional\ demand\ (D_0) - Minimized\ demand\ (D)}{Conventional\ demand\ (D_0)}$$

$$WOI = -\frac{Waste\ exported\ (We)}{Minimized\ demand\ (D)} =_{[Eq.4]} -\frac{Ei + M - Er - Co}{D} =_{[Eq.6]} -\frac{D - C - R - Co}{D}$$

$$SSI = \frac{Resources\ harvested(Rh) - Exported\ resources\ (Er)}{Minimized\ demand\ (D)} =_{[Eq.3]} \frac{C+R+M-Er}{D} =_{[Eq.7]} \frac{D-Ei}{D}$$

$$REI = \frac{Exported\ resources\ (Er)}{Minimized\ demand\ (D)} =_{[Eq.5]} \frac{Ti-D}{D}$$

Figure 4: Expressions to calculate the four indicators adapted from (Vera, 2012).

2.2 Data collection methods

The data used in this thesis was gathered through literature review and interviews.

2.2.1 Literature review

The mainly literature review used in this research was about UHA, water use, sustainable buildings, rainwater harvesting, and other co-related topics in both scientific sources (published and unpublished articles, books, PhD thesis, master thesis, etc.) and non-scientific sources (governmental webpages, technical manual of appliances, non-governmental webpages, technical reports emitted by several corporations, etc.).

To build a baseline assessment for each building, firstly a literature review was adopted as a method to provide information about the main water consumers' activities within a building. According to Proença & Ghisi (2010), the main water uses in offices buildings are related to toilets flushing, taps for washing hands, cleaning common areas and other uses such as making coffee, drinking water, washing fruits (Proença & Ghisi, 2010).

In this research, all these uses were considered. It was also known that some buildings at WUR have restaurants and laboratories therefore, these two activities were included in the baseline assessment as well.

Basically, two groups of water consumption activities were defined:

- Administrative: toilet, kitchen, cleaning and other; and
- Laboratory: water consumed exclusively inside laboratories.

The three steps of UHA (demand minimization, output minimization and multi-sourcing), were identified by a literature review. This review so provided the necessary information to be gathered through interviews and to perform the applicable calculations.

2.2.2 Interviews

Based on literature review, an interview protocol was developed (see Appendix A) to guide the requested information related to RQ1-RQ4.

The protocol interview was divided into three main parts:

Part 1 – General information: in this section, the basic information about the interview, the building and interviewee's names, the date and time spent of each interview was registered here;

Part 2 – Building information: data about the total area of the building, number of staff and visitors, activities performed, type of roof, basic information about toilets, cleaning, restaurants, and laboratory (where applicable) were registered in this part; and

Part 3 – Water usage information: data about water consumption on a monthly basis, the source of water, if any water reuse was in place in that building and information about how the fire system protection and wastewater system were designed, were registered in this part.

In total 16 interviews were conducted between May 9th until June 27th with WUR employees responsible for water management, building managers and staff responsible for catering and cleaning service. English was the language used. The information gathered was registered in the developed protocol or agreed to be sent by email afterward.

People from 18 out of 19 buildings included in the study area were interviewed. Building 109 (Radix Serre, Klima, Agros) was kept out of this research due to the transitional period to pension of the manager of this building.

2.3 Data analysis methods

The data gathered through literature review and interviews was inserted into an Excel spreadsheet of Microsoft Excel 2013 and all the calculations, graphs, tables were performed through this tool.

Subchapters below describe how data was analyzed for each UHA step.

2.3.1 Baseline assessment

Because building managers did not know the real water consumption of activities from the administrative group, for each water consumption activity, except for 'other', a theoretical water consumption was determined using results of the literature review.

The theoretical amount of water used for toilet, kitchen and cleaning is described below. Consequently, the theoretical water use was compared to the real consumption in order to get insight about the accuracy of using these theoretical formulas in practice.

Before calculating theoretical water consumption, the present seasonality patterns in each building were evaluated. This was done by comparing average on water consumption per month (excepted for holiday period: July and August) to average on water consumption per month for holiday period (July and August). If the difference was higher than 10% (factor < 0.90) the seasonality factor (*sf*) was calculated by dividing the average on water consumption during holiday period to the average on water consumption during non-holiday period and this factor was applied in the theoretical calculations for toilet and kitchen activities. For cleaning activities, seasonality factor was not taken into account.

Water use for toilet

The total water use by toilets depends on building's occupancy, the frequency of using toilets, the type of flushing and tap water installed. The frequency of using toilets depends on personal characteristics. On average, people use a toilet six times per day for urination and once for defecation (Blokker, 2010).

People are assumed to sleep around eight hours a day, therefore, the frequency of urination and defecation was based on the sixteen remaining hours of a day. The population that frequent WUR Campus was considered to be related to staff team, students, and visitors. It was assumed that staff people stay for eight hours per day in a building while students and visitors normally stay half period (four hours).

The ratio between men and women was also considered in order to calculate the total water consumption for using toilets. At WUR, 51.4% of total employees are men while 48.6% are women (Wageningen UR, 2016b). The same ratio was also assumed for the whole population (staff, students and visitors).

Flushing toilet

The types of toilet flushes that normally are in use nowadays differ between water saving option and without water saving option. Most of the time, urinals are also available in men's toilets. Table 3 indicates the water consumption per flush for each option presented in toilets at WUR Campus.

Table 3: Water consumption per flush depending on toilet type.

Toilet type	Water consumption (liters per flush)
Full cycle or no-saving water option	6.0
Saving water option	3.0
Urinals	1.9

Related to urination and defecation purposes and based on the data available on literature review, staff uses toilets on average three times per eight working hours in a day while students and visitors are expected to use once per four hours in a day. Defecation rate is considered to be once a day but to determine if it happens at the WUR Campus is difficult. For this reason, it was assumed that 1/3 of the total population that use WUR Campus buildings daily might defecate while being there.

Equation (1) was applied to calculate the water consumption related to toilet flushing.

$$Wft = \left[(Nm \times 3 \times Vtft) + (Nw \times 3 \times Vtft) + \left(\frac{1}{3}(Nm + Nw) \times 1 \times Vtft\right)\right] \times \frac{22}{1000} \text{ (Eq.1)}$$

Where Wft is the total water consumption by flushing toilets (m3 month-1), Nm is the number of men using building (number day-1), 3 is related to the number of times of urination, $Vtft$ is the volume of water related to the type of flushing toilet (L cycle-1), Nw is the number of women using building (number day-1), 3 is related to the number of times of urination, $\frac{1}{3}$ is an assumption about the fraction of people that defecate in toilets at WUR Campus, 1 is related to number of times of defecation each eight hours inside the building, *22* is the number of working days in a month and *1000* is to convert liters into cubic meters.

Washbasin

The use of water related to washing hands also differs between men and women and it was calculated based on data available on official Dutch drinking water report that establishes that women use 5.0 liters per day while men use 5.5 liters per day (Geudens, 2015a). This water consumption was registered for the whole day therefore, proportionality was applied to evaluate the water consumption through washbasin used within WUR Campus, 1.6 liters each eight hours for women and 1.8 liters each eight hours for men. The ratio between men and women at WUR Campus was kept the same as indicated previously.

Equation (2) was applied to achieve the theoretical water consumption for washbasin.

$$Wwb = [(Nm \times 1.8) + (Nw \times 1.6)] \times \frac{22}{1000} \qquad \text{(Eq.2)}$$

Where Wwb is the total water consumption by washbasin (m^3 $month^{-1}$), Nm is the number of men using building (number day^{-1}), 1.8 is the volume of water related to washing hands by men proportional for eight hours inside the buildings (L), Nw is the number of women using building (number day^{-1}), 1.6 is the volume of water related to washing hands by women proportional for eight hours inside the buildings (L), *22* is the number of working days in a month and *1000* is to convert liters into cubic meters.

Total water consumption for toilets

The total water consumption related to the usage of toilets are the sum of water consumption for flushing toilets and the water consumption for washing hands as described by equation (3) below.

$$TWt = (Wft + Wwb) \times (10\, nM + 2sfM) \qquad \text{(Eq.3)}$$

Where TWt is the total water consumption by toilets (m^3 $year^{-1}$), Wft is water consumption by flushing toilets (m^3 $month^{-1}$), Wwb is the total water consumption by washbasin (m3 month-1), 10 is the quantity of normal months with no seasonality and 2 sfM is related to seasonality factor applied for holidays periods (July and August) when necessary.

Water use in kitchens

To calculate the yearly water consumption by restaurants present within WUR Campus, the number of people served was considered as a base.

Due to the lack of more precise literature on water consumption in restaurants, a Japonese study (Murakawa et al., 2004) where 21 different restaurants were evaluated was adopted in this research and the average of 37.5 L $meal^{-1}$ day^{-1} was applied to estimate water consumption at WUR Campus restaurants.

The quantity of meal prepared and the type of meals were gathered through interviews. Typical hot meals were considered in the equation below while sandwiches, pizzas and soups, were counted with a reduction factor because they consume less water to be prepared (IN-10; IN-14, Personal Interview, May 22; June 2, 2017).

Equation (4) was applied to obtain the yearly water consumption related to restaurants.

$$TWk = \left\{[(Np \times 37.5)] \times \frac{22}{1000}\right\} \times (10\, nM + 2sfM) \qquad \text{(Eq.4)}$$

Where TWk is the total water consumption by kitchen (m^3 $month^{-1}$), Np is the number of people served based on meals prepared (number day^{-1}), 37.5 is related to the average of water consumption for cooking meals (L $person^{-1}$ day^{-1}), 22 is the quantity of working days in a month, 1000 is to convert liters into cubic meters, 10 is the quantity of normal months with no seasonality and 2 sfM is related to seasonality factor applied for holidays periods (July and August) when necessary.

Water use for cleaning floors

Cleaning activity related to the floors was one of the activities performed in buildings that uses water. The process of cleaning in this research was related to the floors of each building.

It was assumed the same type of floor for all buildings which is a hard floor without carpets. McCall and McNeil (2007) compares the energy, time and water usage for maintaining hard and carpet floors in commercial buildings. On hard floors, the cleaning processes which use water are wet mopping and scrubbing (McCall & McNeil, 2007).

Wet mopping cleaning

The quantity of water used during wet mopping cleaning depends on the area to be cleaned and the frequency of the cleaning activity. The frequency also depends on how this area is used (traffic pattern). Intense traffic area requires around seven times more water in the process of cleaning than low traffic area, 18.25 L m^{-2} year comparing to 2.60 L m^{-2} year respectively due to higher usage of this area and therefore it gets dirty more frequently (McCall & McNeil, 2007).

The water consumption used for cleaning through wet mopping is described in equation (5).

$$Wwm = [(Tait \times 18.25) + (Talt \times 2.60)] \times 1000 \qquad \text{(Eq.5)}$$

Where Wwm is water consumption related to wet-mopping cleaning (m^3 $year^{-1}$), $Tait$ is the total area to be cleaned classified as intense traffic (m^2 $year^{-1}$), *18.25* is the water consumption for cleaning intense traffic area (L $year^{-1}$), $Talt$ is the total area to be cleaned classified as low traffic (m^2 $year^{-1}$), *2.60* is the water consumption for cleaning low traffic area (L $year^{-1}$) and *1000* is to convert liters into cubic meters.

Scrubbing cleaning

The second type of cleaning processes on a hard floor that uses water is scrubbing. This process requires a machine and it is applied to remove heavy dirt on the floor and it is performed with lower frequency when compared to wet-mopping (McCall & McNeil, 2007).

To determine the quantity of water used in the scrubbing process, a common scrubbing machine was selected in order to get its patterns regarding water consumption. The productivity of @ 3 mph = 3,924 m^2 h^{-1} and heavy scrub set which uses 2.3 L min^{-1} was assumed (Warrior, 2011).

Equation (6) was used to calculate the water consumption used for cleaning through scrubbing:

$$Wsc = [(Tasc \times tsc \times wsc)]/1000 \qquad \text{(Eq.6)}$$

Where Wsc is the water consumption related to scrubbing cleaning (m^3 $year^{-1}$), $Tasc$ is the total area to be scrubbed (m^2 $year^{-1}$), *tsc* is the time to scrub the defined area (year), *wsc* is the water consumption according technical specifications for scrubbing (L $year^{-1}$), and *1000* is to convert liters into m^3.

Total water consumption for cleaning floors

The total water consumption related to cleaning process of floors will be the sum of water used in both cleaning processes: wet mopping and scrubbing and it was calculated as described by equation (7).

$$TWc = Wwm + Wsc \qquad \text{(Eq.7)}$$

Where TWc is the total water consumption for cleaning (m^3 $year^{-1}$), Wwm is the total water consumption related to wet mopping (m^3 $year^{-1}$) and Wsc is the total water consumption related to scrubbing (m^3 $year^{-1}$).

Water use related to other uses

Even though the activities described above represent higher water consumption activities it is known that some other activities such as making coffee, drinking water, washing fruits also contribute to a minor water consumption. These small water uses under 'other uses' category were not considered in this thesis however any discrepant value was considered by evaluating building by building.

Water use for laboratory

Some of WUR Campus buildings have laboratories and research areas that use water to perform their activities. There was no available information in literature that is correlated to water consumption of WUR laboratories. Moreover, the water consumption in laboratory depends on the type of analyses performed, therefore, each building had to be evaluated separately based on information provided through interviews.

The detailed investigation regarding water consumption in laboratories activities was out of this thesis' scope.

2.3.2 Demand minimization

After performing the baseline assessment, an evaluation of the highest water consumption activities was performed in order to identify in which activity a demand minimization was applicable.

The starting point was to consider all activities that consume more than 10% (Vera, 2012) of total water use and evaluate if it is possible to implement a technology to reduce water demand.

For instance, the potential water demand reduction by installing saving water flushes on those toilets that did not present this option as well as the installation of urinals. Since there was no information regarding real water consumption by toilets, the calculations were made based on theoretical values from each building.

Regarding kitchen and cleaning activities, techniques that could be implemented in order to provide a reduction in water demand were considered.

2.3.3 Output minimization

After evaluating the potential improvement through demand minimization, the second step of UHA, which is the output minimization, was performed. Once more, the focus of this step was toilet use.

It was evaluated the potential of minimizing the output in toilets by cascading water used for washing hands to flush toilet. The remaining quality of water after being used to wash hands was considered to be adequate to the second use which is to flush toilet.

To avoid double counting, the calculation of the percentage of output minimization by cascading water was done after DM calculations.

2.3.4 Multi-sourcing

Multi-sourcing is the last step of UHA and aims to determine the options for supplying the remaining demand (if needed) by local and renewable sources (Vera, 2012). In each building, a rainwater harvesting (RWH) potential from roofs was determined.

To estimate the potential volume of rainwater harvesting the total roof area, the annual average rainfall and runoff coefficient (Abdulla & Al-Shareef, 2009) were used. Data about the average of rainfall in the Netherlands was gathered from the Climate Change Knowledge Portal from 1991 till 2015 (The World Bank Group, 2017).

The average of these 25 years of measurements were considered to calculate the potential volume of rainwater that could be harvested monthly. Google maps was used to measure total roof area, which corresponds to the catchment area in a rainwater harvest system.

Ultimately, the runoff coefficient was assumed to be 0.8 because many designers assume a 20% loss of annual rainfall due to roof material, evaporation, losses in gutters and storage tanks and inefficiency of collecting rainwater (Abdulla & Al-Shareef, 2009).

Equation (8) was used to calculate the potential volume of rainwater harvesting within WUR Campus.

$$VR = (R \times A \times c/1000) \qquad \text{(Eq.8)}$$

Where VR is the monthly volume of rainwater that could be harvested in each building (m^3), R is the average monthly rainfall in the Netherlands (mm $month^{-1}$), A is the total roof area of each building (m^2), c is the run-off coefficient which was assumed to be 0.8 (non-dimensional) and 1000 is the conversion factor from mm to m.

3 Results

An overview of the three steps of UHA for the whole WUR Campus is provided and a comparison between theoretical and real values is made. The main purposes of WUR buildings are also presented briefly. More detailed information about each building and the results obtained by applying UHA are presented in the Appendix B.

3.1 Baseline assessment

Table 4 presents an overview of water consumption obtained through theoretical calculations in comparison to real water consumed by each WUR building covered by this research.

Theoretical values were obtained through the application of equations described previously while real values were obtained through technical reports and water scheme provided by interviews. Theoretical values comprise the following activities: toilets, kitchen and cleaning while real values comprise total water consumption of each building including laboratory when present.

To verify the accuracy of theoretical values in comparison to real values, a factor (t/r) was determined in buildings that total water consumption related to administrative activities were available. This was done by dividing the sum of theoretical values of administrative activities by total administrative water consumption whenever this value was known.

Before any comment about theoretical and/or real values presented in Table 4 below, it is relevant to evaluate whether defined model used to calculated theoretical values is reliable or not. In 10 out of 18 buildings, the factor (t/r) was possible to be determined. In eight buildings which water consumption by laboratories was not available the factor (t/r) was not calculated.

The range of factor (t/r) varied from 0.33 up to 1.37. However, the lowest value of 0.33 was excluded because it is related to building SBC where sports activities are performed and water consumed by showers was not evaluated in this research. Therefore, it was assumed that this low factor was associated to this gap and, consequently this result should not be included.

Excluding factor (t/r) for building SBC, the new range of factor (t/r) varied from 0.75 up to 1.37. By applying the average calculation, a result of 1.01 was obtained. It was considered, therefore, that the model applied in this research could be used to compare theoretical values with real values and, ultimately theoretical values could be used to support the evaluation of the three steps described by UHA.

Related to theoretical results, some data were estimated due to lack of information about requested data. For instance, regarding toilets, in 5 out of 18 buildings, the number of visitors was not provided during interviews and were estimated to be 10% of total staff present in these buildings. In 2 of these 5 estimated buildings the factor (t/r) was calculated: building Impulse with a factor (t/r) of 0.83 and building Innovatron with a factor (t/r) of 1.00. Based on that it seems that these estimated values related to the number of visitors did not have an expressive influence on calculating factor (t/r).

Table 4: Overview of water consumption obtained through theoretical calculations in comparison to real water consumed by each WUR building.

		THEORETICAL					REAL				
		Administrative consumptions				Lab. cons[3]					
Building	Seasonality	Toilet[1] (m^3/year)	Cleaning (m^3/year)	Kitchen[2] (m^3/year)	Total (m^3/year)	(m^3/year)	Total Adm (m^3/year)	Total Lab (m^3/year)	Total Building (m^3/year)	Period considered	Factor (t/r)
100 - Lumen	-	3.541	271	413	4.225	#	*	*	3.124	2014-2016	#
101 - Gaia	0,77	1.604	233	-	1.837	-	1.538	-	1.538	2014-2016	1,19
102 - Forum	0,62	3.521	723	1.452	5.696	3.844	*	*	9.540	2014-2016	#
103 - Orion	0,52	3.106	450	1.822	5.378	#	3.916	5.199	9.115	2014-2016	1,37
104 - Atlas	0,88	1.486	221	645	2.353	#	2.206	1.318	3.524	2014-2016	1,07
107 - Radix	0,90	5.908	599	-	6.508	#	8.696	5.371	14.067	2015-2016	0,75
115 - Impulse	0,73	816	91	516	1.423	-	1.717	-	1.717	2015-2016	0,83
116 - Actio	0,89	816	40	-	856	-	971	-	971	2015-2016	0,88
117 - Nexus	-	216	33	-	249	-	270	-	270	2015-2016	0,92
118 - Axis	0,81	1.743	425	-	2.168	12.338	*	*	14.506	2014-2016	#
119 - Triton	0,69	77	20	-	97	120	*	*	217	2014-2016	#
120 - Carus	0,67	117	179	-	295	6.186	*	*	6.481	2014-2016	#
121 - Innovatron	-	32	37	-	69	-	69	-	69	2014-2016	1,00
122 - Zodiac	-	2.637	287	-	2.923	3.506	*	*	6.429	2014-2016	#
123 - Vitae	0,87	1.239	301	-	1.541	14.802	*	*	16.343	2014-2016	#
124 - Helix	-	2.556	300	-	2.855	5.441	*	*	8.296	jul/16-dez/16	#
130 - SBC	0,52	1.255	154	-	1.409	#	4.329	-	4.329	2016	0,33
201 - Leeuw.	0,74	2.713	342	1.421	4.475	#	4.080	-	4.080	2014-2016	1,10

Legend

ESTIMATED VALUES
1- number of visitors estimated to be 10% of total staff (based on interview)
2- numbers of meals served per day was estimated based on proportionality of water consumption from other buildings
3- laboratory consumption estimated as the difference of total water consumption and theoretical water consumption

- not existent
* data not available
# not applicable

For kitchen, 3 out of 6 buildings number of meals prepared were also estimated since there was no information about the quantity of meals prepared daily and literature used to calculate water consumption for kitchen activities was based on liters per meal prepared (Murakawa et al., 2004). In two buildings where values were estimated, (Lumen and Forum) it was not possible to calculate factor (t/r) but for building Atlas, where also estimated value was used, a factor (t/r) of 1.07 was calculated. The three remaining buildings; Orion, Impulse and, Leeuwenborch factor (t/r) obtained were 1.37, 0.83 and, 1.10 respectively.

Ultimately, 7 out 10 buildings where laboratory activities are present, information about water consumed by this area was estimated by discounting the total theoretical water consumption from total real water consumption. This was done to provide an estimation of water consumed by laboratory although, in this research, laboratory consumptions were not considered in the steps of UHA.

Related to real water consumption, in all 18 buildings, the total water consumption per month was available. In none of the buildings, there was specific information about water consumption related to toilets, kitchen and cleaning activities. Based on technical reports and water scheme provided through interviews, in 3 out of 10 buildings that present laboratory activities, specific water consumption by this area was possible to be determined.

The annual average water consumption from 2014 until 2016 was used as the standard for real water consumed by each building. A different period was defined when a variation of 10% on the annual average of each year was noticed.

This was needed because theoretical values were calculated based on data gathered through interviews that were related to recent information, such as the number of staff and visitors as well as the number of meals served per day.

In 12 out of 18 buildings were possible to consider as the standard period (2014-2016). 4 out of 18 buildings the defined period was changed to 2015 until 2016, in 1 building the period considered was 2016 and 1 building a 6 months period (from July until December-2016) was defined.

Finally, the percentage of water use in administrative activities was compared to group WUR buildings with the same main purpose. Table 5 presents the percentage of water consumption in administrative activities (toilet, kitchen, and cleaning) for each group of buildings.

Table 5: Percentage of water consumption in administrative activities comparing to each group of buildings.

			Administrative water distribution			
Group of purposes		Buildings	**Toilet (%)**	**Cleaning (%)**	**Kitchen (%)**	**Other (%)**
1	- classrooms - laboratory - offices - restaurants	100 - Lumen	84	6	10	-
		102 - Forum	62	13	25	-
		103 - Orion	58	8	34	-
		104 - Atlas	63	9	27	-
2	- classrooms - offices - restaurants	115 - Impulse	48	5	30	17
		201 - Leeuwenborch	60	8	32	-
3	- classrooms - offices - laboratory	107 - Radix	68	7	-	25
		118 - Axis	80	20	-	-
		119 - Triton	79	21	-	-
		122 - Zodiac	90	10	-	-
4	- classrooms - offices	101 - Gaia	87	13	-	-
5	- offices	116 - Actio	84	4	-	12
		121 - Innovatron	46	54	-	-
6	- laboratory - offices	120 - Carus	40	60	-	-
		123 - Vitae	80	20	-	-
		124 - Helix	89	11	-	-
7	- other	117 - Nexus	80	12	-	8
		130 - SBC	29	4	-	67

Legend

(shaded)	Based on theoretical values
-	Not existent

Percentage distribution related to the first group shows that toilets are the highest water consuming activity followed by kitchen and cleaning. Although these four buildings have restaurants as one administrative activity, building Lumen showed the lowest percentage compared to the other activities. The main service in Lumen's restaurant is related to sandwiches and soups and there are no hot meals served there (see Appendix C).

Two buildings belong to the second group (Impulse and Leeuwenborch) and both demonstrated the same pattern as the first group. Impulse showed 17% of water use related to other use and this could be related to the fact that the number of visitors was estimated because real data was not available during the interview. Impulse building frequently provides entertainment with music and talks during lunchtime, therefore, during this activities number of visitors might be higher than the estimated 10% of total staff (see Appendix C).

In the third group, there are no restaurants and all buildings (except for Radix building) kept the same patterns related to the previous groups (toilet is the highest water consuming followed by cleaning). In Radix building the second highest activity was related to other (with 25% of total water use). Based on data gathered through interview, Radix is a building with highest number of occupancy (considering staff and students) and the second biggest area compared to all evaluated buildings. Therefore, it seems that cleaning activity might has a higher percentage on water consumption than the 7% obtained in this research.

Forth group presents one building (Gaia) which followed the same pattern, toilet followed by cleaning. At the moment of this research was conducted, Gaia building was making use of rainwater harvested to flush toilets. However, the quantity of rainwater harvested was not available during interviews and, therefore was not considered in this research.

In the fifth group, only offices are present and two buildings belong to this group (Actio and Innovatron). Innovatron building stands out of other buildings because presented cleaning as the highest water consuming activity, which seems to make no sense. One reason that could lead to this result is the fact that Innovatron building has a huge area when comparing to its occupancy, therefore the methodology defined for cleaning activity might not follow the same pattern for Innovatron and the results could show that less area are being cleaned than actually is.

The sixth group of buildings presents three buildings and one of them (Carus) showed the same pattern as in the previous group regarding to Innovatron building, where cleaning was higher water consuming than the toilet. Consequently, with the same characteristics as Innovatron, Carus has a big area when comparing to its occupancy, and this could be the same reason responsible for this result (see Appendix C).

The last group of buildings is related to another purpose. Two buildings (Nexus and SBC) belong to this group. Nexus building performs medical attendances and could be considered as a building with offices. In this building, the same pattern as the majority was noticed (toilet followed by cleaning). SBC building is where the gym is installed and therefore a different water consuming activity such as showering is performed there and it was not considered in this research.

In most buildings, 15 out of 18, the toilet was the highest water consuming activity with a range from 48% up to 90% (excluding the three exceptions – Carus, Innovatron and, SBC described previously). This result is supported by literature where toilets are also highest water consuming activity in commercial buildings (Proença & Ghisi, 2010).

Kitchen was the second highest water consuming activity after toilet. Range distribution when considering all 6 buildings that have restaurants was from 10% up to 34%. The lowest water consumption was related to Lumen building where 10% was registered. Highest water consumption was registered for Orion where the highest number of hot meals are served.

Cleaning activity, like the toilet, is present in all buildings and the range of water consumption was from 4% up to 60% when considering all buildings. When excluding the two highest percentages (Carus and Innovatron) the range goes from 4% up to 21%. This range is higher when comparing to literature where 1.3% up to 5.6% was detected but it was not possible to compare the cleaning processes considered in the literature used because they were not described (Proença & Ghisi, 2010).

As explained before, 'Other' is a category that represents water remaining after considering all activities performed within a building (administrative and laboratory). In 5 out of 18 buildings, 'other' category was applicable and the range goes from 8% up to 67% for SBC and to evaluate this category it is necessary to consider case by case as done previously.

Laboratory activities are also water consumers. 10 out of 18 buildings have a laboratory. In 3 of them, real water consumption was possible to be calculated due to information available in technical reports and water scheme. In 7 remaining buildings which no precise information on water consumption by laboratories was available, the percentage was calculated based on theoretical values. Table 6 shows the water distribution between administrative and laboratory uses.

Water consumption in laboratories depends on the type of analysis that is performed in each laboratory. Therefore, calculating the average among different buildings does not make sense and each case has to be evaluated separately. Based on this, and due to lack of time, laboratory activity was not considered in the next steps of UHA.

Table 6: Water distribution between administrative and laboratory uses.

Building	Percentage of water distribution ADM %	Percentage of water distribution LAB %
100 - Lumen	#	#
101 - Gaia	-	-
102 - Forum	60	40
103 - Orion	43	57
104 - Atlas	63	37
107 - Radix	62	38
115 - Impulse	-	-
116 - Actio	-	-
117 - Nexus	-	-
118 - Axis	15	85
119 - Triton	45	55
120 - Carus	5	95
121 - Innovatron	-	-
122 - Zodiac	45	55
123 - Vitae	9	91
124 - Helix	34	66
130 - SBC	-	-
201 - Leeuwenborch	-	-

Legend

(shaded)	Based on theoretical values
-	Not present
#	Not possible to calculate

3.2 Demand minimization

Real and theoretical values indicate that laboratory activities are the highest water consumers within evaluated buildings in this research. However, these activities are not taken into account for the next strategy of UHA.

After laboratory, the toilet is the most water consuming activity reaching 90% of total water consumption by administrative usage in some cases. Demand minimization considers the potential of reducing water demand by installing water saving flushing systems and/or urinals wherever is possible.

Table 7 shows the actual pattern in each building and the potential on water saving in m^3 $year^{-1}$ as well as the percentage on water reduction compared to the total demand of each building.

Table 7: Overview of demand minimization.

WUR				Demand minimization	
Building	Toilet pattern		Total water consumption "theoretically" TOILET (m^3/year)	Total saving water potential "theoretically" (m^3/year)	Potential percentage of reduction on water consumption based on total building water consumption "theoretically" (%)
	Saving water	Urinal			
100 - Lumen	No	No	3.541	1.165	28
101 - Gaia	No	Yes	1.604	317	17
102 - Forum	Yes	Yes	3.521	-	-
103 - Orion	Yes	Yes	3.106	-	-
104 - Atlas	Yes	Yes	1.486	-	-
107 - Radix	Yes	Yes	5.908	-	-
115 - Impulse	Yes	Yes	185	-	-
116 - Actio	Yes	Yes	816	-	-
117 - Nexus	Yes	No	216	78	31
118 - Axis	Yes	Yes	1.743	-	-
119 - Triton	Yes	No	77	29	30
120 - Carus	Yes	No	117	45	15
121 - Innovatron	Yes	No	32	12	17
122 - Zodiac	No	Yes	2.637	500	17
123 - Vitae	Yes	No	1.239	457	30
124 - Helix	No	Yes	2.556	485	17
130 - SBC	Yes	Yes	1.255	-	-
201 - Leeuwenborch	Yes	Yes	2.713	-	-
Campus			32.752	3.089	

A potential to reduce water demand exists from 15% up to 31% on the total water demand by installing water saving option and/or urinals in 9 out of 18 evaluated buildings.

Followed by the toilet, the kitchen was the next activity that demand minimization was evaluated. This research did not gather detailed information on how water is used and distributed among activities performed within the kitchen area.

A study of 21 restaurants (Murakawa et al., 2004) established that higher water consumption is related to preparation and service meals (92% of total water) while cleaning contributes with 8%.

Although a demand minimization could be achieved by changing human behaviors while cooking, this is not included in this research since UHA does not consider human behaviors as an option to reduce demand (Vera, 2012). One possible option to reduce water demand in restaurants could be related to cleaning process but in all 6 buildings dishwasher installed already present close water system.

The last administrative activity to be evaluated through demand minimization is cleaning activity. As described previously, cleaning activity is related to two processes; wet-mopping and scrubbing. According to interview with the manager of cleaning company contracted by WUR (IN-16, Personal Interview, June 27, 2017) these processes are kept the same in all buildings.

Therefore demand minimization was not considered in these activities because reduction related to wet-mopping is based on human behaviors and so not included in the UHA, and reduction related to scrubbing is not applicable because there is no additional technique to be implemented that focus on reducing water use during scrubbing process.

3.3 Output minimization

After evaluating the potential improvement through demand minimization, the second strategy of UHA, which is the output minimization, was performed. This step contains three strategies: cascading, recycling or recovering the outputs (Vera, 2012).

Once more, the focus in this strategy was toilet use due to its higher water consumption. The potential for reuse the water used for washing hands through 'cascading' strategy to flush toilet was evaluated. It was considered that the remaining quality on water after washing hands was enough to be used for flushing toilets.

In fact, according to Chilton *et al.*, 2000 water quality has little significance for flushing toilets and treated water is used only for transporting human waste resulting in underused of high quality resource (Chilton et al., 2000).

Table 8 presents the theoretical potential on minimizing the output of water used to flush toilets by cascading water used to wash hands in each building.

Table 8: Overview of output minimization.

WUR				Output minimization	
Building	**Toilet pattern**		**Total water consumption "theoretically" TOILET (m^3/year)**	**Saving water by using wastewater from wash hands to flush toilets (with demand minimization) (m^3/year)**	**Potential percentage of reduction on water consumption based on total building water consumption "theoretically" (after applying demand minimization if applicable) (%)**
	Saving water	Urinal			
100 - Lumen	No	No	3.541	278	9
101 - Gaia	No	Yes	1.604	185	12
102 - Forum	Yes	Yes	3.521	641	11
103 - Orion	Yes	Yes	3.106	575	11
104 - Atlas	Yes	Yes	1.486	258	11
107 - Radix	Yes	Yes	5.908	1.024	16
115 - Impulse	Yes	Yes	185	33	2
116 - Actio	Yes	Yes	816	142	17
117 - Nexus	Yes	No	216	31	18
118 - Axis	Yes	Yes	1.743	307	14
119 - Triton	Yes	No	77	12	17
120 - Carus	Yes	No	117	18	7
121 - Innovatron	Yes	No	32	5	8
122 - Zodiac	No	Yes	2.637	292	12
123 - Vitae	Yes	No	1.239	184	17
124 - Helix	No	Yes	2.556	283	12
130 - SBC	Yes	Yes	1.255	232	16
201 - Leeuwenborch	Yes	Yes	2.713	483	11
Campus			32.752	4.984	

The range of potential reduction on the output is 2% up to 18%. In all evaluated buildings, there is an opportunity to reduce output of flushing toilets by cascading water from washing hands.

Regarding kitchen and cleaning activities, output minimization was not considered because it was not detected potential improvement related to these activities.

3.4 Multi-sourcing

After applying the demand minimization and output minimization, the third step of UHA is evaluated. Multi-sourcing aims for harvesting local renewable resources in order to supply a remaining demand after the two first UHA steps (Vera, 2012).

This research focuses on potential rainwater harvesting as a Multi-sourcing step. Table 9 presents an overview of theoretical water consumption (total and after DM and OM) as well as the rainwater harvesting potential and their correspondent percentage on supplying total water demand with and without considering DM and OM.

Table 9: Overview of Multi-sourcing after demand minimization and output minimization.

	Theoretical			Multisourcing		
Building	Total water demand (m^3/year)	Total water demand after DM (m^3/year)	Total water demand after DM and OM (m^3/year)	Potential rainwater harvesting (m^3/year)	Percentage of total annual water consumption "theoretically" (%)	Percentage of total annual water consumption after applying DM and OM (if applicable) "theoretically" (%)
100 - Lumen	4.225	3.059	2.783	2.896	69	104
101 - Gaia	1.837	1.525	1.342	565	31	42
102 - Forum	5.696	5.696	5.013	2.203	39	44
103 - Orion	5.378	5.378	4.786	1.205	22	25
104 - Atlas	2.353	2.353	2.094	1.050	45	50
107 - Radix	6.508	6.508	5.466	4.837	74	88
115 - Impulse	1.423	1.423	1.394	1.012	71	73
116 - Actio	856	856	710	981	115	138
117 - Nexus	249	172	139	560	225	403
118 - Axis	2.168	2.168	1.865	3.726	172	200
119 - Triton	97	68	56	258	265	462
120 - Carus	295	251	234	5.689	1925	2436
121 - Innovatron	69	57	53	910	1319	1727
122 - Zodiac	2.923	2.426	2.135	3.031	104	142
123 - Vitae	1.541	1.078	884	2.703	175	306
124 - Helix	2.855	2.370	2.086	1.145	40	55
130 - SBC	1.409	1.409	1.169	1.701	121	145
201 - Leeuwenborch	4.475	4.475	3.983	1.569	35	39
WUR Campus	44.357	41.271	36.192	36.042	81	100

The annual rainwater that could be potentially harvested from the 18 evaluated buildings supply 81% of total annual water demand from these buildings when considering only administrative activities and without applying DM and OM. In 9 out of 18 buildings, rainwater has the potential to supply 100% of total water demanded.

When DM and OM are applied, it is noticed an improvement on supplying water demand from 81% up to 100% when considering the sum of water demanded from all buildings although it is known that harvesting rainwater has a seasonal pattern because it depends on climate characteristics. After considering DM and OM, 10 out of 18 building have the potential to provide 100% of water demand by applying Multi-sourcing strategy.

The Figure 5 below presents an overview of reduction on water demand when applying the three UHA steps. Water demand was based on theoretical values of administrative activities for each building.

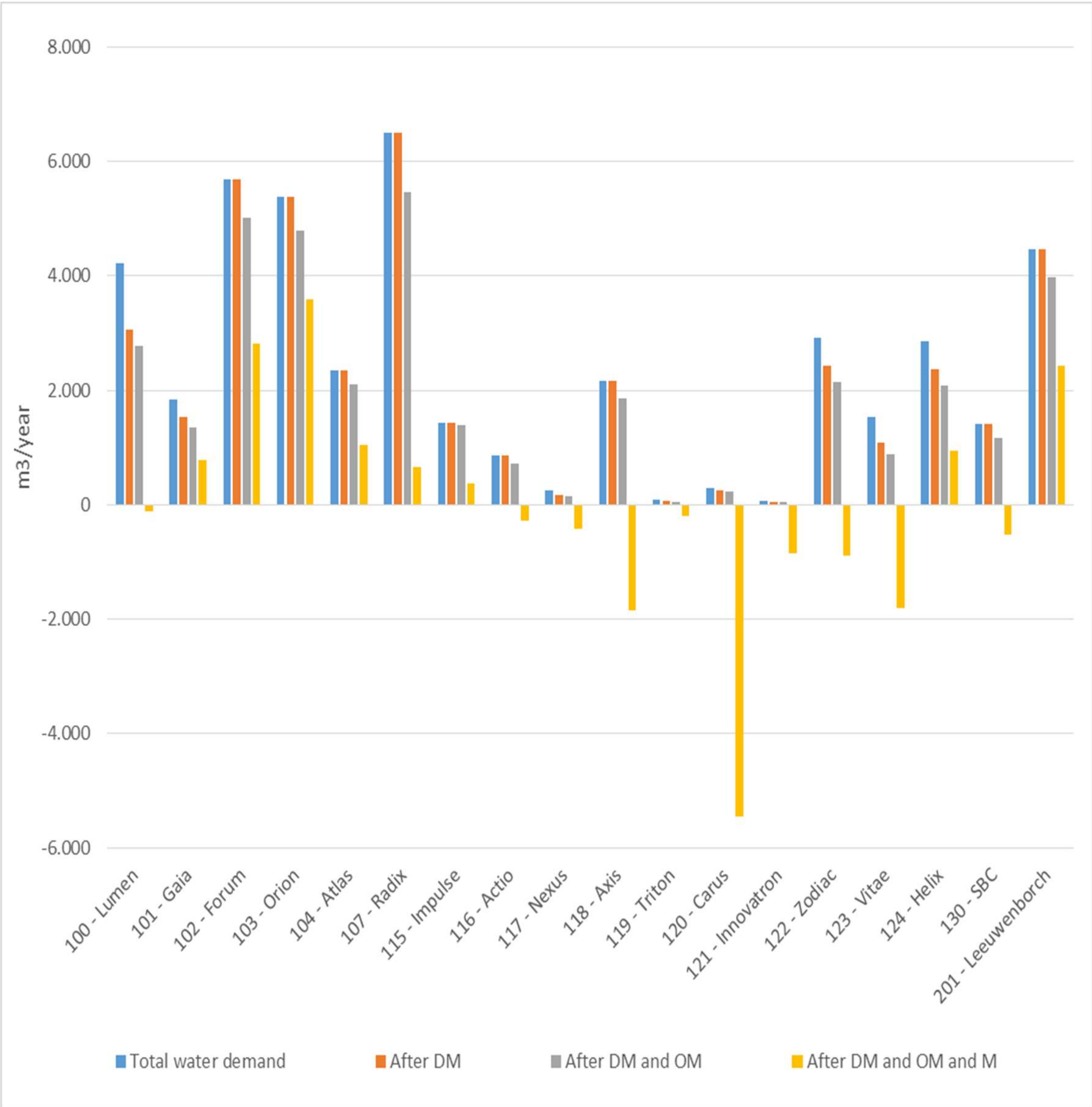


Figure 5: Overview of water demand reduction after DM, OM and M.

As mentioned before, DM has an impact on those buildings that do not present water saving system and/or urinals installed. The more expressive improvements is noticed for buildings Lumen, Gaia, Zodiac, Vitae and, Helix. Regarding to OM, in all buildings it was provided an improvement by applying this step.

Multi-sourcing, in this research related to rainwater harvesting, is an important step because there is a huge potential on supplying the water demanded by administrative activities such as toilet and cleaning (non-potable uses). Some buildings have also the potential on being suppliers for other buildings for instance, the three highest potential are related to buildings Carus, Innovatron and, Triton.

3.5 UHA indicators

The Table 10 below presents the indicators calculated based on the results. It was defined three indicators as described below. The indicator 'Waste Output Index (WOI)', described on chapter 2, was not considered in this research because waste generated within WUR buildings was not evaluated in this research:

- Demand Minimization Index (DMI);
- Self-Sufficiency Index (SSI) and;
- Resource Export Index (REI).

Table 10: UHA indicators.

	UHA INDICATORS		
	DMI	**SSI**	**REI**
100 - Lumen	0,3	1,0	0,0
101 - Gaia	0,2	0,5	0,0
102 - Forum	0,0	0,5	0,0
103 - Orion	0,0	0,3	0,0
104 - Atlas	0,0	0,6	0,0
107 - Radix	0,0	0,9	0,0
115 - Impulse	0,0	0,7	0,0
116 - Actio	0,0	1,0	0,3
117 - Nexus	0,3	1,0	2,4
118 - Axis	0,0	1,0	0,9
119 - Triton	0,3	1,0	3,0
120 - Carus	0,2	1,0	21,7
121 - Innovatron	0,2	1,0	15,0
122 - Zodiac	0,2	1,0	0,4
123 - Vitae	0,3	1,0	1,7
124 - Helix	0,2	0,6	0,0
130 - SBC	0,0	1,0	0,4
201 - Leeuwenborch	0,0	0,5	0,0

Regarding DMI, a result higher than zero means that there is potential to improve DM and in 9 out of 18 buildings, this potential exists. This result is at similar level when comparing to another study where DMI of 0.34 up to 0.36 was achieved by considering the implementation of devices to reduce water demand (Vera, 2012).

The next indicator is SSI and when its value equals to 1 means that the building could be self-sufficient of the evaluated resource in case all three steps of UHA are implemented. In this research, 10 out of 18 buildings have the potential to become self-sufficient of a water resource.

Finally, REI indicates which buildings could be considered as an exporter of water resource if a result higher than one is presented. 5 out of 18 buildings could be a supplier of water for other WUR buildings.

4 Discussion

This research provides an overview of the potential improvement on water resource use within WUR Campus by applying UHA. As showed in Figure 3, step 0 of UHA is related to the baseline assessment, which is the base for the following three UHA steps.

Related to the baseline assessment, two main groups of water use activities were defined: the first one is related to the administrative group that includes toilet, kitchen, and cleaning and the second one is related to laboratory group. Administrative activities were explored and detailed by this research while laboratories were just measured whenever possible.

Regarding to the administrative activities, toilets were most important role because they were responsible for most water use. The main parameters to calculate water consumption due to the use of toilets were: occupancy of buildings (through the number of staff, students and visitors); ratio of male and female; patterns of toilets (presence of saving water system and/or urinals), patterns for washing hands and ratio of using toilet for urination and defecation (see Equations 1, 2 and, 3).

Possible weaknesses and uncertainties related to toilet activities are the occupancy of buildings. It was assumed that occupancy of a building was related to staff members, students, and visitors.

Staff member includes WUR direct employees as well as external contracted people from cleaning and restaurants companies and this information was considered reliable because it is a value that does change slowly but the number of visitors fluctuate enormously on a daily basis.

The main concern about this data was that in there the majority of WUR buildings there is no official system of registering the number of visitors and, the data gathered through interviews was based on interviewer's perception. For instance, in Orion building the number of visitors is 83 times the number of staff indicating that visitors are an important actor for toilet use.

Another concern related to the toilet is the gender ratio at WUR buildings. Water consumption in toilets varies depending on gender (Geudens, 2015b). Data available about the percentage of male and female was related to WUR employees (Wageningen UR, 2016b) but it was assumed to be the same for students and visitors. When a toilet presents urinal option this has a big influence on water used to flush it, therefore, increasing the precision of data of gender ratio will increase the robustness and trustworthiness of the results as well.

Even with the weaknesses described above, the overview of the baseline assessment obtained in this research showed the toilet as the highest water consuming activity related to administrative activities. The range was from 48% up to 90% of total administrative water consumption. This range is slightly wider when compared to the literature used which appointed to a range of 52% up to 84% in commercial buildings (Proença & Ghisi, 2010).

In kitchens, the main parameter considered to calculate water consumption was the quantity of meals served per day (see Equation 4). A weakness of this thesis was a lack of literature that provides useful information about water consumption by restaurants. Additionally, a lack of information regarding the water consumption by WUR restaurants or the quantity of meals served per day contributed to this weakness.

Nevertheless, a literature used that provided water consumption per meal prepared based on 21 restaurants located in Japan (Murakawa et al., 2004) was useful to build the correspondent equation. The average on water consumption indicated by this literature (Murakawa et al., 2004), (37 liters per meal) was considered in this research and it was assumed to be similar to another literature that suggests considering 25 liters per meal prepared (de Souza et al., 2012).

Difficulty on finding different options of literature with information about water consumption in the kitchen and, the fact that there is no detailed information about how many meals are served or how much water is used in these kitchens increases the uncertainty about these calculations. Further research should consider a more exploratory investigation of water consumption in kitchens in order to increase the reliability of this research.

Cleaning was the third activity associated to the administrative group. Its water consumption was calculated based on area to be cleaned; traffic patterns and technical characteristics of devices (see Equations 5, 6 and, 7). A weakness detected in this research is because the same process of cleaning was adopted for all buildings and this seems to be not realistic due to differences in traffic patterns in buildings with a low occupancy, for instance at Carus and Innovatron buildings in which water use from cleaning was higher than for toilets, contrary to other results.

The second group of water consumer activity was related to the laboratory. The majority of WUR buildings presents laboratory activities (11 out of 18) but in only three of them, it was possible to obtain the real water consumption based on water scheme and technical report. The reason for that is because the technical report did not present detailed information regarding water consumed by laboratory or this information was not easily identified as laboratory activity. More detailed information provided by these technical reports could increase the robustness of these results.

When evaluating Multi-sourcing strategy, an important information is the roof area since it affects directly rainwater harvesting because it is related to the catchment system (Abdulla & Al-Shareef, 2009). In fact, one study showed that by increasing the catchment area from 2200 m^2 (half roof are) up to 4400 m^2 (whole roof are) the potential recovery went from 51% up to 82% (Chilton et al., 2000).

In this research, the total area of each roof was considered as potentially available to harvest rainwater except for Gaia that has already a rainwater harvest system implemented. In this case, the real roof area adopted nowadays, which correspond to 30% of total roof area, was used for calculating the potential on harvesting rainwater for this building.

Consequently, if the same reduction on roof area available for harvesting rainwater was applied for all buildings, a huge decrease in water supply by rainwater might be noticed. Additionally, the calculation of roof area was done as flat roof even though buildings present different configuration. That is because in order to calculate the roof area of other types of roof, information such as angles and roof dimensions are needed and they were not available on the material gathered through interviews.

Another point to consider in a rainwater system is the volume of a storage tank which is also an important item that determines if the totality of rainwater harvested could or not be used (Mun & Han, 2012). In this research, the information about the storage tank was not taken into account and therefore, it was considered that the whole potential on rainwater harvested could be available for non-potable water uses within WUR buildings.

Besides providing a remaining in water demand of each building, harvesting rainwater has other benefits such as reduction in surface or groundwater drainage and diminished flooding risk (Chilton et al., 2000).

Although there are points of weakness associate to Multi-sourcing calculation, this research provided an overview of the potential improvement that could be achieved by adopting this step of UHA. Moreover, further studies could go deeper in the rainwater harvesting potential on supplying non-potable water for WUR buildings.

Human behavior was not considered in this research although it plays an important role regarding water use and, therefore, an approach for implementing an environmental friendly behavior might result in huge savings (Viebahn, 2002) for all resources demanded for a building and not only related to water.

Moreover, many tools have been developed in order to support universities moving towards a more sustainable performance but the majority of these tools still is related to the field of operations while the minority englobes the human engagement aspect (Fischer et al., 2015), therefore, a different approach in future researches considering the gain on water management at WUR Campus by evaluating changes in human behaviors might enlarge the coverage of this important theme.

Important to mention is that this research was based on the theoretical improvements that could be achieved by applying UHA at the WUR Campus. However, it did not evaluate the technical and financial feasibility of its implementation and, therefore, new uncertainties might be identified if further studies are performed.

An overview of potential improvements on water use within WUR Campus is important to provide basic information on where to focus for further researches or to establish an action plan to implement these improvements. This research showed possibilities to improve water use within WUR buildings and keeping studies on this theme could foment the attractiveness for implementing such improvements.

5 Conclusion

This thesis demonstrates that the sustainability of water resource use within WUR Campus can be improved. Applying all three UHA steps (DM, OM and M) showed that theoretically even a complete self-sufficiency on water resource among all 18 evaluated buildings can be achieved.

The baseline assessment (RQ-1) showed that toilet is the highest water consumer activity within WUR buildings being responsible for 48% up to 90% of total water use relate to administrative activities. Kitchen (when present) showed to be the second highest water consumption activity with 10% up to 21%. Lastly is cleaning activity with 4% up to 21%.

Laboratory is also a water consumer activity and it is present in 11 out of 18 WUR buildings. Although it seems to represent the major contributor for water consumption, their detailed information were out of this research and, therefore, laboratory activity was not consider in the three steps of UHA.

Demand minimization (RQ-2) focus on the highest water consumption activity, consequently, an evaluation on how to reduce water demand by installing water saving system and urinals in toilets was considered. A reduction on water demand from 15% up to 31% could be achieved in 9 out of 18 buildings that do not have saving water system and/or urinals installed yet.

Besides the improvement that could be provided by DM, a reduction from 2% up to 18% of the output from toilets is possible by cascading water used for washing hands to flush toilets (RQ-3). This improvement is applicable to all 18 evaluated buildings.

The last UHA step evaluated was M (RQ-4). The potential on harvesting the rainwater from each roof building was evaluated. The lowest potential percentage to supply water for non-potable uses is 25% while the highest is 2436%. In 10 out of 18 buildings there is a potential to export the exceeded rainwater harvested to another building covering 100% of total water demanded by WUR buildings.

Finally, this thesis did not investigate the technical and financial feasibility of implementing the improvement options suggested in this research, nor the influence of human behavior on improving water use. To gain more insights in the real improvement options more research is needed as more research on real water consumption by various activities within each building, for instance by laboratories and the potential of harvesting rainwater.

Although the Netherlands does not face water scarcity yet, WUR, being a well-recognized university for its effort on working on global environmental concerns, can set a nice example by becoming water self-sufficient.

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List of interviews

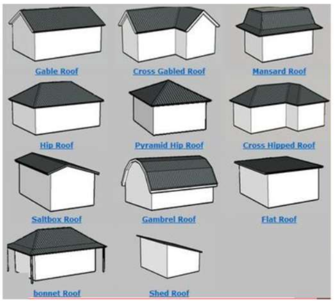
Interview number	Date	Time	Minutes spent	Interviewee's name	Job position	Building related	Building Code
IN-1	9-mai-17	15:30	50	Pim Marcusse Dick Verhagen	Building manager Technical person	Orion	103
IN-2	10-mai-17	10:30	50	Ludy Zeeuwen Dick Verhagen	Building manager Technical person	Forum	102
IN-3	11-mai-17	13:00	50	Thera Leenhouwers	Building manager	Zodiac Carus Triton	122 120 119
IN-4	15-mai-17	12:30	60	Annemarie de Vries Dick Wolters	Building manager Technical person	Axis Helix Innovatron Impulse	118 124 121 115
IN-5	15-mai-17	14:00	40	Antoon van Brakel Twan Gutte	Building manager Technical person	Gaia Lumen Atlas	101 100 104
IN-6	16-mai-17	11:00	30	Remy Bach	Building manager	Acio Nexus SCB	116 117 130
IN-7	16-mai-17	14:00	45	Ineke Rus-Kortekaas	Building manager	Vitae	123
IN-8	17-mai-17	14:30	35	Rolf Heling	Building manager	Leeuwenborch	201
IN-9	18-mai-17	10:00	30	Tanja Borst	Laboratory responsible	Orion	103
IN-10	22-mai-17	10:00	40	Ron Nagtegaal	Kitchen manager	Forum Lumen Atlas	102 100 104
IN-11	23-mai-17	11:00	50	Monique Groen	Wasterwater responsible	Campus	-
IN-12	30-mai-17	10:00	40	Michiel van der Wal	Energy coordinator	Campus	-
IN-13	31-mai-17	13:00	45	Sonja Nooy	Building manager	Radix	107
IN-14	2-jun-17	14:00	30	Jeoren van Rosevelt	Kitchen manager	Leeuwenborch	201
IN-15	21-jun-17	09:00	40	Twan Gutte	Technical person	Lumen Gaia	100 101
IN-16	27-jun-17	12:00	40	Bjorn Aaldering	Cleaning manager	Campus	-

Appendices

Appendix A – Material for data collection

Interview protocol

Rev.04

INTERVIEW	
Before starting	
Explanation	This interview is the field work of my thesis which objective is to identify the potential opportunities to improve water resource management at Wageningen Campus by applying the UHA (Urban Harvest Approach). In order to gather data, I will perform an interview and a checklist in each of 19 buildings. None of data will be published without previous authorization.
Record allowed?	( ) Yes ( ) No
General Information	
Name of building:	
Code of building:	
Date of interview:	
Interview conducted by:	
Interviewee's names:	
Time spent:	Started at: Ended at:
Building information	
Number of floors:	
Total area (m^2):	( ) na
Layout available?	( ) Yes ( ) No
Total staff / occupancy	( ) people ( ) women ( ) men
Total visitors	( ) people per day / week / month / year ( ) na
Activities	( ) study (classrooms, meeting area) ( ) work (offices) ( ) research (laboratories) ( ) green house ( ) fitness (gym, swiming pools) ( ) others
Diurnal pattern	Is there any noturnal activities? If yes, which ones?
Roof's type	

Toilets information	( ) based on checklist
Coffee machine	Is there information about water consumption? ( ) frequency of use. Unity: ( ) na
Restaurant information	( ) equipment based on checklist ( ) frequency of washing machine. Unity: ( ) quantity of meals served. Unity:
Cleaning information	Brief description on how the cleaning system is organized. ( ) times per day ( ) use of specific equipment ( ) photo time
Laboratory information	Brief description about laboratory activities. ( ) use of specific equipment ( ) photo time
Water usage information	
Total water consumption	( ) unity: m^3/month other:
Type of water source	( ) public system ( ) groundwater ( ) surface other ( ) other:
Consumption of water in 2016 per month (jan - dez)	( ) info available ( ) to be sent ( ) na
Water reuse	Is there any reuse of water in this building? ( ) Yes ( ) No If Yes, how much? ( ) unity: If Yes, for what purpose?
Fire protection system	Brief description on how the system works. Is there any water reservoir for this purpose? ( ) Yes ( ) No ( ) na
Waste water system	Brief description on how the system works. Is there any analysis of the waste water quality? If yes, could the results be sent by email? ( ) Yes ( ) No
Closing interview	
Aknowledgment	Thanks a lot for your important contribution. The results of this research will be shared to facilities department and they will be responsible for further communication or not.

na: not available

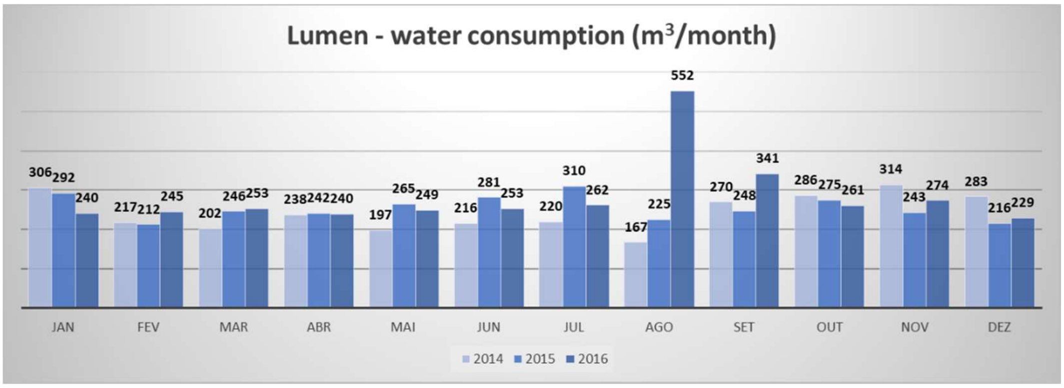
Appendix B – Detailed information about each WUR building

Lumen – 100

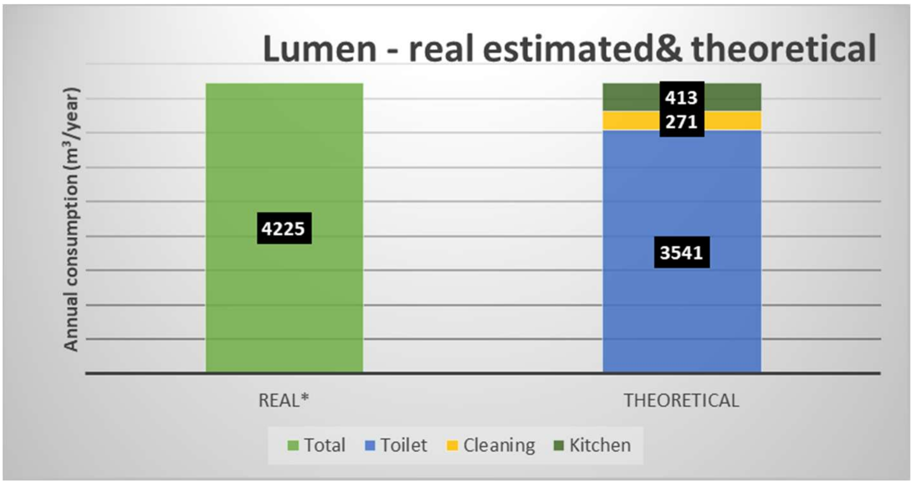
Main characteristics:

- Total area: 13,477 m^2
- Number of employees per day: 600
- Average of visitors per day: 36
- Period of water measurement: 2014 – 2016
- Seasonal factor: 0.93
- Activities: classrooms, offices, laboratory and, restaurants

Historical water consumption



Baseline assessment



Steps of UHA

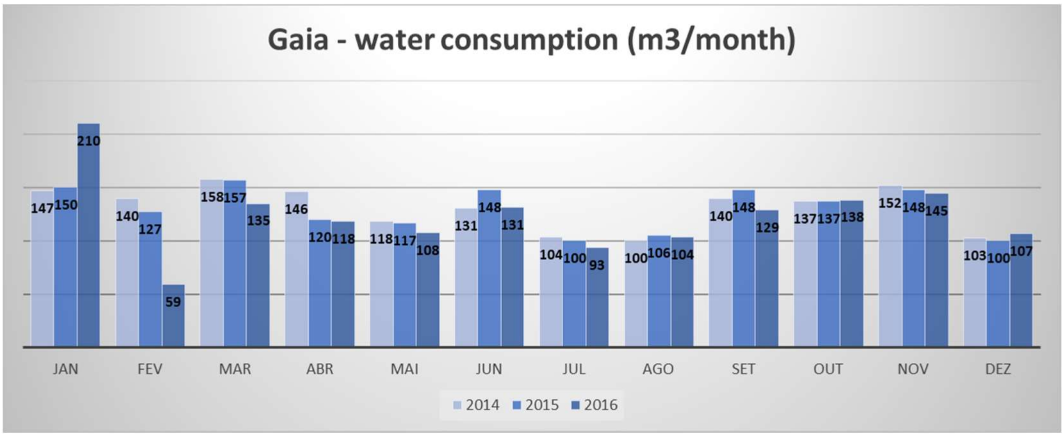
Demand minimization	Output minimization	Multi-sourcing
28 %	9 %	104 %

Gaia – 101

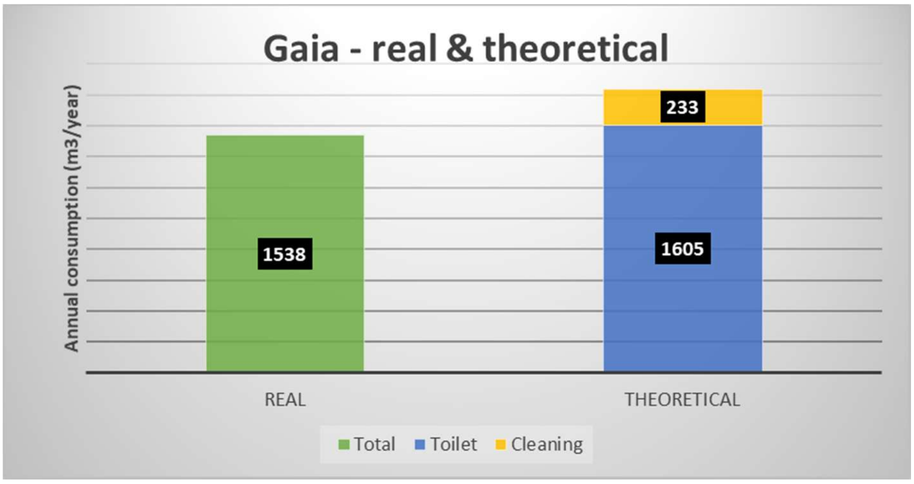
Main characteristics

- Total area: 15,590 m^2
- Number of employees: 400
- Average of visitors per day: 24
- Period of water measurement: 2014 – 2016
- Seasonal factor: 0.76
- Activities: offices and classrooms

Historical water consumption



Baseline assessment



Steps of UHA

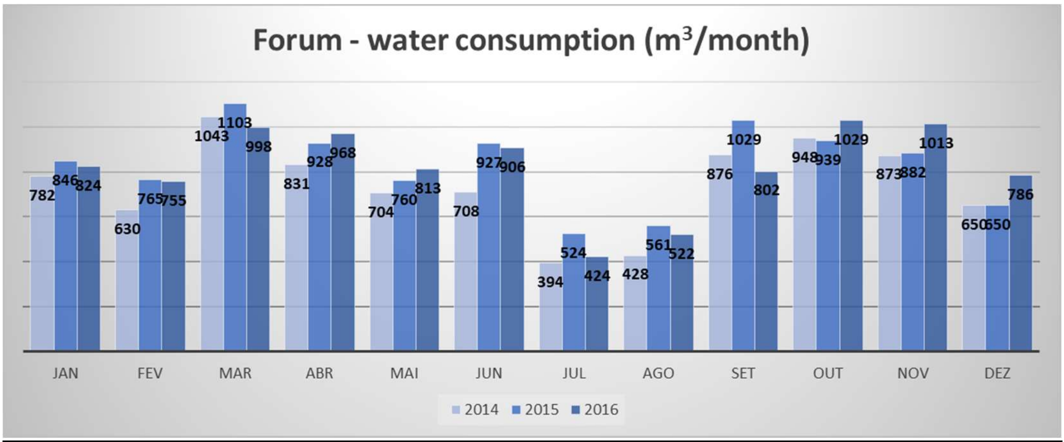
Demand minimization	Output minimization	Multi-sourcing
17%	12 %	42 %

Forum – 102

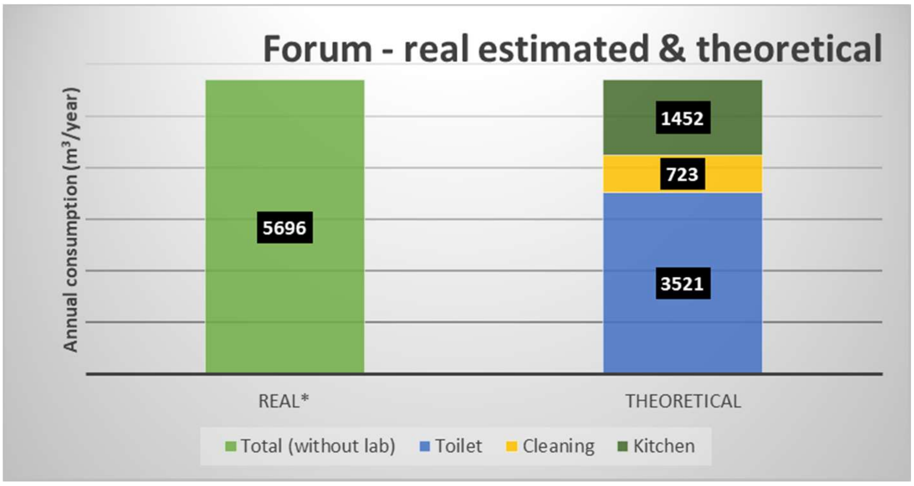
Main characteristics

- Total area: 36,000 m^2
- Number of employees: 175
- Average of visitors per day: 2500
- Period of water measurement: 2014 – 2016
- Seasonal factor: 0.62
- Activities: offices, classrooms, laboratory and, restaurant

Historical water consumption



Baseline assessment



Steps of UHA

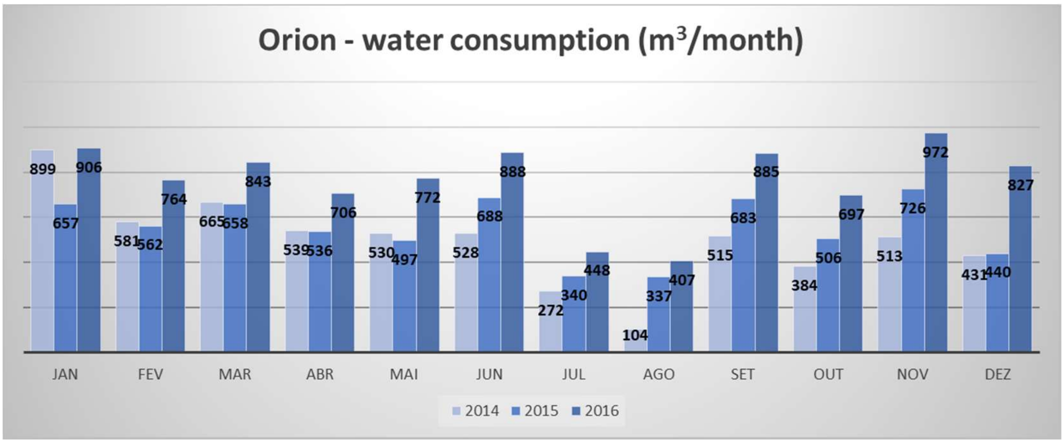
Demand minimization	Output minimization	Multi-sourcing
0 %	11 %	44 %

Orion – 103

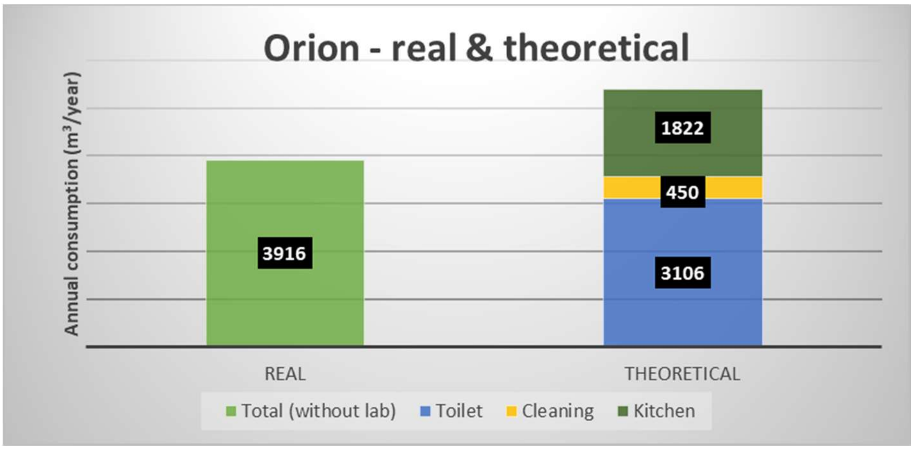
Main characteristics

- Total area: 22,400 m^2
- Number of employees: 30
- Average of visitors per day: 2500
- Period of water measurement: 2016
- Seasonal factor: 0.52
- Activities: offices, classrooms, laboratory and, restaurant

Historical water consumption



Baseline assessment



Steps of UHA

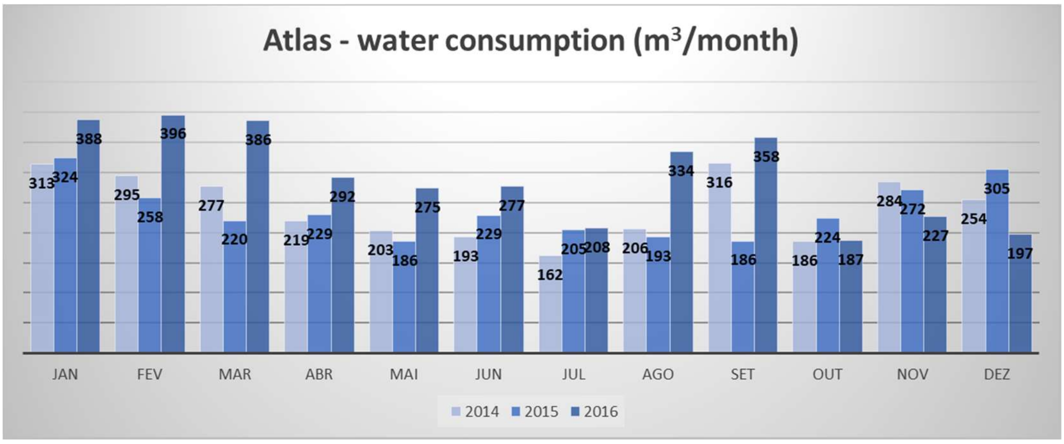
Demand minimization	Output minimization	Multi-sourcing
0 %	11 %	25 %

Atlas – 104

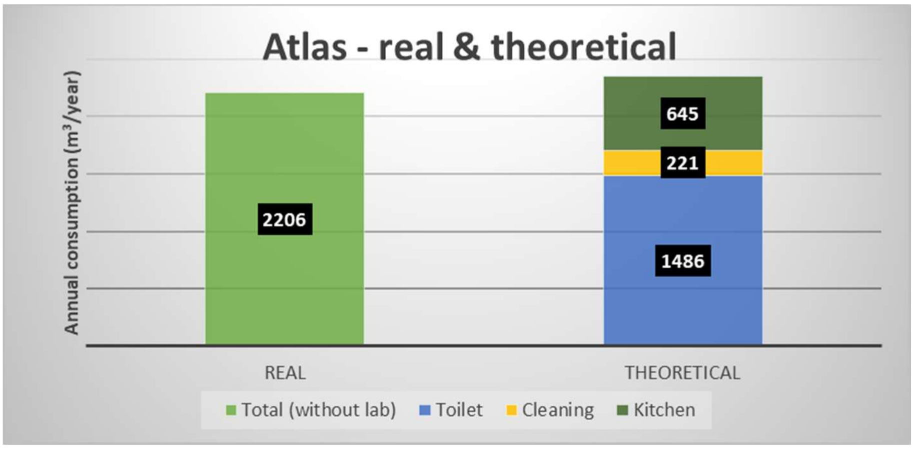
Main characteristics

- Total area: 11,000 m^2
- Number of employees: 500
- Average of visitors per day: 150
- Period of water measurement: 2014 – 2016
- Seasonal factor: 0.88
- Activities: offices, classrooms, laboratory and, restaurant

Historical water consumption



Baseline assessment



Steps of UHA

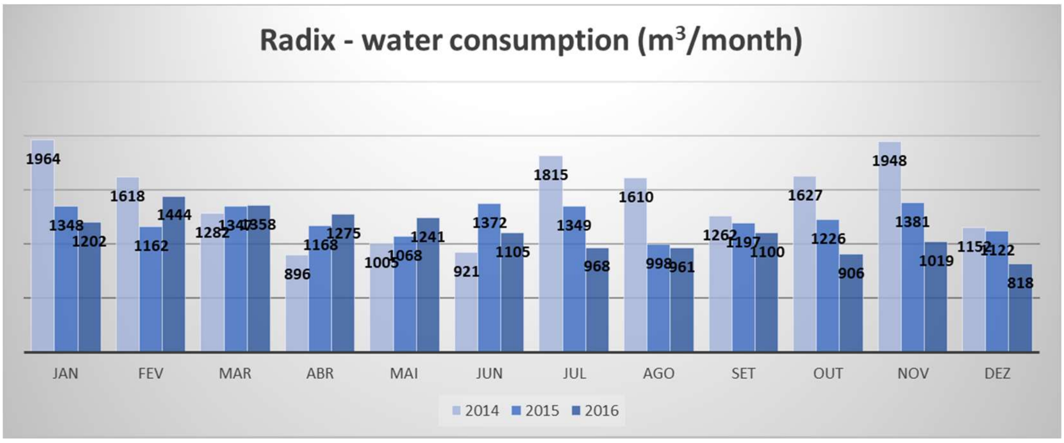
Demand minimization	Output minimization	Multi-sourcing
0 %	11 %	50 %

Radix – 107

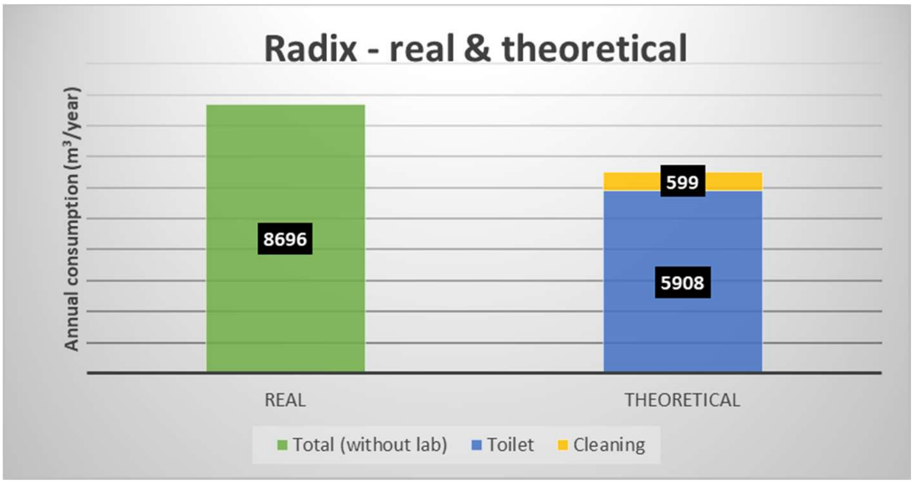
Main characteristics

- Total area: 29,820 m^2
- Number of employees: 1778
- Average of visitors per day: 1000
- Period of water measurement: 2015 – 2016
- Seasonal factor: 0.90
- Activities: offices, classrooms and, laboratory

Historical water consumption



Baseline assessment



Steps of UHA

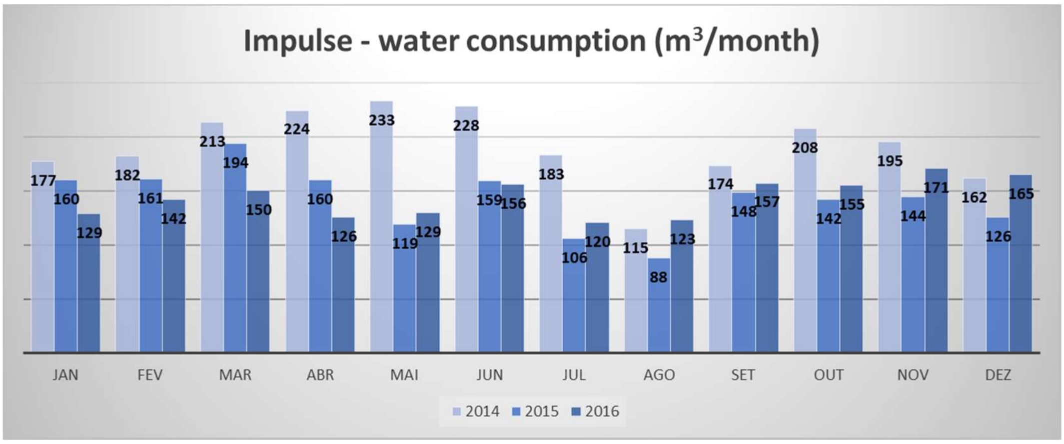
Demand minimization	Output minimization	Multi-sourcing
0 %	16 %	88 %

Impulse – 115

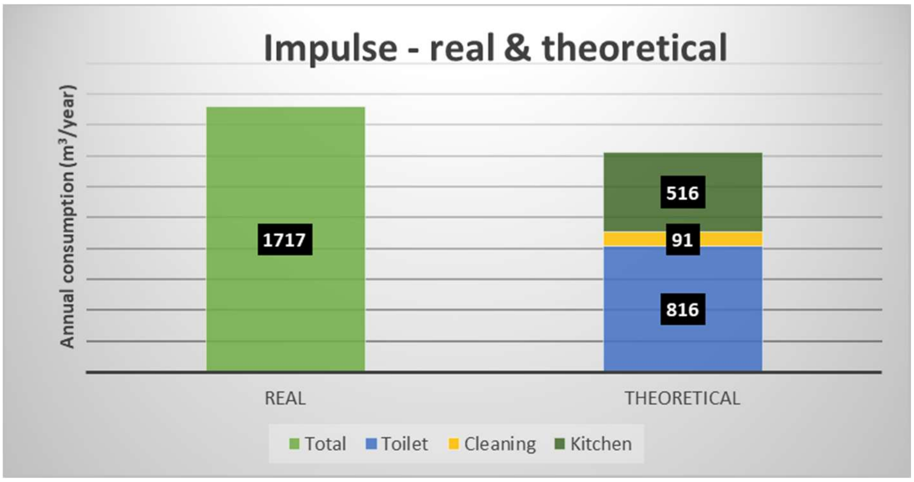
Main characteristics

- Total area: 4,524 m^2
- Number of employees: 70
- Average of visitors per day: 7
- Period of water measurement: 2015 – 2016
- Seasonal factor: 0.73
- Activities: offices, classrooms and, restaurant

Historical water consumption



Baseline assessment



Steps of UHA

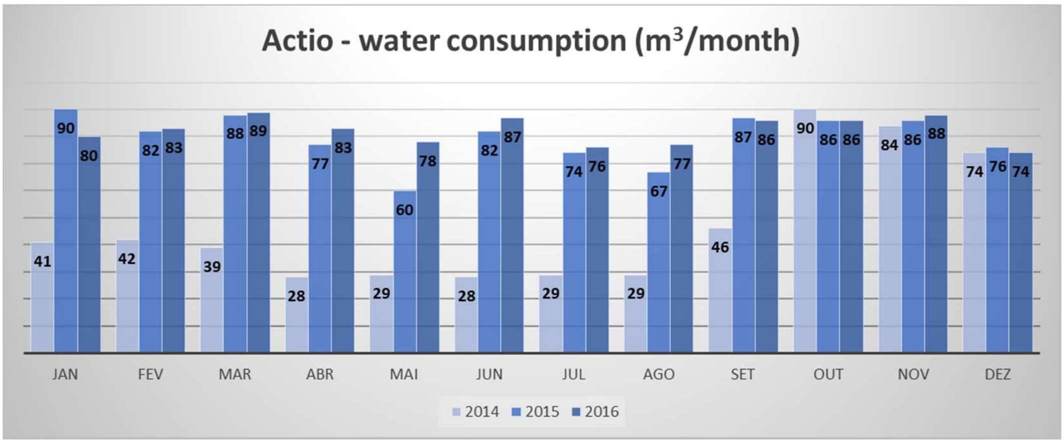
Demand minimization	Output minimization	Multi-sourcing
0 %	2 %	73 %

Actio – 116

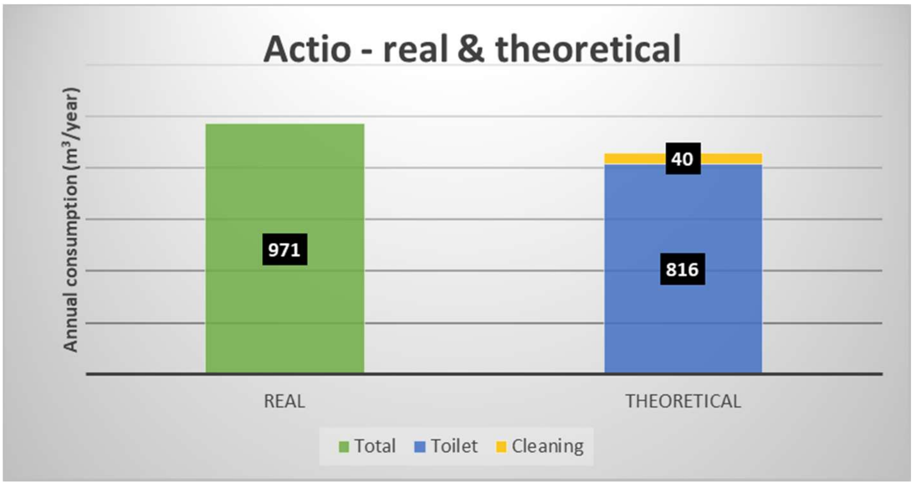
Main characteristics

- Total area: 1,992 m^2
- Number of employees: 300
- Average of visitors per day: 30
- Period of water measurement: 2015 – 2016
- Seasonal factor: 0.89
- Activities: offices

Historical water consumption



Baseline assessment



Steps of UHA

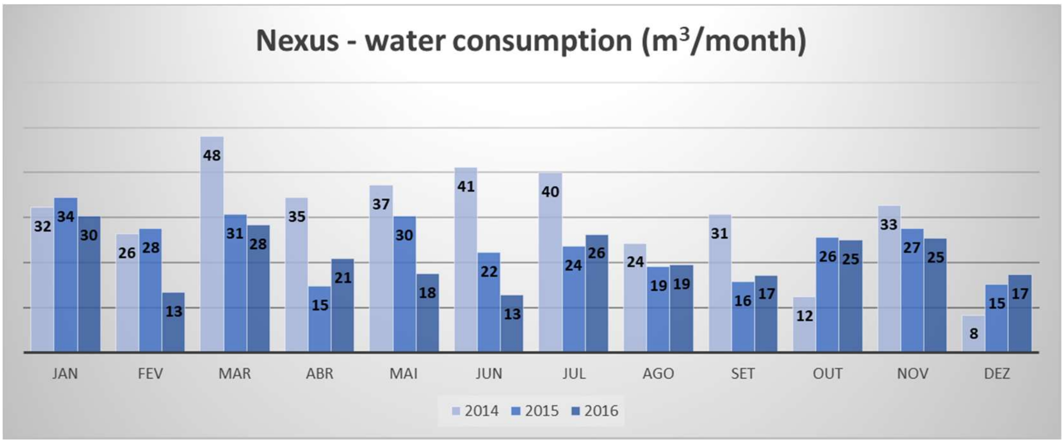
Demand minimization	Output minimization	Multi-sourcing
0 %	17 %	138 %

Nexus – 117

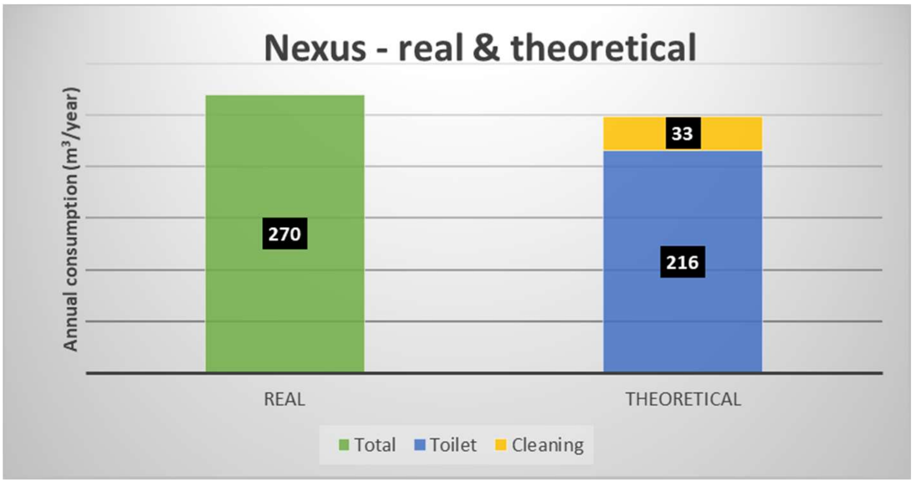
Main characteristics

- Total area: 1,620 m²
- Number of employees: 70
- Average of visitors per day: 0
- Period of water measurement: 2015 – 2016
- Seasonal factor: 0.98
- Activities: offices (medical attendances)

Historical water consumption



Baseline assessment



Steps of UHA

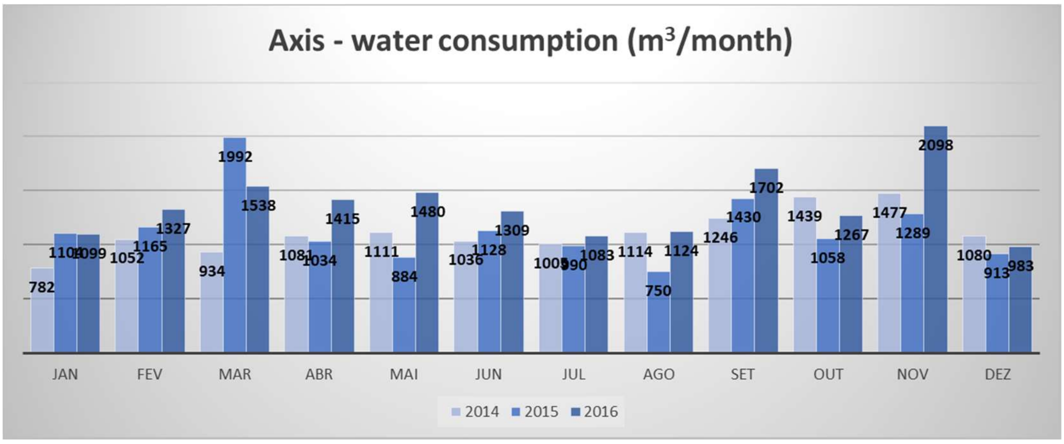
Demand minimization	Output minimization	Multi-sourcing
31 %	18 %	403 %

Axis – 118

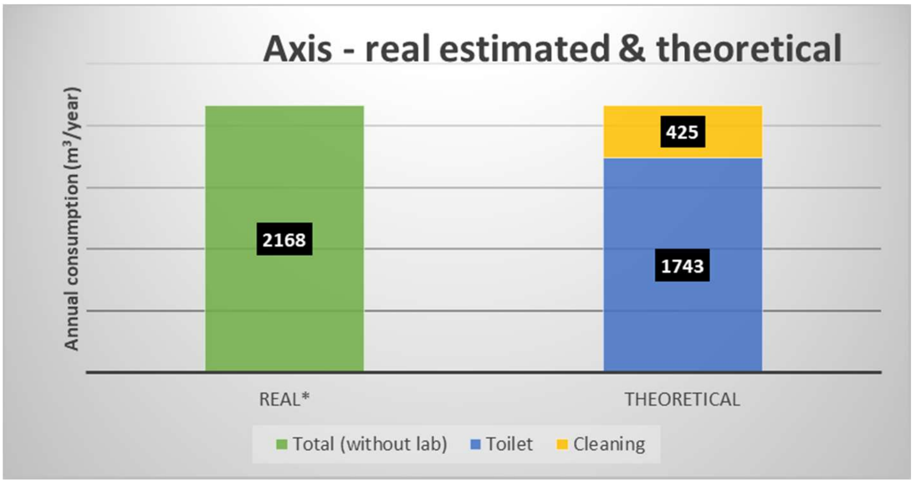
Main characteristics

- Total area: 21,158 m^2
- Number of employees: 650
- Average of visitors per day: 65
- Period of water measurement: 2014 – 2016
- Seasonal factor: 0.81
- Activities: offices, classrooms and, laboratory

Historical water consumption



Baseline assessment



Steps of UHA

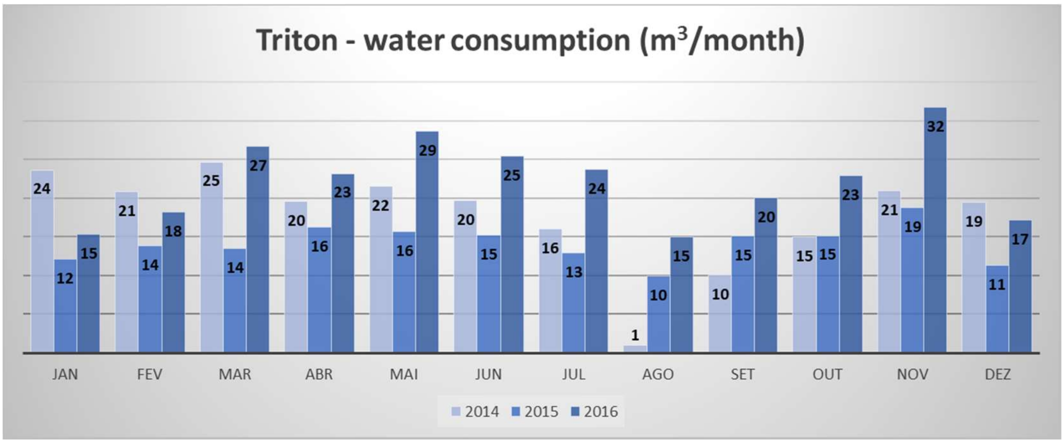
Demand minimization	Output minimization	Multi-sourcing
0 %	14 %	200 %

Triton – 119

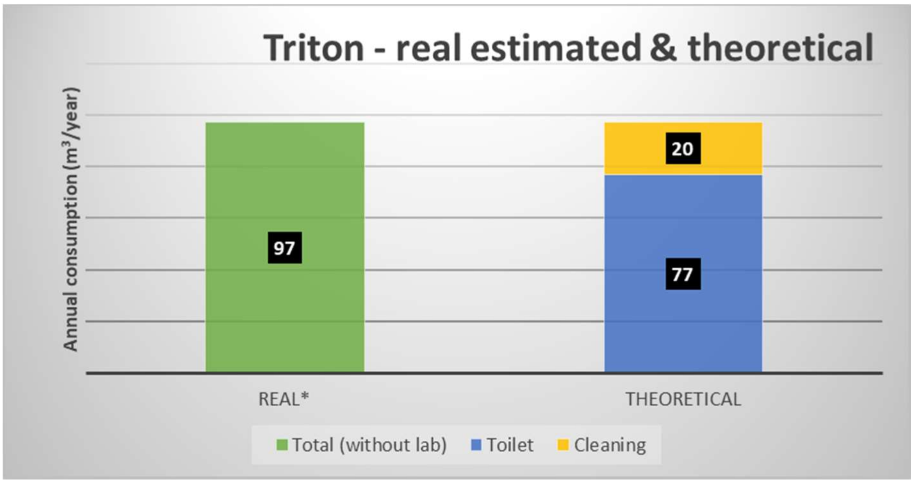
Main characteristics

- Total area: 1,015 m^2
- Number of employees: 20
- Average of visitors per day: 3
- Period of water measurement: 2014 – 2016
- Seasonal factor: 0.69
- Activities: offices, classrooms and, laboratory

Historical water consumption



Baseline assessment



Steps of UHA

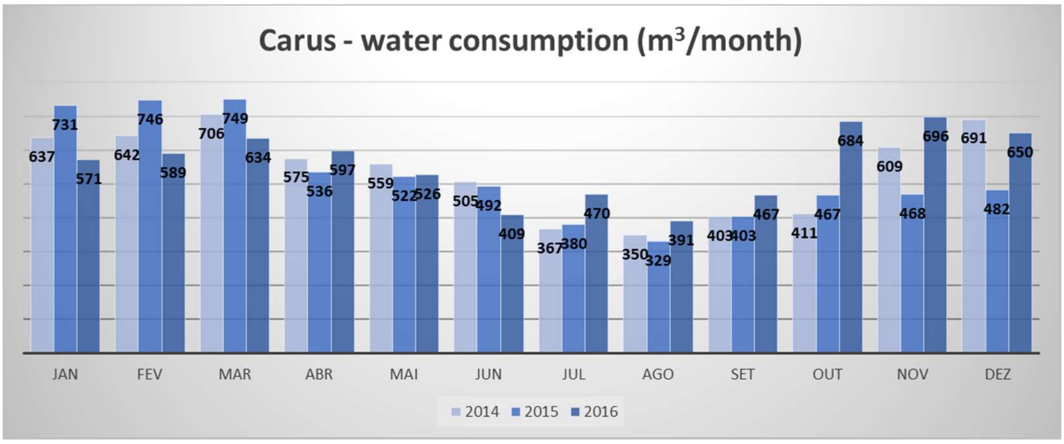
Demand minimization	Output minimization	Multi-sourcing
30 %	17 %	462 %

Carus – 120

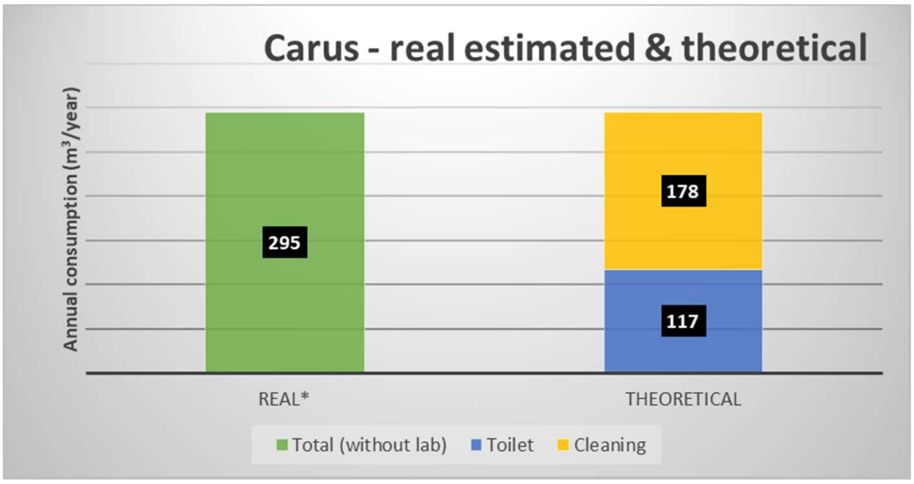
Main characteristics

- Total area: 8,893 m^2
- Number of employees: 20
- Average of visitors per day: 40
- Period of water measurement: 2014 – 2016
- Seasonal factor: 0.67
- Activities: offices and, laboratory

Historical water consumption



Baseline assessment



Steps of UHA

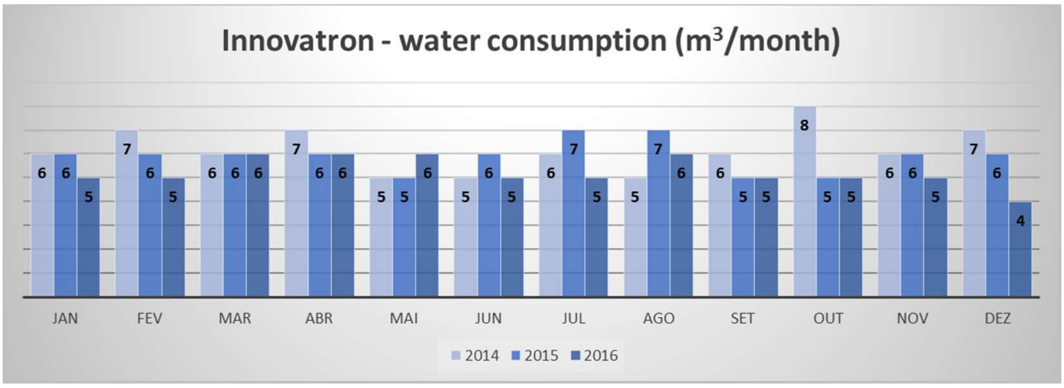
Demand minimization	Output minimization	Multi-sourcing
15 %	7 %	2436 %

Innovatron – 121

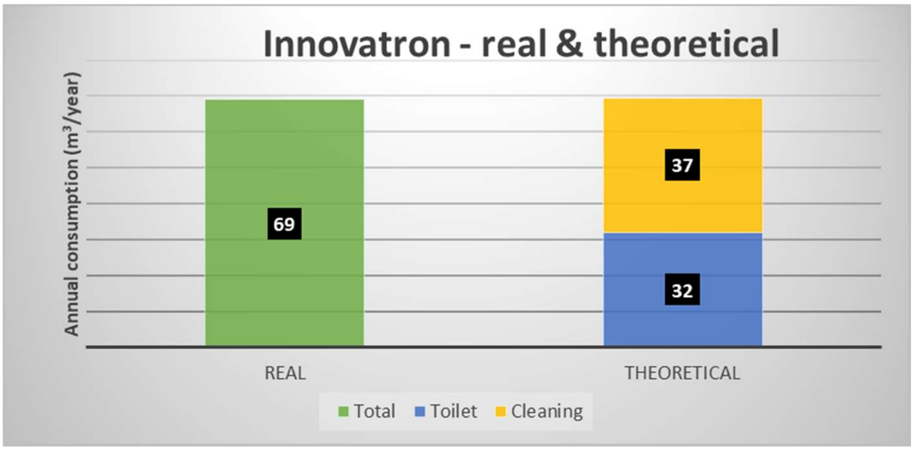
Main characteristics

- Total area: 1,860 m^2
- Number of employees: 10
- Average of visitors per day: 1
- Period of water measurement: 2014 – 2016
- Seasonal factor: no applicable
- Activities: offices

Historical water consumption



Baseline assessment



Steps of UHA

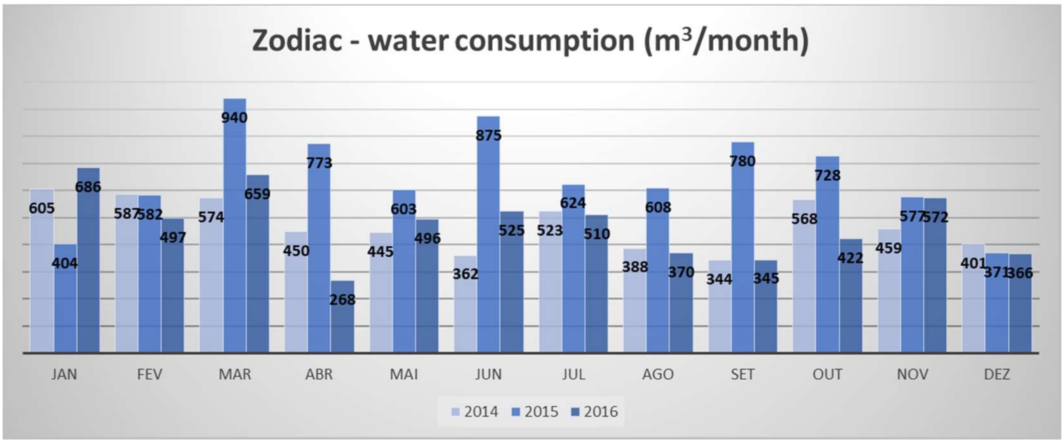
Demand minimization	Output minimization	Multi-sourcing
17 %	8 %	1727 %

Zodiac – 122

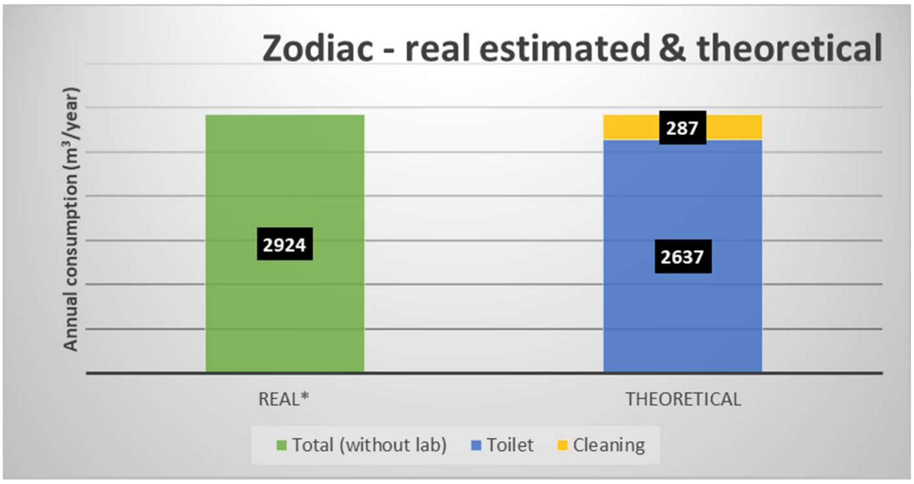
Main characteristics

- Total area: 14,259 m^2
- Number of employees: 600
- Average of visitors per day: 100
- Period of water measurement: 2014 – 2016
- Seasonal factor: 0.93
- Activities: offices, classrooms and, laboratory

Historical water consumption



Baseline assessment



Steps of UHA

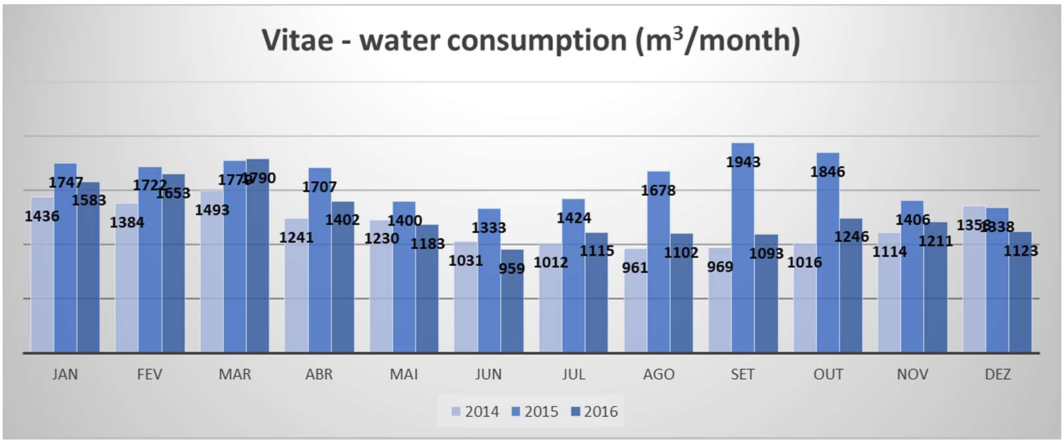
Demand minimization	Output minimization	Multi-sourcing
17 %	12 %	142 %

Vitae – 123

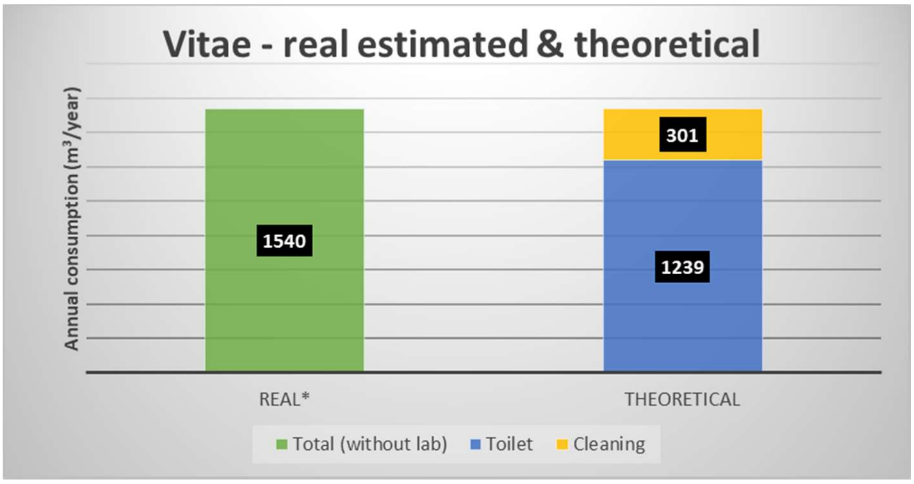
Main characteristics

- Total area: 15,000 m^2
- Number of employees: 400
- Average of visitors per day: 20
- Period of water measurement: 2014 – 2016
- Seasonal factor: 0.87
- Activities: offices and, laboratory

Historical water consumption



Baseline assessment



Steps of UHA

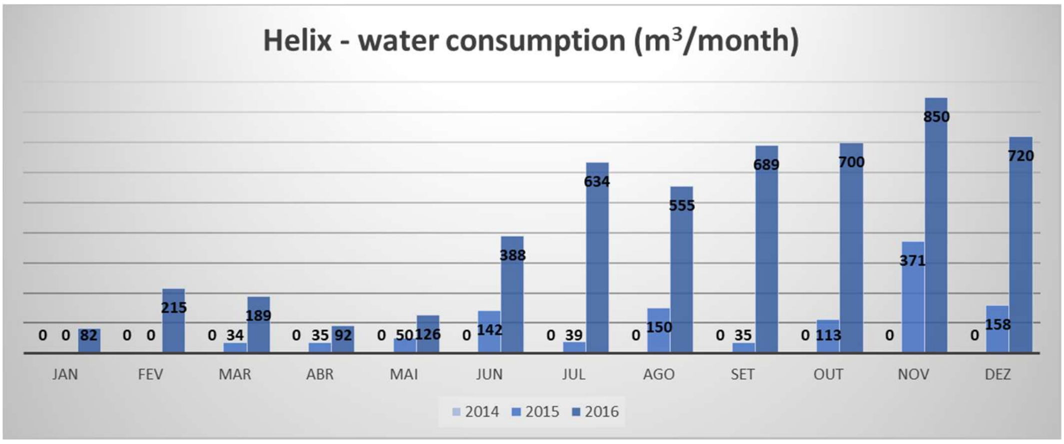
Demand minimization	Output minimization	Multi-sourcing
30 %	17 %	306 %

Helix – 124

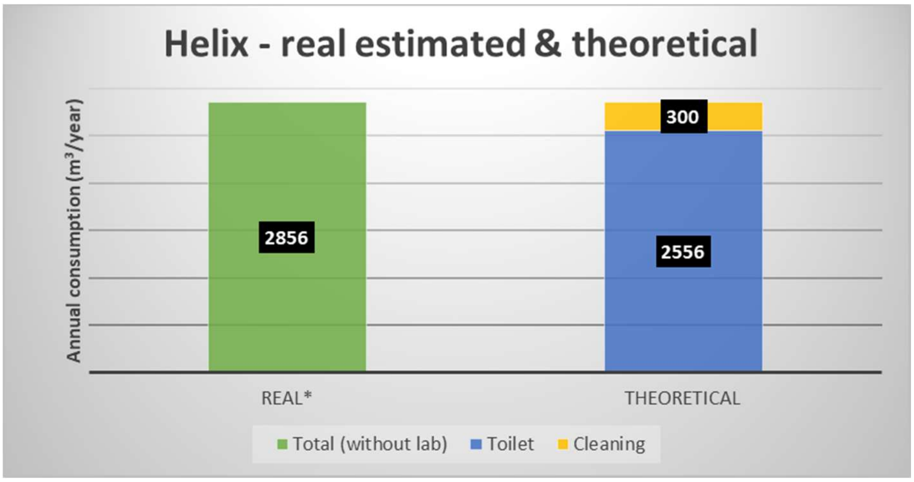
Main characteristics

- Total area: 14,926 m²
- Number of employees: 600
- Average of visitors per day: 60
- Period of water measurement: jul/2016 – dez/2016
- Seasonal factor: not applicable
- Activities: offices and, laboratory

Historical water consumption



Baseline assessment



Steps of UHA

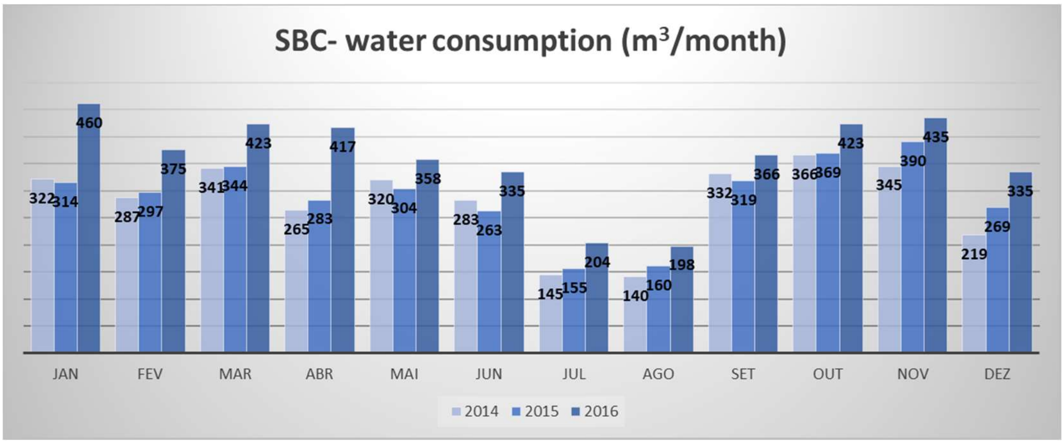
Demand minimization	Output minimization	Multi-sourcing
17 %	12 %	55 %

SBC – 130

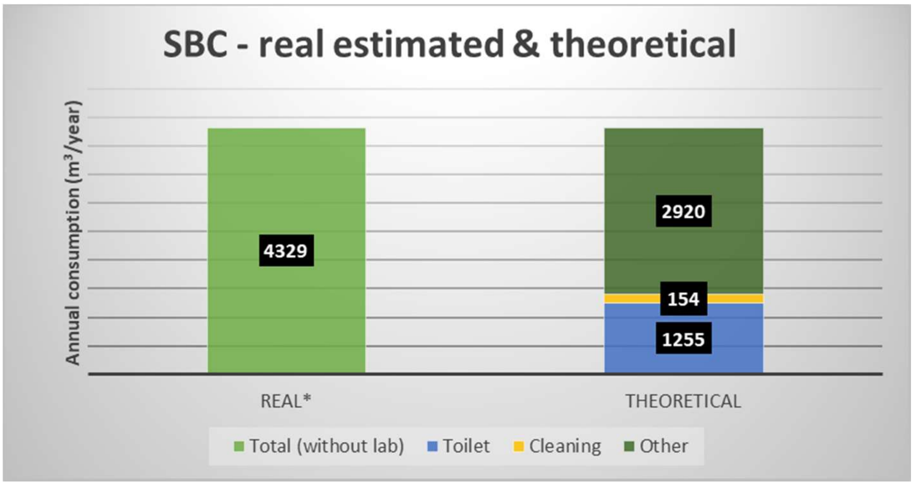
Main characteristics

- Total area: 7,687 m^2
- Number of employees: 17
- Average of visitors per day: 1000
- Period of water measurement: 2016
- Seasonal factor: 0.52
- Activities: sports

Historical water consumption



Baseline assessment



Steps of UHA

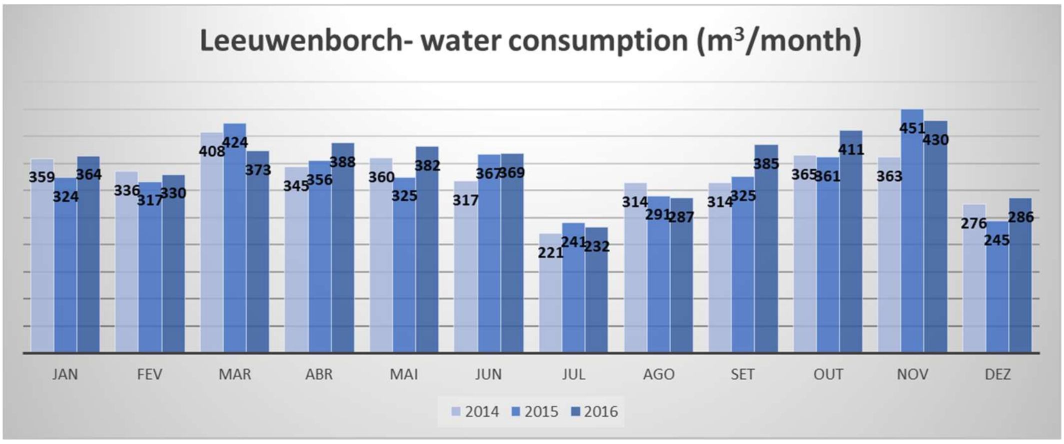
Demand minimization	Output minimization	Multi-sourcing
0 %	16 %	145 %

Leeuwenborch – 201

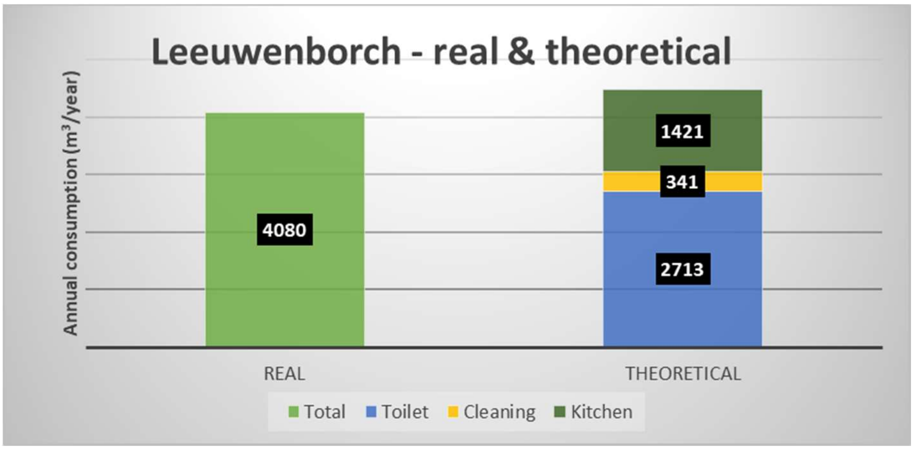
Main characteristics

- Total area: 17,000 m^2
- Number of employees: 450
- Average of visitors per day: 1250
- Period of water measurement: 2014 – 2016
- Seasonal factor: 0.74
- Activities: offices, classrooms and, restaurant

Historical water consumption



Baseline assessment



Steps of UHA

Demand minimization	Output minimization	Multi-sourcing
0 %	11 %	39 %

Appendix C – Main results from three steps of UHA

Toilet calculations page 1/3

			Population							WUR	
Building	**Seasonality factor**		**Staff**			**Visitors**				**Toilet pattern**	
			Total	Men	Women	% of staff	Total	Men	Women	Saving water	Urinal
100 - Lumen	No	-	600	308	292	6	36	9	9	No	No
101 - Gaia	Yes	0,77	400	206	194	6	24	6	6	No	Yes
102 - Forum	Yes	0,62	175	90	85	1.429	2.500	643	608	Yes	Yes
103 - Orion	Yes	0,52	30	15	15	8.333	2.500	643	608	Yes	Yes
104 - Atlas	Yes	0,88	500	257	243	30	150	39	36	Yes	Yes
107 - Radix	Yes	0,90	1778	914	864	56	1.000	257	243	Yes	Yes
115 - Impulse	Yes	0,73	70	36	34	10	7	2	2	Yes	Yes
116 - Actio	Yes	0,89	300	154	146	10	30	8	7	Yes	Yes
117 - Nexus	No	-	70	36	34	0	0	0	0	Yes	No
118 - Axis	Yes	0,81	650	334	316	10	65	17	16	Yes	Yes
119 - Triton	Yes	0,69	25	13	12	10	3	1	1	Yes	No
120 - Carus	Yes	0,67	20	10	10	200	40	10	10	Yes	No
121 - Innovatron	No	-	10	5	5	10	1	0	0	Yes	No
122 - Zodiac	No	-	600	308	292	17	100	26	24	No	Yes
123 - Vitae	Yes	0,87	400	206	194	5	20	5	5	Yes	No
124 - Helix	-	-	600	308	292	10	60	15	15	No	Yes
130 - SBC	Yes	0,52	17	9	8	5.882	1.000	257	243	Yes	Yes
201 - Leeuwenborch	Yes	0,74	450	231	219	278	1.250	321	304	Yes	Yes
Campus			6.695								

Number of visitors assumed to be 10% of total daily staff

Building	Water consumption flushing toilet - urine (L/day)		Water consumption flushing toilet - faeces (L/day)	Water consumption flushing toilet (m^3/mês)	Water consumption washbasin (L/day)		Water consumption washbasin (m^3/mês)	Total water consumption "theoretically" TOILET (m^3/mês)	Total water consumption "theoretically" TOILET (m^3/year)
	Water								
	Men	Women	Men+Women	Men+Women	Men	Women	Men+Women		
100 - Lumen	5718	5406	1236	272	572	481	23	295	3.541
101 - Gaia	1201	3604	824	124	381	320	15	139	1.604
102 - Forum	4153	6233	1425	260	1318	1108	53	313	3.521
103 - Orion	3730	5599	1280	233	1184	995	48	281	3.106
104 - Atlas	1676	2515	575	105	532	447	22	126	1.486
107 - Radix	6639	9964	2278	415	2108	1771	85	501	5.908
115 - Impulse	214	321	74	13	68	57	3	16	185
116 - Actio	918	1378	315	57	291	245	12	69	816
117 - Nexus	324	306	70	15	65	54	3	18	216
118 - Axis	1989	2985	683	124	631	531	26	150	1.743
119 - Triton	121	115	26	6	24	20	1	7	77
120 - Carus	185	175	40	9	37	31	1	10	117
121 - Innovatron	49	46	11	2	10	8	0	3	32
122 - Zodiac	1894	5686	1300	195	601	505	24	220	2.637
123 - Vitae	1897	1793	410	90	379	319	15	106	1.239
124 - Helix	1836	5511	1260	189	583	490	24	213	2.556
130 - SBC	1507	2261	517	94	478	402	19	114	1.255
201 - Leeuwenborch	3133	4702	1075	196	995	836	40	236	2.713
Campus									32.752

Toilet calculations page 3/3

Building	Total water consumption "theoretically" TOILET (m^3/year)	Demand minimization: Saving water by installing urinols (m^3/mês)	Demand minimization: Saving water by installing saving water flushing (m^3/mês)	Demand minimization: Total saving water potential "theoretically" (m^3/mês)	Demand minimization: Total saving water potential "theoretically" (m^3/year)	Demand minimization: Potential percentage of reduction on water consumption based on total building water consumption "theoretically" (%)	Output minimization: Saving water by using wastewater from wash hands to flush toilets (with demand minimization) (m^3/year)	Output minimization: Potential percentage of toilet flushin by cascading wastewater from wash hands to flush toilets (after demand minimization if applicable) (%)	Output minimization: Potential percentage of reduction on water consumption based on total building water consumption "theoretically" (after applying demand minimization if applicable) (%)
100 - Lumen	3.541	57,4	39,6	97	1.165	28	278	11,7	9
101 - Gaia	1.604		26,4	26	317	17	185	14,4	12
102 - Forum	3.521				-	-	641	18,2	11
103 - Orion	3.106				-	-	575	18,5	11
104 - Atlas	1.486				-	-	258	17,4	11
107 - Radix	5.908				-	-	1.024	17,3	16
115 - Impulse	185				-	-	33	17,8	2
116 - Actio	816				-	-	142	17,4	17
117 - Nexus	216	6,5		7	78	31	31	22,8	18
118 - Axis	1.743				-	-	307	17,6	14
119 - Triton	77	2,4		2	29	30	12	24,8	17
120 - Carus	117	3,7		4	45	15	18	24,9	7
121 - Innovatron	32	1,0		1	12	17	5	22,8	8
122 - Zodiac	2.637		41,7	42	500	17	292	13,7	12
123 - Vitae	1.239	38,1		38	457	30	184	23,6	17
124 - Helix	2.556		40,4	40	485	17	283	13,7	12
130 - SBC	1.255				-	-	232	18,5	16
201 - Leeuwenborch	2.713				-	-	483	17,8	11
Campus	32.752				3.089		4.984		

Building	Presence of restaurant	Company	Meals prepared	People considered	Total water consumption "theoretically" KITCHEN (m^3/month)	Total water consumption "theoretically" KITCHEN (m^3/year)	Preparation (m^3/year)	Service (m^3/year)	Cleaning (m^3/year)
100 - Lumen	Yes	Cormet	- estimated number	42	34	413	64	315	34
101 - Gaia	No	-	-	-	-	-	-	-	-
102 - Forum	Yes	Cormet	- estimated number	158	129	1.452	242	1.183	127
103 - Orion	Yes	??	- 200 meals - 70 pizzas	200	165	1.822	309	1.511	162
104 - Atlas	Yes	Cormet	- estimated number	68	56	645	104	509	55
107 - Radix	No	-	-	-	-	-	-	-	-
115 - Impulse	Yes	Restaurant of the future	- 60 meals	60	45	516	84	412	44
116 - Actio	No	-	-	-	-	-	-	-	-
117 - Nexus	No	-	-	-	-	-	-	-	-
118 - Axis	No	-	-	-	-	-	-	-	-
119 - Triton	No	-	-	-	-	-	-	-	-
120 - Carus	No	-	-	-	-	-	-	-	-
121 - Innovatron	No	-	-	-	-	-	-	-	-
122 - Zodiac	No	-	-	-	-	-	-	-	-
123 - Vitae	No	-	-	-	-	-	-	-	-
124 - Helix	No	-	-	-	-	-	-	-	-
130 - SBC	No	-	-	-	-	-	-	-	-
201 - Leeuwenborch	Yes	Good Food	- 60 hot meals - 120 sandwiches - 160 soups	150	124	1.421	232	1.133	122
Campus					699	6.269			

Number of meals estimated based on water consumption proportional to other buildings

Cleaning calculations page 1/1

Building	Total area (m^2)	Scrub: Total area scrubbed (m^2/week)	Scrub: Total time for scrubbing per week (min)	Scrub: Water consumption - scrubb (m^3/year)	Wet-mopping: Total area wet-mopping Intense traffic (m^2/week)	Wet-mopping: Total area wet-mopping Low traffic (m^2/week)	Wet-mopping: Water consumption - wet-mopping (m^3/year)	Total water consumption "theoretically" CLEANING (m^3/year)
100 - Lumen	13.477	2.453	38	4,49	13.477	8.086	266,31	271
101 - Gaia	11.590	2.109	32	3,86	11.590	6.954	229,02	233
102 - Forum	36.000	6.552	100	11,98	36.000	21.600	711,36	723
103 - Orion	22.400	4.077	62	7,46	22.400	13.440	442,62	450
104 - Atlas	11.000	2.002	31	3,66	11.000	6.600	217,36	221
107 - Radix	29.820	5.427	83	9,93	29.820	17.892	589,24	599
115 - Impulse	4.524	823	13	1,51	4.524	2.714	89,39	91
116 - Actio	1.992	363	6	0,66	1.992	1.195	39,36	40
117 - Nexus	1.620	295	5	0,54	1.620	972	32,01	33
118 - Axis	21.158	3.851	59	7,04	21.158	12.695	418,08	425
119 - Triton	1.015	185	3	0,34	1.015	609	20,06	20
120 - Carus	8.893	1.619	25	2,96	8.893	5.336	175,73	179
121 - Innovatron	1.860	339	5	0,62	1.860	1.116	36,75	37
122 - Zodiac	14.259	2.595	40	4,75	14.259	8.555	281,76	287
123 - Vitae	15.000	2.730	42	4,99	15.000	9.000	296,40	301
124 - Helix	14.926	2.717	42	4,97	14.926	8.956	294,94	300
130 - SBC	7.687	1.399	21	2,56	7.687	4.612	151,90	154
201 - Leeuwenborch	17.000	3.094	47	5,66	17.000	10.200	335,92	342
Campus								4.706

Laboratory information page 1/1

Building	Presence of laboratory	Water consumed by laboratory is known through water scheme and technical report? (Yes / No)	Total water consumption "real" LABORATORY (m^3/year)	Percentage of laboratory usage (%)
100 - Lumen	Yes	No	not known	not known
101 - Gaia	No	-	-	-
102 - Forum	Yes	No	not known	not known
103 - Orion	Yes	Yes	5.199	57
104 - Atlas	Yes	Yes	1.318	37
107 - Radix	Yes	Yes	5.371	38
115 - Impulse	No	-	-	-
116 - Actio	No	-	-	-
117 - Nexus	No	-	-	-
118 - Axis	Yes	No	not known	not known
119 - Triton	Yes	No	not known	not known
120 - Carus	Yes	No	not known	not known
121 - Innovatron	No	-	-	-
122 - Zodiac	Yes	No	not known	not known
123 - Vitae	Yes	No	not known	not known
124 - Helix	Yes	No	not known	not known
130 - SBC	No	-	-	-
201 - Leeuwenborch	No	-	-	-

Rainfall average in the Netherlands from 1991 till 2015 (mm)

Source: *http://sdwebx.worldbank.org/climateportal/index.cfm?page=downscaled_data_download&menu=historical*

Access: 22/jun/17

Jan	70,35
Feb	54,60
Mar	53,15
Apr	39,89
May	59,27
Jun	64,75
Jul	82,76
Ago	80,99
Set	70,46
Oct	75,39
Nov	75,57
Dec	79,71
Annual	806,88

Multi-sourcing calculation page 2/2

	Theoretical			Multisourcing		
Building	Total water demand (m^3/year)	Total water demand after DM (m^3/year)	Total water demand after DM and OM (m^3/year)	Potential rainwater harvesting (m^3/year)	Percentage of total annual water consumption "theoretically" (%)	Percentage of total annual water consumption after applying DM and OM (if applicable) "theoretically" (%)
100 - Lumen	4.225	3.059	2.783	2.896	69	104
101 - Gaia	1.837	1.525	1.342	565	31	42
102 - Forum	5.696	5.696	5.013	2.203	39	44
103 - Orion	5.378	5.378	4.786	1.205	22	25
104 - Atlas	2.353	2.353	2.094	1.050	45	50
107 - Radix	6.508	6.508	5.466	4.837	74	88
115 - Impulse	1.423	1.423	1.394	1.012	71	73
116 - Actio	856	856	710	981	115	138
117 - Nexus	249	172	139	560	225	403
118 - Axis	2.168	2.168	1.865	3.726	172	200
119 - Triton	97	68	56	258	265	462
120 - Carus	295	251	234	5.689	1925	2436
121 - Innovatron	69	57	53	910	1319	1727
122 - Zodiac	2.923	2.426	2.135	3.031	104	142
123 - Vitae	1.541	1.078	884	2.703	175	306
124 - Helix	2.855	2.370	2.086	1.145	40	55
130 - SBC	1.409	1.409	1.169	1.701	121	145
201 - Leeuwenborch	4.475	4.475	3.983	1.569	35	39
WUR Campus	44.357	41.271	36.192	36.042	81	100