

Optimization of energy and water cycles at block level in Wageningen



Author: Robert Jan Voogt
Study program: MSc Biotechnology



Author: Robert Jan Voogt

Registration number author: 890629-903-020

Study program: MSc Biotechnology

Supervisors: 1. Claudia Agudelo Vera & Ingo Leusbrock (from ETE)
2. Karel Keesman (from SCO)

University: Wageningen UR (University and Research centre)

Wageningen, May 2011

Abstract

Today urbanisation, the expected growth of the world population and the higher living standards are trending topics, which contribute to an increased pressure on available resources. These resources have a limited availability. Thus the renewability of resources becomes increasingly important. Where centralized systems are found to be unsustainable, decentralized systems gain more attention. There are many knowledge gaps about decentralized systems; one of them is related to the linkages of energy and water streams at block level. These linkages are investigated with “a new approach”; the Urban Harvest Approach. This approach evaluates the effects of demand minimization, recycling/recovery and multisourcing with a set of indices. First a water and an energy model were developed for both a low- as a high-density block, after which they were combined. Combining the energy and water cycles, by looking at the linkages, leads to a combined system. This combined system is compared with a merged water and energy model, at which the linkages are neglected. Finally the combined system is tested on two blocks located in Wageningen. This is done with a static analysis of a moderate yearly balance. Dynamics are not involved in this study.

Table of content

Abstract	1
1. Introduction.....	4
1.1 Current situation & Problem statement	4
1.2 Objective.....	6
1.3 Research questions.....	6
1.4 Outcome.....	7
1.5 Outline of the report	7
2. Materials & Methods.....	8
2.1 Materials.....	8
2.2 Methods	8
2.2.1 Starting points, Preconditions & Assumptions.....	8
2.2.2 General balances & Selection criteria for the blocks	9
2.2.3 Urban Harvest Approach	9
2.2.4 Indicators	12
3. General Balances	13
3.1 Water balances.....	13
3.1.1 Overall water balance.....	13
3.1.2 Block	14
3.1.3 Evaluation	18
3.2 Energy balances.....	20
3.2.1 Overall energy balance	20
3.2.2 Block	21
3.2.3 Evaluation	25
3.3 Linked energy and water balances.....	27
3.3.1 Linkages	28
3.3.2 Evaluation	30
4. Model Evaluation & Techniques.....	31
4.1 Theoretical cases	31
4.2 Water balances.....	33
4.2.1 Baseline assessment.....	33

4.2.2 Demand minimization	33
4.2.3 Recycling	35
4.2.4 Multisourcing.....	36
4.2.5 Evaluation	37
4.3 Energy balances.....	38
4.3.1 Baseline assessment.....	39
4.3.2 Demand minimization	39
4.3.3 Recycling	41
4.3.4 Multisourcing.....	42
4.3.5 Evaluation	44
4.4 Combined balances	445
4.4.1 Baseline assessment.....	45
4.4.2 Demand minimization	45
4.4.3 Recovery	46
4.4.4 Evaluation	467
5. Case selection.....	49
5.1 Cases.....	49
5.1.1 Jasmijnplantsoen – Drouwlaan – Bremlaan – Meidoornplantsoen	49
5.1.2 Hollandseweg – Nobelweg – Lorentzstraat – Van ’t Hoffstraat	49
5.2 Inputs.....	50
5.3 Results	502
6. Conclusion/Discussion.....	55
Bibliography.....	58

Appendices:

Appendix A: Energy demand tables	I
Appendix B: Insulation levels in Energiebesparingsverkenner	IV
Appendix C: Window types in Energiebesparingsverkenner	V
Appendix D: Detailed overview of both selected blocks.....	VI
Appendix E: Detailed overview of inputs and intermediate results of both selected blocks	IX
Appendix F: List of all Word variables	X
Appendix G: List of all MATLAB variables.....	XIV

1. Introduction

1.1 Current situation & Problem statement

Today more and more people are moving from the rural area towards urban areas, a process which is called urbanization. This results in growing cities with a dense structure, with lots of opportunities for becoming more sustainable (WCED, 1987)¹. Worldwide, it is found that urban form, urban density and environmentally-friendly public transport can support the energy reduction per capita extremely (Habitat, 2008). Although the rich generally consume more energy than the poor, applying the benefits of urbanization resulted in some rich cities with fewer carbon emissions per capita than cities in some less developed countries (Habitat, 2008). In case of Europe, it is known that nearly 75% of the European population lives in cities. Although, the population in cities consumes the largest percentage of energy (69%), the rural population consumes more energy (4.9 million tonnes of oil equivalent (Mtoe) vs. 3.5 Mtoe) per capita (EEA, 2009).

Simultaneously to this urbanization trend and the expected world population growth (from 7 billion in October 2011 to 9.3 billion in 2050) (Roberts, 2011), more people will reach higher living standards, which results in a higher consumption of goods and materials. This leads to an increased pressure on the resources available (Agudelo-Vera et al., 2011).

Therefore, it is important to understand and investigate the current energy and water cycles and to look for possibilities, like decentralized systems, to create a more sustainable system, in which the renewability (Stremke, 2010)² of these sources is one of the key concepts.

Next to the increased pressure on the resources available, other concerns are about the changing climate, the related production of CO₂ (e.g. during the production of energy), and how to reduce the (severe) effects, like the possible shifts in rainfall pattern (Verstraete and Vlaeminck, 2011). To reduce the CO₂ production, to limit the impacts of climate change (possible shifts in rainfall pattern, etc.), it is important to decrease the energy demand and to increase the energy efficiency.

Decreasing the demand can e.g. be achieved via research on resource flows; increasing the energy efficiency via the exergy concept. As the exergy value of electricity is equal to one, only the efficiency of heat can be improved by applying the exergy concept (Dewulf et al., 2008).

Although there has been a lot of research on resource flows through and in cities, e.g. about the complexity of demand and supply patterns (Pedersen et al., 2008), there are still many uncertainties left (e.g. about the transition of current urban systems towards closed resource cycles (Agudelo-Vera et al., 2011) or about the future impacts of climate change (EEA, 2009)).

¹ Sustainable development is development which meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987).

² Renewable sources can be defined as sources with essentially infinite availability (e.g. solar energy) or that can regenerate (e.g. energy from biomass) (Stremke, 2010).

A study from Australia made clear that the current centralized systems are unsustainable from a resource point of view. As in these centralized systems there are fewer possibilities for the reuse of streams with lower quality and there is a lot of energy needed for transportation of the streams through the pipelines. Therefore decentralized systems were developed. The aging and the needed refurbishment of the pipelines is another factor, which supports research to decentralized systems (Sharma et al., 2010).

Recently, a wide variety of decentralised infrastructure and technologies, both for water cycles (Sharma et al., 2010) as energy cycles (Hiremath et al., 2007), which can be applied at block or household level have been developed. Examples of measures which can be taken are the improvement of the building envelope³, the evaluation of the supply and disposal systems, the use of endogenous resources and the increase of the efficiency of the energy conversion systems (Girardin et al., 2010). There is however a lack of knowledge in their application, as decentralised systems are relatively new and involve an increased complexity. These knowledge gaps include planning, design, implementation, operation and management (Sharma et al., 2010).

Currently the integration of the water and energy cycles in urban areas is not performed in an optimal way. There are articles which only apply the integration to a specific case as e.g. an article about solar water heating systems in residential buildings (Golić et al., 2011), where others focus on the optimization of water and energy cycles in other systems like the biofuel plant (Grossmann and Martín, 2010).

It is found that both cycles can be linked, as energy is needed for heating water and water treatment. This heated water can be used as energy source for heat recovery.

During this thesis both cycles⁴, including the possibilities for improvement, are investigated at block level, which is between neighbourhood and building level. A block is defined as a block of buildings (houses, offices, factories etc.) surrounded by roads (a way accessible by car) or an uninterrupted sidewalk, without any roads in between. This spatial unit is set as logical result after the analyses of Agudelo Vera et al. on water cycles at household level and Struchiner on energy cycles at building level (Agudelo-Vera et al., 2012a) (Agudelo-Vera et al., 2012b) (Struchiner, 2011).

As there is no standardized method for quantification of the available data (Hashimoto and Moriguchi, 2004), there are a lot of incomparable results, due to e.g. the use of different time scales. Therefore this thesis aims to contribute to the standardization of this research by applying the Urban Harvest Approach, an approach which is not limited to a time scale. During this research it is applied at yearly balances, but it can be applied at e.g. daily balances too.

The Urban Harvest Approach aims *“for improved resource management by closing urban cycles, applying innovative techniques and harvesting urban resources”* (Agudelo-Vera et al., 2012a). Minimizing the dependency on external resources is achieved by minimizing the demand, minimizing the outputs and by multi-sourcing by using local and renewable sources.

³ The building envelope is the physical border of an existing building. This border separates the interior of the building from the outdoor environment.

⁴ The investigation of the cycles is not only quantitatively and qualitatively, but includes the temporal and spatial distributions too. This is needed as e.g. energy demand and rainfall patterns changes seasonally and as e.g. the effects of solar radiation depend on the urban typology.

1.2 Objective

The objective of this report is to optimize the energy and water cycles at block level for different building typologies. This means that the demand and the outputs will be minimized and that local and renewable sources will be harvested to obtain a more sustainable system.

The results will present which measures have to be taken to reduce this demand and these outputs, and which alternative resources, like solar energy, can be harvested effectively and efficiently at block level in Wageningen to improve the sustainability of this city.

1.3 Research questions

To obtain these results the following research questions are defined:

The main research question of this project is:

How can the energy and water cycles at block level in Wageningen be optimized to achieve (almost) resource-neutral urban areas?

The sub questions are:

1. What are the current sources, both quantitatively as qualitatively, of water and energy at the selected blocks?
2. What are the current demands, both quantitatively as qualitatively, for water and energy at the selected blocks?
3. What are the current outputs, both quantitatively as qualitatively, related to energy and water balances?
4. Which factors (urban typology, outside temperature, wind, bad weather, etc.) affect the water and energy balances significantly in Wageningen?
5. To what extent are these factors affecting the energy and water balances of the selected blocks?
6. How can the water and energy demands, both quantitatively as qualitatively, of the selected building blocks be reduced by the application of technologies which are nowadays available?
7. How can the water and energy outputs, both quantitatively as qualitatively, from the selected building blocks be reused?
8. What are the potential renewable sources, both quantitatively as qualitatively, of water and energy at the selected blocks?
9. How can the energy and water system be combined and what are the main nexus between the energy and water cycle at the selected blocks?

1.4 Outcome

The project will result in a combined, water and energy, model which describes the potential of applying the Urban Harvest Approach at block level.

In case of the demand minimization index the outcomes will give a clear indication by which percentage the current demand can be reduced. In case of the waste output indices, which output is used inefficient. To what extent the buildings can be adapted to achieve a more sustainable situation is represented by the self-sufficiency indices. This means that the outcomes will describe to which degree it is possible to transit the current non-renewable system to a system with more responsiveness to our environment.

Finally the results from this model will make clear why certain combinations of techniques are better than others, and how this is related to the building characteristics. This is important if the results of this study will be applied at other blocks.

1.5 Outline of the report

After this introduction, Chapter 1, the materials and methods will be presented in Chapter 2. In Chapter 3 the general balances are introduced. Chapter 4 evaluates these general balances to know which flows and factors are significant. This is combined with a technology selection to improve the system performance. The results of this combined model are evaluated and tested with two cases, located in Wageningen, in Chapter 5.

Chapter 6 contains a conclusion and Chapter 7 is introduced for the recommendations. This last chapter will contain some critical notes about the methods applied.

2. Materials & Methods

2.1 Materials

Most of the information in this report is found during a literature study on water and energy flows, and reuse and multisource techniques in either scientific databases or other scientific sources (books, unpublished articles, etc.).

Another very important source of the information is the internet module 'Energiebesparingsverkenner' (SenterNovem, 2010) developed by SenterNovem which is used to identify and evaluate the energy usage and the effect of applying energy reducing techniques.

To evaluate these data MATLAB, a modelling program, Excel and Word are used.

2.2 Methods

For the investigation at block level, a certain existing block, which is located in Wageningen, will be selected. Before this block can be selected, its selection criteria have to be determined. This is done by setting up general balances for the water and energy cycles at this level to evaluate which flows and factors are important. After this block selection more detailed models are developed to research this block according to the Urban Harvest Approach.

2.2.1 Starting points, Preconditions & Assumptions

First it is important to define the starting points, preconditions and assumptions, after which a case can be selected.

The optimization of the water and energy cycles is done by the creation of a model, which analyses the impacts of the 'largest current' and 'most promising future' energy and water flows relative to the concept of sustainability. These flows will be evaluated with three indicators (section 2.2.4).

In case of the energy cycles the consumption⁵ of electricity, gas and heat is evaluated. Other energy cycles, like the energy needed for transport are not considered, as they can be estimated with less accuracy than the building related impacts (Schremmer et al., 2009). In case of heat consumption both the primary sources (e.g. district heating) as the secondary sources (e.g. heat obtained after conversion of gas and electricity) are evaluated. Indirect cycles, like footprints of products, are not taken into account. Also the influence of the solar radiation on the energy demand is neglected as this disturbance is assumed to be encased in the demand data.

With respect to the water cycles the indoor water demand is evaluated and combined with precipitation data. Other water sources, like pools or groundwater extraction are neglected (Agudelo-Vera et al., 2012c).

After the separate analysis of the energy and water cycles both cycles are combined to look to what extent these cycles are dependent and whether they can support each other or not. With the outcomes from the models the efficiencies of the energy and water cycles are analysed and optimized.

⁵ Consumption in relation to energy is defined as energy which leaves the system as heat.

Next to these starting points is it important to define preconditions and assumptions.

The following preconditions and assumptions are defined:

1. The supply security has to be guaranteed.
2. Only significant⁶ energy and water streams are considered.
3. Only technical aspects (improved apparatus) of energy and water demand minimization are considered.
4. The quality of the buildings will not decrease in time (no additional leakages etc.).
5. Rebuilding is not an option.
6. The energy and water cycles are, both quantitatively as qualitatively, investigated for a time period of one year.
7. Factors outside the block are outside the boundaries of current research, which means e.g. that the origin of the streams is not investigated.
8. The quality of water, gas and electricity from the supplying companies is assumed to be constant.

2.2.2 General balances & Selection criteria for the blocks

Now the general balances for the water and energy cycles are set up. This is done at block scale for two theoretical cases. The first case describes a block with 8 freestanding houses and thus a low urban density and a high roof area/citizen ratio. The second case describes a block with 3 mid-rise apartments and thus a high urban density and a low roof area/citizen ratio. This is done to make sure that the urban spectrum is evaluated on both its counterparts, and that the results of the case analysis can be applied at other cases too.

The outcomes of these balances are used to evaluate which water and energy flows are important when city blocks are investigated. Combined with a technology selection to harvest or reuse the most important streams the selection criteria for a specific block in Wageningen are determined.

2.2.3 Urban Harvest Approach

Now, as the starting point, all preconditions and assumptions and the case are defined, the analysis is started. This analysis is based on the Urban Harvest Approach, which, as mentioned in section 1.1, integrates improving urban resource cycles by applying innovative technologies and harvesting local and renewable urban resources (Agudelo-Vera et al., 2012a).

The Urban Harvest Approach (Figure 1) starts with describing the current situation; this situation is called the baseline assessment. After the construction of the baseline assessment, it is investigated how the demand and the outputs can be reduced. Finally the potential of local resources to match the remaining demand is investigated; this is called multisourcing.

⁶ Significant means larger than 10% of the total demand.

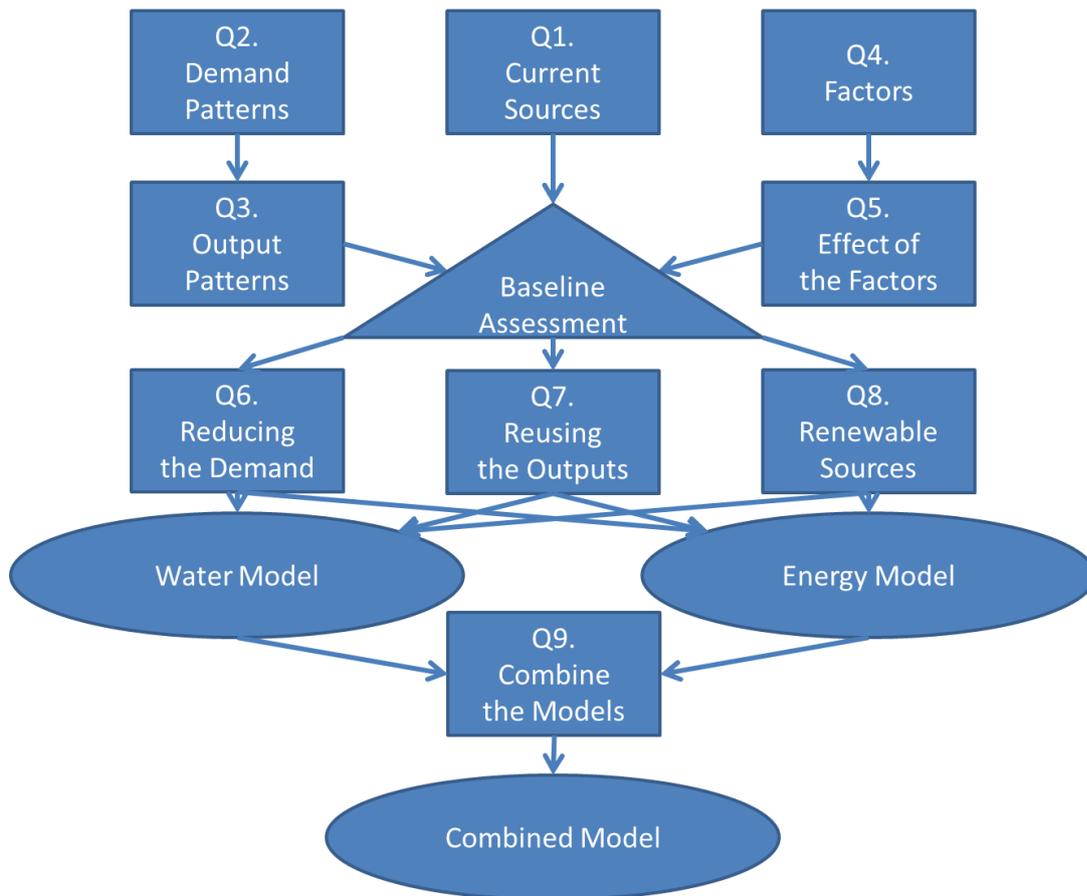


Figure 1: Overview of the Urban Harvest Approach (incl. research questions) as applied during this research.

Current situation (Baseline assessment, Q1 till Q5)

Starting point of this analysis is a baseline assessment which describes the existing situation. It analyses the current water and energy demands, which are fulfilled from the current sources, and the outputs. This is done both in a quantitative as a qualitative way. During this assessment the factors (e.g. building type and building age) which affect the balances are investigated too.

Demand minimization (Q6)

Now for both cases the significant demand streams will be minimized. This will be done by evaluating technologies (see Chapter 4) which are currently applied or developed, like demand reducing showers or improving the window quality. Also it is evaluated to which extent and at which scale (whole block, part of a block or house wise) these technologies are able to reduce the demand optimally.

Most interesting, from research perspective, with respect to demand minimization are the situations in which water reduction leads to an increased energy consumption or vice versa. These situations will be evaluated with use of the indicators (see section 2.2.4).

Output minimization (Q7 and Q8)

After the demand reduction, output reduction is the second step after the baseline assessment. In general; outputs can be reduced by recovery, cascading or recycling (see below), although it depends per source which of these three methods can be applied. In case of water and energy it turned out that water can be cascaded and recycled and that energy can only be recovered. This difference is caused by the fact that the quality of energy cannot change, although the quality of its sources (e.g. gas and water) can change.

As output minimization is done by applying certain techniques, the best scale of application and any additional energy inputs are evaluated too.

Recovery

Recovery is the direct reuse of outputs which have kept their quality.

After water usage, water becomes polluted (e.g. dander) and cannot be recovered, as it is economically/technically impossible to obtain fully cleaned water. In spite of this solutes might be recovered or removed. As this research is investigating energy and water cycles, only heat flows from water will be considered as recoverable.

Cascading

The direct reuse of outputs which have lost some of their quality is called cascading (e.g. the direct use, without any treatment, of used kitchen water for flushing the toilet). Cascading is not considered in this research. Although mentioned in literature, cascading of heat is a form of energy recovery, as the heat quality does not change. This can be compared with eating cookies out of a box, when there are 5 cookies in a box and you eat 1 cookie, the quality of the other 4 cookies is unaffected by the fact that you ate 1 cookie.

Recycling

Recycling is the reuse of outputs after upgrading its quality. Usually there is energy needed to recycle materials and this will be evaluated. The recycling technologies will be selected from literature studies.

Multisourcing

Looking at the demands and the outputs is one thing; make use of regional sources of energy and water is another. These resources will be studied in both their maximum potential (maximum efficiency precursor scenario) as in their rationality (rational investment precursor scenario) (Sørensen, 2008). Finally the aspect of exporting or storing the leftovers will be considered.

Combining the models (Q9)

After both (water and energy) models are made, a combined model is constructed. This combined model evaluates the total system by including the linkages between both cycles (e.g. effect of water demand minimization on the gas demand for heating water).

2.2.4 Indicators

All the scenarios will be evaluated and ranked with three indicators which evaluate to what extent the demand and the outputs are minimized and to what extent renewable sources are used to fulfil this demand.

Demand Minimization Index:

The demand minimization index (DMI) is used to evaluate to what extent the conventional demand (D_0) (obtained from the baseline assessment) is reduced by the application of demand minimization techniques. This results in an actual demand (D). The value of this index will be between 0 and 1, and is read as a percentage of reduced demand. A DMI of 0 means that it turned out to be impossible to reduce the demand, a value of 1 that there is no demand left. Thus the DMI is preferred to be as high as possible.

Demand Minimization Index:

$$DMI = \frac{\text{Initial Demand } (D_0) - \text{Actual Demand } (D)}{\text{Initial Demand } (D_0)} \quad (2.1)$$

(Waste) Output Index:

The (waste) output index ((W)OI) is an index to evaluate to what extent the (waste) outputs ((W)O) can be minimized and which unused potential is left. The value of the waste output index is preferred to be close to 0, as in that case there is no waste production and there are no potential sources unused.

(Waste) Output Index:

$$(W)OI = - \frac{\text{(Waste) Outputs } ((W)O)}{D} \quad (2.2)$$

Self-Sufficiency Index:

Finally the self-sufficiency index (SSI) is used to investigate to what extent renewable resources (RH) are used to fulfil the demand. It is found that the SSI has a lower boundary of zero as the amount of resources harvested is not limited to the demand. Additional harvested resources will be stored or in case of electricity send back to the grid. The SSI is read as a percentage of the demand which is fulfilled by harvested resources.

Self-Sufficiency Index:

$$SSI = \frac{\text{Resources Harvested } (RH)}{D} \quad (2.3)$$

3. General Balances

This thesis is about the water and energy cycles at block level (see sections 1.1 and 2.2.1). For the investigation of these cycles balances have to be set up, although the water balances are based on the results of Agudelo-Vera (Agudelo-Vera et al., 2012c). Different schemes are set up to visualize the system boundaries (Figures 3 and 5).

3.1 Water balances

3.1.1 Overall water balance

Overall water balance

With use of the system boundaries (Figure 3 on page 19), neglecting the accumulation, the following overall balance is constructed:

$$0 = M_{\text{pot}} + EI - Ro - In - Et - DWW \quad (3.1)$$

From this balance it is clear that the amount of water present in the system depends on six different flows. These flows can be distinguished by their nature as inputs, outputs and consumption flows.

Inputs

In general it is found that there are two different inputs of water at this level; potable water from an external input (EI) and water from alternative water sources. Although there are many alternative water sources (e.g. groundwater, pools, precipitation), in this study only precipitation (M_{pot}) is considered as being both harvestable in a significant amount as sustainable (Agudelo-Vera et al., 2012c). All other alternative sources are neglected.

Outputs

Runoff (Ro), excess of rainwater leaving the block area, and domestic waste water (DWW) are the two outputs of the system. They are unwanted and need to be removed to avoid the system having problems with its water capacity. As these flows are removed via the sewer system towards the wastewater treatment plant, they are observed as waste outputs (WO_{w}).

$$WO_{\text{w}} = Ro + DWW \quad (3.2)$$

Consumption flows

Infiltration (In), the process by which water on the ground surface enters the pores of the soil, and evapotranspiration (Et), can be defined as consumption flows. In contrast with the outputs, consumption flows are needed as they perform a function in the system; therefore these flows are not removed via the sewer system. In case of infiltration the function is clear as the plants are fed by infiltrated water. Evapotranspiration is functional as it cools down the urban area.

3.1.2 Block

Although the overall balance gives a first indication of the system, the Urban Harvest Approach cannot be applied without knowing what happens inside. The system contains four different modules, two demand units, which will be minimized, a storage and treatment unit and a harvest unit (Figure 3). As these last two units deal with recycling and multisourcing of water, they are so-called 'self-sufficiency units'.

Demand units

Due to demand quality restrictions the actual water demand (D_W) is split into two different demand units, one unit containing the potable water demand (D_{WQ1}) and one unit containing the non-potable water demand (D_{WQ2}) (Table 1).

$$D_W = D_{WQ1} + D_{WQ2} \quad (3.3)$$

The potable water demand has to be delivered from the water company as the quality standards needed are that high, that recycled and multisourced water sources are not allowed (VROM, 2003). Practically this is the case with water used for personal hygiene, the preparation of food and doing the dishes. Drinking water has to be potable too.

As the total amount of potable water consumed (e.g. potable water used as drinking water) is very small (<2%) compared with the total potable demand (Foekema and Van Thiel, 2011), the external input (EI_{Q1}) is assumed to be equal to the potable water demand and equal to the wastewater stream of this demand (DWW_{Q1}).

$$D_{WQ1} = EI_{Q1} = DWW_{Q1} \quad (3.4)$$

All the other demands for water can be considered as non-potable. These demands include the water used for toilet flushing and the mechanical washing of clothes. The water for the outside tap may have the same low quality.

Table 1: Different appliances split to different water demands.

Water demand	Potable water	Non-potable water
Bathtub	X	-
Coffee and tea	X	-
Doing the dishes (by hand)	X	-
Doing the dishes (mechanical)	X	-
Other appliances kitchen tap	X	-
Outside tap	-	X
Preparation of food	X	-
Shower	X	-
Toilet	-	X
Washbasin	X	-
Washing clothes (by hand)	X	-
Washing clothes (mechanical)	-	X
Water drinking	X	-

This non-potable water demand can be fulfilled from three different sources, one external and two local sources:

1. Potable water from the water supplying company (EI_{Q2})
2. Potential amount of wastewater recycled (R_{pot})
3. Harvested precipitation (M_{har})

Neglecting the water demand outdoors (Foekema and Van Thiel, 2011) results in the following equations and constraints, in which the renewable sources are represented by the harvested (local) resources (RH_W):

$$D_{WQ2} = EI_{Q2} + RH_W \quad (3.5)$$

$$RH_W \leq D_{WQ2} \quad (3.6)$$

$$EI_{Q2} \geq 0 \quad (3.7)$$

As there are demand quality restrictions it becomes clear why the total flow of external input water is split in an external input flow to fulfil the potable demand and an external input flow to fulfil the non-potable demand (Figure 3).

$$EI = EI_{Q1} + EI_{Q2} \quad (3.8)$$

Domestic wastewater

After the usage of water wastewater is produced; based the demand quality restrictions these flows of domestic wastewater are split in a wastewater stream after the use of potable water (DWW_{Q1}) and a wastewater stream after the use of non-potable demand (DWW_{Q2}). Considering the effects of recycling and multisourcing this results in equation 3.9, in which the overflow from the storage and treatment units (OF) (page 16) and the recycling potential from used potable water (R_{pot}) (water used in the shower) count these two effects.

$$DWW = DWW_{Q1} + DWW_{Q2} + OF - R_{pot} \quad (3.9)$$

More insight can be obtained if the wastewater stream from the potable demand is split into a recyclable potential and a non-recyclable part (DWW_{Q1ut}), which contains the insignificant streams (<10%). The effect of multisourcing is represented by the harvested precipitation (M_{har}).

$$DWW_{Q1} = DWW_{Q1ut} + R_{pot} \quad (3.10)$$

$$DWW_{Q2} = EI_{Q2} + RH_W \quad (3.11)$$

$$RH_W = M_{har} + R_{pot} - OF \quad (3.12)$$

Self-sufficiency units

Storage & Treatment

The storage and treatment units consists of 2 different storage units and 1 treatment unit, which are linked in series (Figure 2) (Agudelo-Vera et al., 2012c).

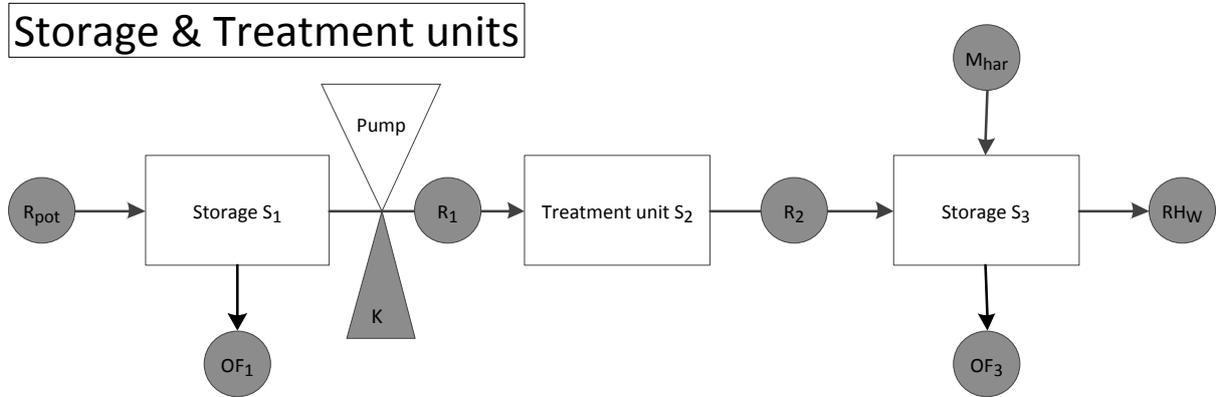


Figure 2: Overview of the storage and treatment units.

In the first storage tank wastewater from the potable demand is stored, after which it is treated in the treatment unit. The inflow to this treatment unit (R_1) is limited by its treatment capacity (K). After treatment this water (R_2) is stored again in another storage tank, after which it is used to fulfil the non-potable water demand. The last storage unit is also used to store the harvested precipitation, as the quality of this stream is high enough such that a treatment is unnecessary (Agudelo-Vera et al., 2012c).

$$R_1 \leq K \quad (3.13)$$

Neglecting storage dynamics, the overflow out of the storage units (OF_1 and OF_3) is defined as the sum of the leftovers. These leftovers exist due to treatment capacity limitations and/or demand shortages. This results in the following equations and constraints:

$$R_1 = R_{pot} - OF_1 \quad (3.14)$$

$$R_2 = R_1 \quad (3.15)$$

$$R_{HW} = M_{har} + R_2 - OF_3 \quad (3.16)$$

$$OF = OF_1 + OF_3 \quad (3.17)$$

$$OF_1 \geq 0 \quad (3.18)$$

$$OF_3 \geq 0 \quad (3.19)$$

Precipitation (Harvesting)

The treatment of used potable water is one way to reduce the external water demand. Another way to reduce the external input of potable water is harvesting precipitation.

The total precipitation can be split into 4 different streams, harvested precipitation, infiltration, runoff and evapotranspiration.

$$M_{\text{pot}} = \text{In} + \text{Ro} + \text{Et} + M_{\text{har}} \quad (3.20)$$

The evapotranspiration and infiltration streams can easily be split off from the total precipitation with use of two coefficients, as it is assumed that the evapotranspiration and infiltration streams are unaffected by multisourcing: the infiltration and evapotranspiration coefficients (In_c and Et_c). These coefficients depend on the division between grey (the impervious area) and green (the pervious area) land.

$$\text{Et} = \text{Et}_c * M_{\text{pot}} \quad (3.21)$$

$$\text{In} = \text{In}_c * M_{\text{pot}} \quad (3.22)$$

When there is no precipitation multisourced ($M_{\text{har}}=0$) the runoff stream can be found with a similar coefficient: the runoff coefficient (Ro_c). The value of this coefficient can be found with the precipitation constraint (3.24). In case of multisourcing the amount of water harvested will be subtracted from the original runoff stream.

$$\text{Ro} = \text{Ro}_c * M_{\text{pot}} - M_{\text{har}} \quad (3.23)$$

$$1 = \text{Et}_c + \text{In}_c + \text{Ro}_c \quad (3.24)$$

In a scenario in which there is multisourcing, the precipitation will be collected from the roofs of the buildings in the block, therefore the area of the roofs (A_r) relative to the area of the block (A_b) is determined. At this surface there will be a harvesting yield (Y_h) (Water4all, 2007), this yield is limited by the harvesting constraint (3.26).

$$M_{\text{har}} = \frac{A_r}{A_b} * Y_h * M_{\text{pot}} \quad (3.25)$$

$$M_{\text{har}} \leq \text{Ro}_c * M_{\text{pot}} \quad (3.26)$$

3.1.3 Evaluation

Finally the water system will be evaluated with use of three indicators (see 2.2.4), which are applied to the water cycle. This results in the following equations:

Demand Minimization Index Water Cycle:

$$DMI_W = \frac{\text{Initial Water Demand } (D_{W0}) - \text{Actual Water Demand } (D_W)}{\text{Initial Water Demand } (D_{W0})} \quad (3.27)$$

Waste Output Index Water Cycle:

$$WOI_W = - \frac{\text{Water Waste Outputs } (WO_W)}{\text{Actual Water Demand } (D_W)} \quad (3.28)$$

Self-Sufficiency Index Water Cycle:

$$SSI_W = \frac{\text{Water Resources Harvested } (RH_W)}{\text{Actual Water Demand } (D_W)} \quad (3.29)$$

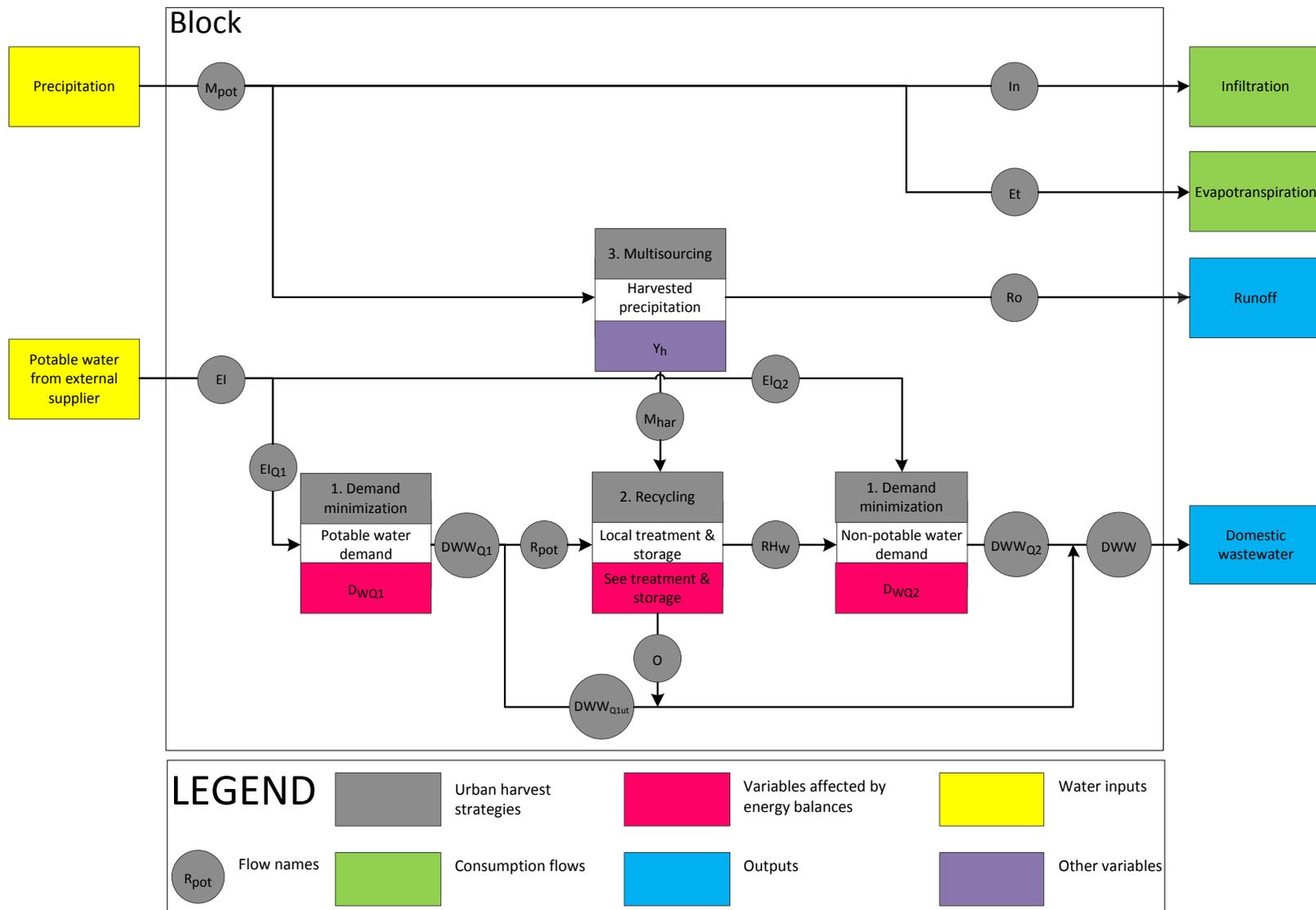


Figure 3: The overall water balance at block level.

3.2 Energy balances

3.2.1 Overall energy balance

Overall energy balance

With use of the system boundaries (Figure 5 on page 26), neglecting energy accumulation inside the block (e.g. electricity in batteries), the following overall balance is constructed:

$$0 = EI_E + EI_G + EI_H + HC_{TE} + M_{TEpot} + O_E \quad (3.30)$$

From this balance it is clear that the amount of energy present in the system depends on six different flows. These flows can be distinguished by their nature as inputs, outputs and consumption flows.

Inputs

The overall balance contains 4 different energy inputs, in which the multisourced energy sources are split into multisourced energy to produce electricity and multisourced energy to produce heat:

1. Electricity from an external supplier (EI_E)
2. Gas from an external supplier (EI_G)
3. Heat from an external supplier (EI_H)
4. Multisourced energy sources (M_{TEpot})
 - a. Multisourced energy sources to produce electricity (M_{Epot})
 - b. Multisourced energy sources to produce heat (M_{Hpot})

$$M_{TEpot} = M_{Epot} + M_{Hpot} \quad (3.31)$$

Outputs

In case of electricity generation overproduction is considered, when the generation exceeds the current demand. This stream of overproduced electricity (O_E) can be send back to the grid, to supply the energy demand of other buildings outside the block. Therefore this variable is observed as an output. Thus the total energy outputs (O_{TE}) are equal to the overproduced electricity.

$$O_{TE} = O_E \quad (3.32)$$

Consumption flows

The total heat consumption (HC_{TE}) is split into five different heat consumption types. After generation (HC_{TEg}), heating (HC_{TEh}), recovery (HC_{TEr}) (section 3.3), storage (HC_{TES}) and usage (HC_{TEu}) energy sources are released as heat. As these heat streams cannot be collected they are lost and therefore observed as consumed heat in this study.

$$HC_{TE} = HC_{TEg} + HC_{TEh} + HC_{TEr} + HC_{TES} + HC_{TEu} \quad (3.33)$$

As there are two types of energy generation, generation of electricity or heat, the total heat consumption (the energy entering the block which cannot be converted into useable energy) by generation is split into heat consumption from the electricity generator and heat consumption from the heat generator (HC_{Eg} and HC_{Hg}).

$$HC_{TEg} = HC_{Eg} + HC_{Hg} \quad (3.34)$$

The consumption of heat due to the heaters is split into heat consumption from the electricity heater and heat consumption from the gas heater (HC_{Eh} and HC_{Gh}).

$$HC_{TEh} = HC_{Eh} + HC_{Gh} \quad (3.35)$$

In case of heat consumption due to storage there are two, one from electricity storage and one from heat storage, consumption terms (HC_{ES} and HC_{HS}) too.

$$HC_{TES} = HC_{ES} + HC_{HS} \quad (3.36)$$

Finally the heat consumption due to usage is split into four different consumption (HC_C , HC_{EOD} , HC_{HQ1} and HC_{HSH}) streams as there are four different demand units (section 3.2.2 Block: Demand units).

$$HC_{TEu} = HC_C + HC_{EOD} + HC_{HQ1} + HC_{HSH} \quad (3.37)$$

3.2.2 Block

Although the overall balance gives a first indication of the system, the Urban Harvest Approach cannot be applied without knowing what happens inside. Therefore this block contains eleven different units, four demand units, which will be minimized, two heaters as gas en electricity can be converted to heat, a harvesting unit and two multisourcing units, and two storage units to store the multisourced energy (see Figure 5). As these last five units deal with multisourcing and recycling of energy, they are so-called 'self-sufficiency units'.

Demand units

With respect to energy demand units it is needed to distinguish between 4 different demands; the demand for spatial heat (D_{HSH}), the demand for potable warm water heated with gas (D_{HQ1}), the demand for cooking (D_C) (this demand can be fulfilled both with electricity (D_{EC}) as gas (D_{GC})) and the demand for other electrical devices (D_{EOD}).

$$D_C = D_{EC} + D_{GC} \quad (3.38)$$

With these demands in mind the total energy demand (D_{TE}), the electricity demand (D_E) and the heat demand (D_H) can be defined as:

$$D_E = D_{EC} + D_{EOD} \quad (3.39)$$

$$D_H = D_{GC} + D_{HQ1} + D_{HSH} \quad (3.40)$$

$$D_{TE} = D_E + D_H \quad (3.41)$$

Demand other electrical devices

In principal the demand for other electrical devices has to be split into a demand for waterless devices (D_{EWD}) and a non-potable water demand (D_{EQ2}) from which heat will be recovered (R_{HQ2}) (see section 3.3.1). This is presented in Figure 4. As there is no detailed data available about the splitting and the calculations do not require this level of detail, electricity demand splitting is not considered in this research.

$$D_{EOD} = D_{EQ2} + D_{EWD} \quad (3.42)$$

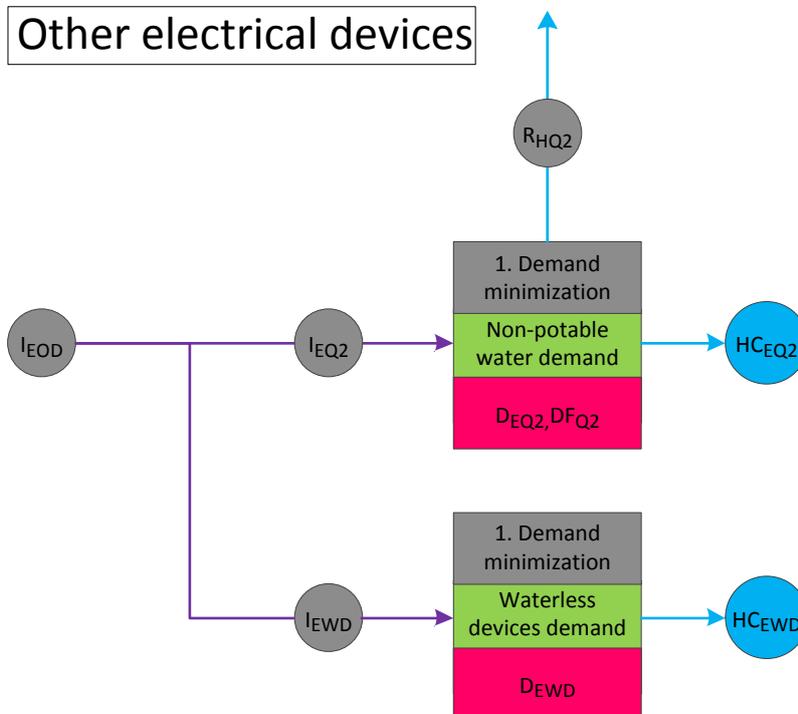


Figure 4: Overview of the other electrical devices demand splitting.

Heaters

A very important difference of the energy cycle with respect to the water cycle is that, in case of the energy cycle, electricity and gas can be converted into heat by a heater. As a result of these heaters, the external input of gas and electricity has to be split in a part that is converted into heat (EI_{Gh} and I_{Eh}) (e.g. for heating water) and a part that is used directly to fulfill the demands. These last demands are the demand for cooking via gas with as input EI_{GC} , the demand for cooking via electricity with as input I_{EC} and the demand for other electricity with as input I_{EOD} . Considering that electricity can be multisourced (M_E) this results in:

$$EI_G = EI_{Gh} + EI_{GC} \quad (3.43)$$

$$EI_E = I_{Eh} + I_{EC} + I_{EOD} - M_E - O_E \quad (3.44)$$

In a heater the energy source is converted into heat. As this heat cannot be harvested completely, there is a need to know the efficiencies of the heaters (Ef_{Eh} and Ef_{Gh}). The harvested heat flows leave the heater as heat from the electricity heater (H_{Eh}) and heat from the gas heater (H_{Gh}); the differences are released as consumed heat.

$$H_{Gh} = Ef_{Gh} * EI_{Gh} \quad (3.45)$$

$$HC_{Gh} = (1 - Ef_{Gh}) * EI_{Gh} \quad (3.46)$$

$$H_{Eh} = Ef_{Eh} * I_{Eh} \quad (3.47)$$

$$HC_{Eh} = (1 - Ef_{Eh}) * I_{Eh} \quad (3.48)$$

Demand balances & Heat inputs

As there are multiple ways to obtain heat, it is needed to define the heat inputs (I_{HQ1} and I_{HSH}) to fulfill the demands for spatial heat and potable warm water. Multisourced heat is presented as M_H .

$$I_{HQ1} + I_{HSH} = EI_H + H_{Eh} + H_{Gh} + M_H \quad (3.49)$$

As all inputs are now determined, the demand balances (incl. the recovery related variables R_{HQ1} and R_{HSH}) are set up:

$$D_{EC} = I_{EC} \quad (3.50)$$

$$D_{GC} = EI_{GC} \quad (3.51)$$

$$D_C = HC_C \quad (3.52)$$

$$D_{EOD} = HC_{EOD} + R_{HQ2} = I_{EOD} \quad (3.53)$$

$$D_{HQ1} = HC_{HQ1} + R_{HQ1} = I_{HQ1} \quad (3.54)$$

$$D_{HSH} = HC_{HSH} = I_{HSH} + R_{HSH} \quad (3.55)$$

Self-sufficiency units

Heat recovery

In this study the only way in which used energy can be recovered is by heat recovery from wastewater. Although this topic is treated section 3.3.1, it is already included in the overall energy balance (Figure 5).

Multisourcing

Energy can be multisourced in two different ways, as electricity or as heat. In both cases there is a generator which converts solar energy (M_{Epot} and M_{Hpot}) into electricity or heat. This is done at the roof (A_{Eg} and A_{Hg}). A storage unit stores the harvested energy (M_{Ehar} and M_{Hhar}) after which it is used or, in case of overproduced electricity, send back to the grid.

Due to the yields of the generators (Y_{Eg} and Y_{Hg}) and the efficiencies of the storage units (Ef_{Es} and Ef_{Hs}), the actual energy multisourced (M_E and M_H) is always lower than the solar potential (M_{Epot} and M_{Hpot}). Another reason for this difference is that the total block area (A_b) is usually larger than the net roof area (A_{rn}). Although the solar potential is the source of all harvested energy, the harvested energy is determined by both the harvesting potentials (M_{Eharp} and M_{Hharp}) as the demands.

The harvesting potentials take into account that part of the net roof area is located in the shadows, the shadowed roof area (A_{rs}), the harvesting yields and the fact that the roof area cannot be used for 100% (A_{empt}) due to limitations in size flexibility of the energy generators and the need of space for framing and cooling (Mulders, 2011a), this difference is represented by the roof conversion factor (CF_r). The total energy multisourced (M_{TE}) is equal to the sum of electricity and heat multisourced.

$$M_{Ehar} = \frac{M_{Eharp} * A_{Eg}}{A_{rn} * CF_r * (1 - A_{rs})} \quad (3.56)$$

$$M_{Hhar} = \frac{M_{Hharp} * A_{Hg}}{A_{rn} * CF_r * (1 - A_{rs})} \quad (3.57)$$

$$M_E = M_{Ehar} * Ef_{Es} \quad (3.58)$$

$$M_H = M_{Hhar} * Ef_{Hs} \quad (3.59)$$

$$M_{TE} = M_E + M_H \quad (3.60)$$

The differences leave the system as consumed heat from the generators and as consumed heat from the storage units.

$$HC_{Eg} = M_{Epot} - M_{Ehar} \quad (3.61)$$

$$HC_{Hg} = M_{Hpot} - M_{Hhar} \quad (3.62)$$

$$HC_{Es} = M_{Ehar} * (1 - Ef_{Es}) \quad (3.63)$$

$$HC_{Hs} = M_{Hhar} * (1 - Ef_{Hs}) \quad (3.64)$$

As the roof area of the buildings is defined as a horizontal area, and generators deal with net roof sizes, the slope of the roof (α) is introduced in eq. 3.65.

$$A_r = A_{rn} * \cos(\alpha) \quad (3.65)$$

$$A_{rn} = A_{Eg} + A_{Hg} + A_{empt} \quad (3.66)$$

The total amount of renewables harvested (RH_{TE}) is equal to the sum of the electrical renewables harvested (RH_E) and the heat renewables harvested (RH_H). This is equal to the amount of the resources recovered and the total amount of energy multisourced.

$$RH_E = M_E \quad (3.67)$$

$$RH_H = M_H + R_{HSH} \quad (3.68)$$

$$RH_{TE} = RH_E + RH_H \quad (3.69)$$

3.2.3 Evaluation

Finally the energy system will be evaluated with use of three indicators (see 2.2.4), which are applied to the energy cycle. This results in the following equations:

Demand Minimization Index Energy Cycle:

$$DMI_{TE} = \frac{\text{Initial Energy Demand } (D_{TE0}) - \text{Actual Energy Demand } (D_{TE})}{\text{Initial Energy Demand } (D_{TE0})} \quad (3.70)$$

Output Index Energy Cycle:

$$OI_{TE} = - \frac{\text{Energy Outputs } (O_{TE})}{\text{Actual Energy Demand } (D_{TE})} \quad (3.71)$$

Self-Sufficiency Index Energy Cycle:

$$SSI_{TE} = \frac{\text{Energy Resources Harvested } (RH_{TE})}{\text{Actual Energy Demand } (D_{TE})} \quad (3.72)$$

In case of the self-sufficiency this index might lead to false results, as the self-sufficiency can be equal to or larger than one, without being self-sufficient in the electricity system. Therefore the self-sufficiency indices for both the heat as the electricity system are defined too.

$$SSI_E = \frac{\text{Electricity Resources Harvested } (RH_E)}{\text{Actual Electricity Demand } (D_E)} \quad (3.73)$$

$$SSI_H = \frac{\text{Heat Resources Harvested } (RH_H)}{\text{Actual Heat Demand } (D_H)} \quad (3.74)$$

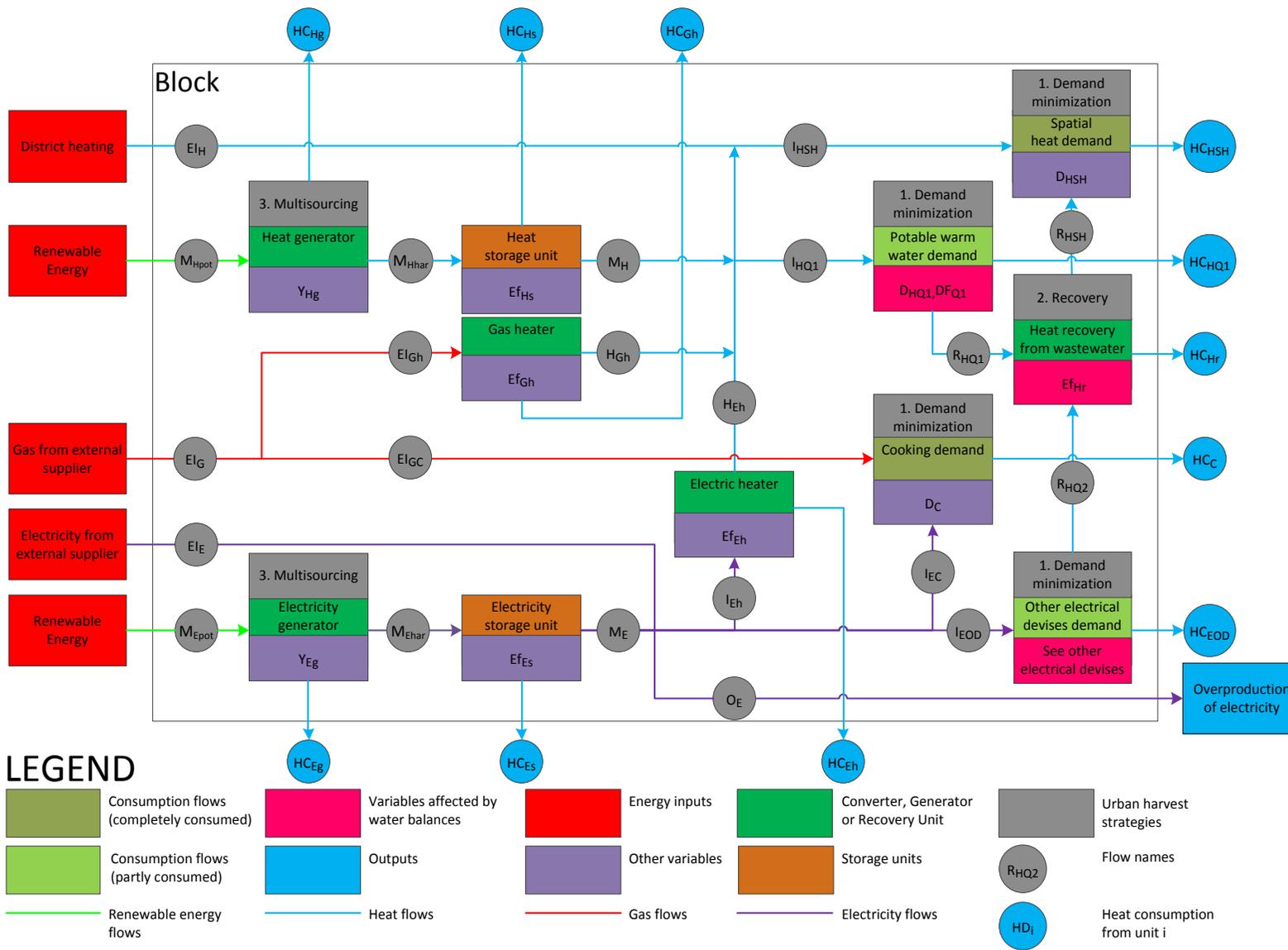


Figure 5: The overall energy balance at block level.

3.3 Linked energy and water balances

Water and energy are linked to each other. These linkages are found in the energy needed for water treatment and water as energy source for heat recovery. Water heating (treated in section 3.2.2) and water pumping are other examples in which water and energy are linked to each other. In this section, the energy needed for water treatment, the heat recovery potential from wastewater and the effects of water demand minimization on the energy demand are discussed. The energy needed for water pumping is neglected.

This combined system is presented in Figure 6.

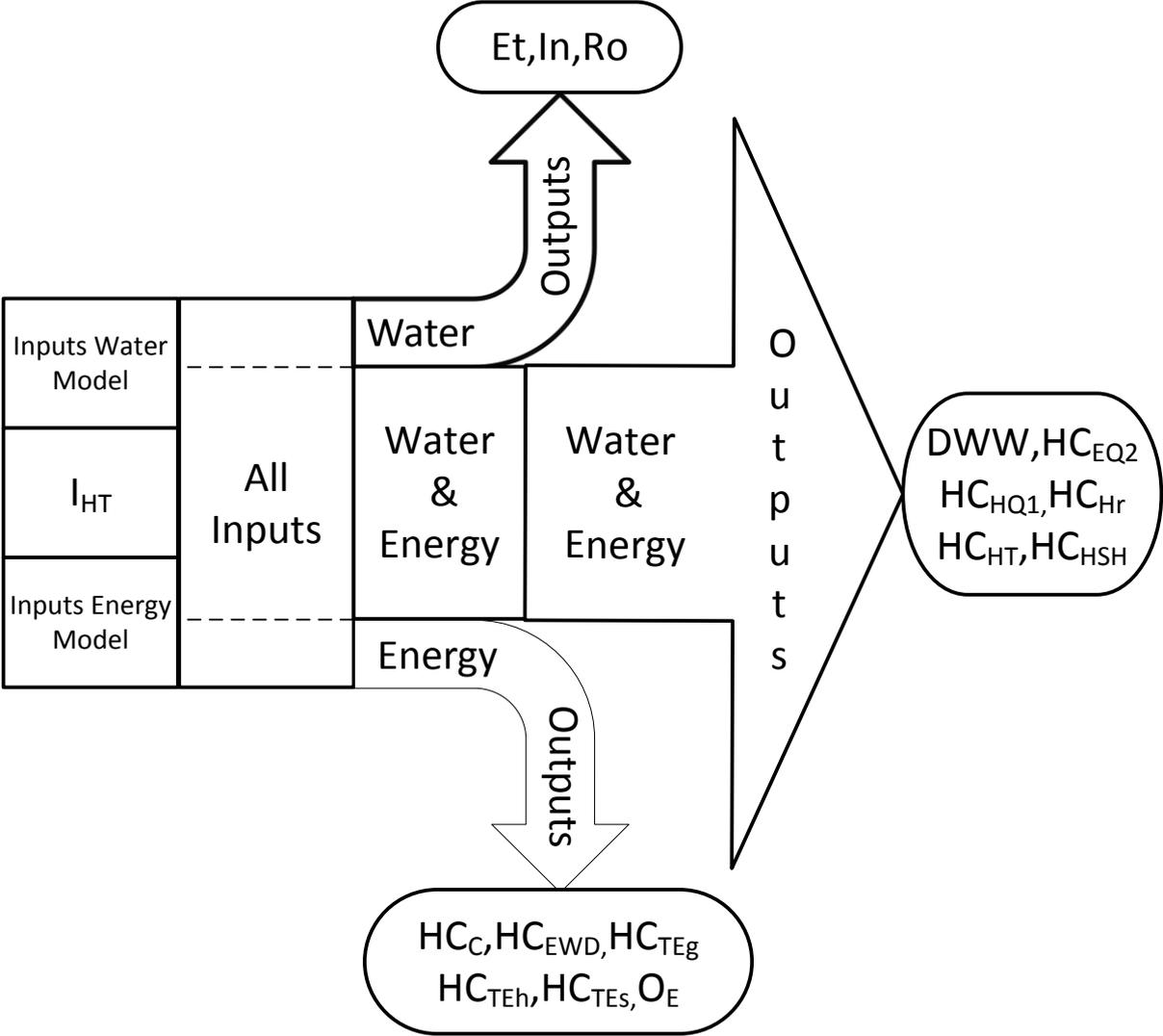


Figure 6: Overview of the combined system.

3.3.1 Linkages

Within the combined system there is a 'water & energy' box, which represents the linked parts of the combined system. This part can be split into 5 compartments (Figure 7).

Water & Energy	Potable water demand
	Recycling
	Non-potable water demand
	Heat recovery
	Spatial heating demand

Figure 7: Linked parts of the combined system.

Water demand

The demand for water, both potable as non-potable water, is a linked variable as water needs energy to be heated. This means that water demand minimization leads to a lower minimized energy demand for water heating, as long as there is no additional energy usage.

The effects of water demand minimization are combined with the effects of energy demand minimization. This results in the next equations in which the minimized water demand of the water system (D_{WQ1min} and D_{WQ2min}) is equal to the minimized demand of the combined system ($D_{WQ1minC}$ and $D_{WQ2minC}$), but the minimized energy demand for potable water (D_{HQ1min}) is higher than the minimized energy demand of the combined system ($D_{HQ1minC}$). This difference is included as a combined factor (CF_{Q1}). All other energy demands, including the energy demand for non-potable water, (D_{EODmin} , $D_{EODminC}$, D_{HSHmin} and $D_{HSHminC}$) are unaffected as being insignificant with respect to the water demand.

$$D_{WQ1minC} = D_{WQ1min} \quad (3.75)$$

$$D_{WQ2minC} = D_{WQ2min} \quad (3.76)$$

$$D_{EODminC} = D_{EODmin} \quad (3.77)$$

$$D_{HQ1minC} = D_{HQ1min} * CF_{Q1} \quad (3.78)$$

$$D_{HSHminC} = D_{HSHmin} \quad (3.79)$$

Combined factor

It is known that from all appliances in which gas is used for water heating, 83% of this heat is used for heating shower water (EC_S) (Blom et al., 2010). Considering the minimization factor of the shower demand (MF_S) and the energy content of other water flows (EC_O) the combined factor is calculated with equation 3.80, in which EC_T stands for the total energy content of all gas heated water flows.

$$CF_{Q1} = (EC_S * MF_S + EC_O) / EC_T \quad (3.80)$$

All relations from previous sections are still valid, as long as the new minimized demands are used.

Recycling

In case of water recycling there is energy needed for treatment (D_{HT}). This demand is fulfilled from a separate input (I_{HT}). As this stream is not present in the single energy or water system it is added as a separate input in Figure 6. This added energy stream is assumed to be completely consumed and leaves the system as heat from the treatment and storage units (HC_{HT}). This means that the energy effects of mixing harvested precipitation and treated water are neglected.

$$D_{HT} = I_{HT} = HC_{HT} \quad (3.81)$$

The water balances of the recycling units are already described in eq. 3.13 till eq. 3.19.

As a result of this additional stream, equations 3.33, 3.40, 3.41 and 3.49 are adapted in:

$$HC_{TE} = HC_{HT} + HC_{TEg} + HC_{TEh} + HC_{TEr} + HC_{TEs} + HC_{TEu} \quad (3.82)$$

$$D_H = D_{GC} + D_{HQ1} + D_{HSH} + D_{HT} \quad (3.83)$$

$$D_{TE} = D_C + D_{EOD} + D_{HQ1} + D_{HSH} + D_{HT} \quad (3.84)$$

$$I_{HQ1} + I_{HSH} + I_{HT} = EI_H + H_{Eh} + H_{Gh} + M_H \quad (3.85)$$

Heat recovery & Spatial heat demand

In this study the only way in which used energy can be recovered is by heat recovery from wastewater from the shower (D_{WS}) or from the washing machine (D_{WW}). Knowing the energy concentration of both flows (EC_{WS} and EC_{WW}) makes it possible to calculate their recovery potential.

The flow of recoverable heat from gas heated water is called R_{HQ1} and the flow of recoverable heat from electrical heated water is called R_{HQ2} . This heat potential is recovered within a recovery unit, in which the effective heat recovered is called R_{HSHC} and the heat consumption is called HC_{Hr} . Factors which take into account that used water leaves the system via others paths than the sewer (e.g. water which is left into the clothes after washing), so called discharge factors, are neglected. Considering the efficiency of the recovery unit (Ef_{Hr}), if the recovery potential is lower than the heat demand for spatial heating, this results in:

$$R_{HQ1} = D_{WS} * EC_{WS} \quad (3.86)$$

$$R_{HQ2} = D_{WW} * EC_{WW} \quad (3.87)$$

$$R_{HSHC} = (R_{HQ1} + R_{HQ2}) * Ef_{Hr} \quad (3.88)$$

The total heat consumption from recovery is equal to the heat consumption from the heat recovery unit (HC_{Hr}), as that is the only recovery unit present.

$$HC_{Hr} = R_{HSHC} - R_{HQ1} - R_{HQ2} \quad (3.89)$$

$$HC_{TEr} = HC_{Hr} \quad (3.90)$$

The stream of recovered heat is used to fulfil (part of) the demand for spatial heating (eq. 3.55).

3.3.2 Evaluation

The combined system is evaluated with use of three relative indices, in which the importance of energy and water is weighted equally.

Demand Minimization Index Combined Cycle:

$$DMI_C = \frac{\frac{D_{W0C} - D_{WC}}{D_{W0C}} + \frac{D_{TE0C} - D_{TEC}}{D_{TE0C}}}{2} \quad (3.91)$$

Output Index Combined Cycle (incl. wastes):

$$OI_C = - \frac{W_{OWC}/D_{WC} + O_{TEC}/D_{TEC}}{2} \quad (3.92)$$

Self-Sufficiency Index Combined Cycle:

$$SSI_C = \frac{RH_{WC}/D_{WC} + RH_{TEC}/D_{TEC}}{2} \quad (3.93)$$

4. Model Evaluation & Techniques

In this chapter the general balances are evaluated with use of two theoretical cases adapted from Agudelo-Vera (Agudelo-Vera et al., 2012b, Agudelo-Vera et al., 2012c). As demand minimization, recycling/recovery and multisourcing involve certain techniques these techniques are treated too.

4.1 Theoretical cases

Agudelo-Vera defined her cases based on a report of SenterNovem (SenterNovem, 2006). In this report some minor inconsistencies between the reports of Agudelo-Vera and SenterNovem, like the number of households per building unit at the high-density block, are changed. This is done to make sure that the data of the SenterNovem report can be used for the energy balances (e.g. the useable floor area (UFA)). The adapted theoretical cases are presented in Table 2.

Table 2: General characteristics of the selected blocks (adapted from Agudelo-Vera).

			
	Variables	Low-density block	High-density block
Total block area (m ²)	A _b	2500	2500
Number of building units per block	Bu	8	3
Number of households per building unit	Hhb	1	27
Household occupancy	Occ	4 ^a	2 ^b
Total block population	Tbp	32	162
House typology	-	Free standing house	Mid-rise apartment flat
Roof type	-	Pitched ^c	Flat
Horizontal roof area per building unit (m ²)	A _{rb}	63	670
Net roof area per building unit (m ²)	A _{rbn}	77	670
Total horizontal roof area (m ²)	A _r	504	2010
Total net roof area (m ²)	A _{rn}	615	2010
Grey water system	-	Single house collection	Shared collection
Rain water collection	-	Single	Shared
Impervious – Pervious percentage	-	20 - 80%	80 - 20%

^aTwo adults and two children. ^bTwo adults full time working. ^cFor a pitched roof a roof angle of 35° is assumed.

In Table 2 there are four variables calculated (equation 4.1 till 4.4).

The total block population (Tbp), the amount of people living at the block, is found to be a function of the amount of buildings at the block (Bu), the number of households in a building (Hhb) and the household occupancy (Occ).

$$Tbp = Bu * Hhb * Occ \quad (4.1)$$

The total (net) roof area (A_r or A_{rn}) is calculated by the summation of all roof areas together. Where the buildings in the selected blocks have the same roof areas, the total (net) roof area can be found by multiplying the amount of buildings with the (net) roof area per building (A_{rb} or A_{rnb}).

$$A_r = A_{rb} * Bu \quad (4.2)$$

$$A_{rn} = A_{rnb} * Bu \quad (4.3)$$

The difference between the horizontal roof area and the net roof area is caused by the angle of the roof (α). In Figure 8 this difference is visually presented.

$$A_{rnb} = A_{rb} / \cos(\alpha) \quad (4.4)$$

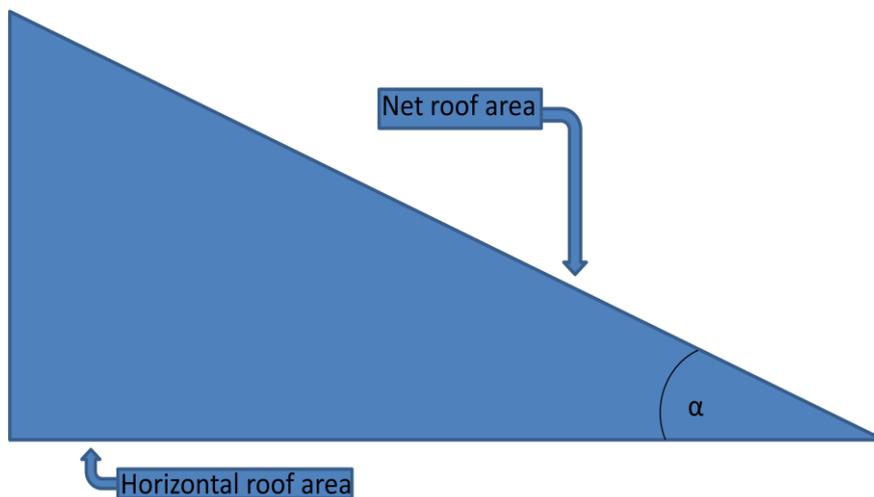


Figure 8: Graphical representation of the difference between the net and the horizontal roof area.

4.2 Water balances

4.2.1 Baseline assessment (BA)

The current water balances are evaluated with use of water demand data (Table 3) (Foekema and Van Thiel, 2011).

Table 3: Initial water demands per block.

Baseline assessment	Variables	Low-density block	High-density block
Initial potable water demand (m ³ /year)	D _{WQ1o}	837	4139
Initial non-potable water demand (m ³ /year)	D _{WQ2o}	513	3199
Initial water demand (m ³ /year)	D _{Wo}	1350	7338

For the evaluation of the total system it is important to define the total water demand:

$$D_{Wo} = D_{WQ1o} + D_{WQ2o} \quad (4.5)$$

4.2.2 Demand minimization (D)

The water demand can be minimized by reducing the largest, most important, streams. It is found that the water used for showering, flushing the toilets and washing clothes mechanically, are the only significant water streams at block level (Foekema and Van Thiel, 2011).

Demand minimization techniques

Agudelo-Vera found that in case of the Netherlands these flows can be reduced by reducing the consumption per time. This is done by the installation of vacuum toilets with a demand of 0.8 l per flush, a shower with a demand of 6 l per minute and a washing machine with a demand of 9 l kg⁻¹ and 4 kg per cycle. As the usage frequencies are left constant (Agudelo-Vera et al., 2012b), minimization factors are used for the calculation of the minimized demands. The initial demands and the minimization factors are presented in Tables 4 till 6, in which the minimization factors are constructed by the division of the minimized demands by the initial demands (equations 4.6 till 4.8).

Table 4: Shower demand minimization: the minimization factor construction.

Demand minimization	Variables	Low-density block	High-density block
Initial shower demand per usage (l)	C _{Wso}	68.7	56.8
Minimized shower demand per usage (l)	C _{WSmin}	46	46
Minimization factor shower	MF _S	0.67	0.81

$$MF_S = C_{WSmin}/C_{WSo} \quad (4.6)$$

Table 5: Toilet demand minimization: the minimization factor construction.

Demand minimization	Variables	Low-density block	High-density block
Initial toilet demand per usage (l)	C _{WTo}	5.74	5.75
Minimized toilet demand per usage (l)	C _{WTmin}	0.8	0.8
Minimization factor toilet	MF _T	0.14	0.14

$$MF_T = C_{WTmin}/C_{WTo} \quad (4.7)$$

Table 6: Washing machine demand minimization: the minimization factor construction.

Demand minimization	Variables	Low-density block	High-density block
Initial washing machine demand per usage (l)	C_{WWo}	55.6	55.6
Minimized washing machine demand per usage (l)	C_{WWmin}	45	45
Minimization factor washing machine	MF_W	0.81	0.81

$$MF_W = C_{WWmin}/C_{WWo} \quad (4.8)$$

With the minimization factors and the initials demands (for showering, toilet flushing and washing with the washing machine) from Foekema and Van Thiel, the minimized demands for these applications are calculated (Table 7 and equations 4.9 till 4.11). With use of these minimized demands the minimized demands per quality level are constructed (Figure 9 and equations 4.12 till 4.14).

Table 7: Overview of the initial water demands.

Demand minimization	Variables	Low-density block	High-density block
Initial water demand for shower (m ³ /year)	D_{WSO}	562	2690
Minimized water demand for shower (m ³ /year)	D_{WSmin}	376	2179
Initial water demand for toilet (m ³ /year)	D_{WTO}	362	2259
Minimized water demand for toilet (m ³ /year)	D_{WTmin}	50	314
Initial water demand for washing machine (m ³ /year)	D_{WWo}	151	940
Minimized water demand for washing machine (m ³ /year)	D_{WWmin}	122	761

$$D_{WSmin} = D_{WSO} * MF_S \quad (4.9)$$

$$D_{WTmin} = D_{WTO} * MF_T \quad (4.10)$$

$$D_{WWmin} = D_{WWo} * MF_W \quad (4.11)$$

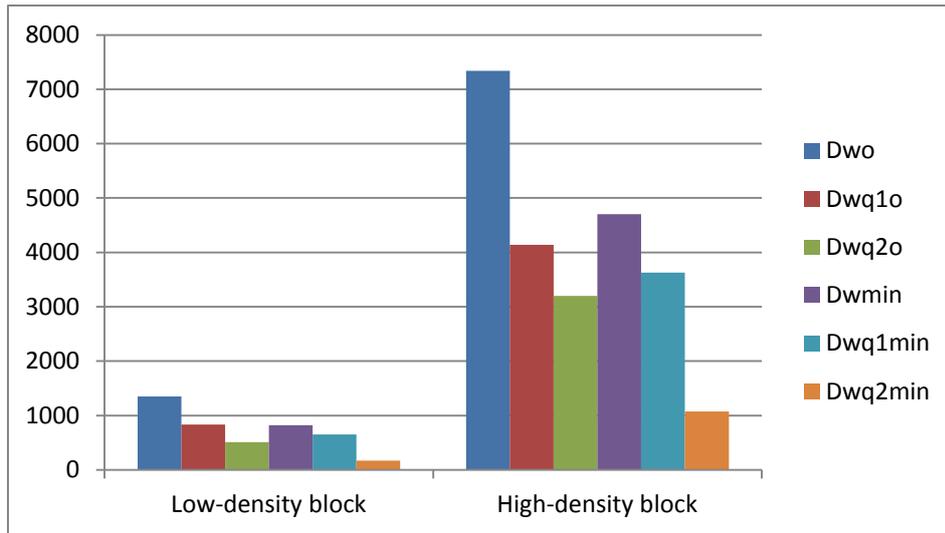


Figure 9: Overview of the water demands with respect to their quality and block.

$$D_{WQ1min} = D_{WQ1o} - D_{WSo} + D_{WSmin} \quad (4.12)$$

$$D_{WQ2min} = D_{WQ2o} - D_{WTo} - D_{Wwo} + D_{WTmin} + D_{WWmin} \quad (4.13)$$

$$D_{Wmin} = D_{WQ1min} + D_{WQ2min} \quad (4.14)$$

From Figure 9 there are three conclusion drawn:

1. The largest demand reduction is achieved by reducing the demand for low quality water (D_{WQ2min}). This is caused mainly by the reduction of the demand for toilet flushing.
2. With respect to reducing the high quality water demand (D_{WQ1min}) the effect of demand minimization is less significant.
3. As expected the high-density block uses more water than the low-density block, as there are more people living at the high-density block.

4.2.3 Recycling (R)

Water can be recycled by treatment. As the water losses during treatment are neglected it is important to find the treatment capacity of the tank. This treatment capacity is assumed to be $40 \text{ l p}^{-1} \text{ d}^{-1}$ (Agudelo-Vera et al., 2012b). More details about the assumptions made to obtain this capacity are found in the document of Agudelo-Vera. The results are presented in Table 8.

Table 8: Results of water recycling.

Recycling		Low-density block					High-density block				
		BA	D	D+R	D+M	D+R+M	BA	D	D+R	D+M	D+R+M
Treatment capacity treatment unit S_2 (m^3/year)	K	467	467	467	467	467	2365	2365	2365	2365	2365
Potential recycling from used potable water (m^3/year)	R_{pot}	0	0	376	0	376	0	0	2179	0	2179
Water resources harvested (m^3/year)	RH_w	0	0	172	172	172	0	0	1075	1027	1075

$$K = Tbp * 40 * 365/1000 \quad (4.15)$$

Combining equations 4.12 till 4.14 with Table 8 leads to the conclusion that recycling covers the low quality water demand left after demand minimization completely. This makes recycling a very efficient technique after demand minimization.

4.2.4 Multisourcing (M)

Water is multisourced via precipitation (KNMI, 2010). This precipitation cannot be harvested completely as parts of it evaporate or infiltrate (Arnold Jr and Gibbons, 1996). The remaining stream, the runoff, can be harvested.

Due to safety issues precipitation will only be collected from the roofs of the buildings in the block. At this surface there will be a harvesting yield, this yield is limited by the harvesting constraint (3.26). This yield is lower than 1, because of front filtration and the roof type (Water4all, 2007).

An overview of the inputs and results of multisourcing is presented in Table 9 and Table 10.

Table 9: Inputs for water multisourcing.

Multisourcing	Variables	Low-density block	High-density block
Evapotranspiration coefficient (-) (Arnold Jr and Gibbons, 1996)	E_{tc}	0.38	0.30
Infiltration coefficient (-) (Arnold Jr and Gibbons, 1996)	I_{nc}	0.42	0.15
Runoff coefficient (-) (Arnold Jr and Gibbons, 1996)	R_{oc}	0.20	0.55
Yield of harvesting (-) (Water4all, 2007)	Y_h	0.72	0.64

Table 10: Results of water multisourcing.

Multisourcing		Low-density block					High-density block				
Variables		BA	D	D+R	D+M	D+R+M	BA	D	D+R	D+M	D+R+M
Potential water multisourcing ($m^3/year$)	M_{pot}	1995	1995	1995	1995	1995	1995	1995	1995	1995	1995
Harvested water multisourcing ($m^3/year$)	M_{har}	0	0	0	290	290	0	0	0	1027	1027
Water resources harvested ($m^3/year$)	RH_w	0	0	172	172	172	0	0	1075	1027	1075

Water multisourcing is found to be less efficient than recycling at the high density block as the amount of water harvested does not cover the low quality water demand completely. This makes water multisourcing worse than water recycling.

4.2.5 Evaluation

Finally both blocks are evaluated with use of the indices. The results are presented in Table 11.

Table 11: Results of the water balances evaluation.

Evaluation		Low-density block					High-density block				
		BA	D	D+R	D+M	D+R+M	BA	D	D+R	D+M	D+R+M
Actual water demand (m ³ /year)	D _w	1350	824	824	824	824	7338	4703	4703	4703	4703
Water resources harvested (m ³ /year)	RH _w	0	0	172	172	172	0	0	1075	1027	1075
Water waste outputs (m ³ /year)	WO _w	1749	1223	1051	1051	1051	8435	5800	4725	4773	4725
Water demand minimization index (-)	DMI _w	0	0.390	0.390	0.390	0.390	0	0.359	0.359	0.359	0.359
Water self-sufficiency index (-)	SSI _w	0	0	0.209	0.209	0.209	0	0	0.229	0.218	0.229
Water waste output index (-)	WOL _w	-1.296	-1.484	-1.275	-1.275	-1.275	-1.150	-1.233	-1.005	-1.015	-1.005

The water demand can be reduced by almost 40% at the low-density block (LDB) and by approximately 36% at the high-density block (HDB). This difference is caused by the lower initial shower demand per usage in the high-density block (Table 4).

As for both blocks the minimized shower demand (LDB: 376m³/year and HDB: 2179m³/year) is larger than the minimized non-potable water demand (LDB: 172m³/year and HDB: 1075m³/year), the recycling potential is limited by the non-potable water demand. With respect to water multisourcing there is a difference between both scenarios, as only at the low-density block the non-potable water demand can be covered fully from harvested precipitation (Table 11: RH_w of D+M scenarios).

4.3 Energy balances

The energy demand is mainly determined by the building type, the building age and the household occupancy (Schremmer et al., 2009). As the building type and household occupancy are already defined in both cases only the building age is variable.

The energy consumption of private houses is closely correlated to the building age of the building. From literature 5 different building age groups can be distinguished (SenterNovem, 2010):

1. Houses build before 1965
2. Houses build during 1966-1975
3. Houses build during 1976-1988
4. Houses build during 1989-2000
5. Houses build after 2001

Although all periods are investigated, only the period between 1966-1975 is presented here, as the mean building age is found to be 38 year (Van Noppen and Verlinden, 1998). Data about other time periods is presented in appendix A.

Cooking demand

The demand for cooking on gas is found to be less than 4% of the total gas demand (Blom et al., 2010). This demand of 4% is found to be 70% of the total energy demand for cooking (Tipsomtebesparen.nl, 2012). Thus the energy demand for cooking is found to be insignificant and therefore neglected (eq. 4.16 till 4.21).

$$D_E = D_{EOD} \quad (4.16)$$

$$D_H = D_{HQ1} + D_{HSH} \quad (4.17)$$

$$D_{TE} = D_E + D_H \quad (4.18)$$

$$HC_{TEu} = HC_{EOD} + HC_{HQ1} + HC_{HSH} \quad (4.19)$$

$$EI_G = EI_{Gh} \quad (4.20)$$

$$EI_E = I_{Eh} + I_{EOD} - M_E - O_E \quad (4.21)$$

4.3.1 Baseline assessment (BA)

The analysis of the energy balances is performed with use of the ‘Energiebesparingsverkenner’ (SenterNovem, 2010). During the baseline assessment, the cases are tested based on the inputs delivered from Table 2, all other variables, like insulation variables, are unaffected. The results are presented in Table 12.

Table 12: Results of the baseline assessment.

Baseline assessment	Variables	Low-density block	High-density block
Installations	-	Central heating (IE-combi)	Collective central heating (IE-combi)
Initial electricity demand (MJ/year)	D_{EODo}	141840	979776
Initial heat demand for warm potable water (MJ/year)	D_{HQ1o}	113434	1276698
Initial heat demand for spatial heating (MJ/year)	D_{HSHo}	705415	1737015
Initial total energy demand (MJ/year)	D_{TEo}	960689	3993489
External input of district heat (MJ/year)	EI_H	0	0
Useable floor area per household (m ²)	UFA	170	92

$$D_{TEo} = D_{EODo} + D_{HQ1o} + D_{HSHo} \quad (4.22)$$

Combining Table 2 and Table 12 it is concluded that although there are many more citizens at the high-density block (162 vs. 32 at the LDB) the heat demand for spatial is only twice as high, as the apartments are smaller and have less outer surface. The heat demand for warm potable water is eleven times higher at the HDB compared with that demand at the LDB. As the population ratio is only 5.1 there need to be another additional reason for this difference. This difference can be explained by the different installations used, as heating at one central point at the HDB leads to longer transportation lines and thus an increased loss of heat due to the water transfer in the buildings.

The other electricity demand is stronger correlated to the total block population, with an energy ratio (demand HDB/demand LDB) of 6.9 in stead of 5.1.

4.3.2 Demand minimization (D)

Demand minimization techniques

In case of energy demand minimization there are two different aspects:

1. Energy demand minimization by water demand minimization
2. Energy demand minimization due to efficiency increasing techniques

Energy demand minimization by water demand minimization

As both water as energy are involved in this type of demand minimization, this topic is treated in section 4.4.2.

Energy demand minimization due to efficiency increasing techniques

The energy efficiency can be increased by insulation or by upgrading the installation. The replacement of apparatus by more efficient devices is left out of scope, as found to be insignificant (Blom et al., 2010).

Insulation

With respect to insulation there are 4 different places which can be insulated:

1. Roof
2. Floor
3. Outer walls
4. Window

In case of roof, floor or outer wall insulation it can be stated that more is less. More insulation leads reduced heat consumption, as spatial heat leaves the building slower. This effect can be represented by a heat resistance value (Rc-value). This Rc-value is preferred to be as high as possible. An overview of all insulation levels for different building ages is presented in appendix B.

There are 3 different window qualities, single glazing, insulated glazing or HR-glazing considered in this study. In principal HR-glazing, especially HR++glazing, is preferred above single or insulated glazing, as it has a lower heat transfer coefficient (see appendix C), although historical or practical reasons (HR-glazing and insulated glazing are thicker than single glazing) might limit the installation. In this study it is assumed that there are no limits to the installation of HR-glazing.

Installations

In the 'Energiebesparingsverkenner' there are twenty different installations applied, these installations are presented in Table 13.

Table 13: Overview of all installations applied in Energiebesparingsverkenner.

Demand minimization Installations	Applicable in:	
	Single family-dwelling	Multiple family-dwelling
Local gas heating + Tank less heater	X	X
Central heating (SE-combi)	X	X
Central heating (IE-combi)	X	X
Central heating (HE-combi)	X	X
Central heating (HEe)	X	X
Central heating (IE-combi) incl. solar thermal collector	X	X
Central heating (HE-combi) incl. solar thermal collector	X	X
Collective central heating (SE-combi)		X
Collective central heating (IE-combi)		X
Collective central heating (IE-combi) + Tank less heater		X
Collective central heating (IE-combi) + Electrical boiler		X
Collective central heating (HE-combi)		X
Collective central heating (HE-combi) + Tank less heater		X
Collective central heating (HE-combi) + Electrical boiler		X
Collective central heating (Heat pump soil)		X
Central heating (HE) + Heat pump boiler		X
Central heating (IE) + Tank less heater	X	
Heat pump soil + boiler	X	
Heat pump air + boiler	X	
District heating	X	

These twenty installations can easily be reduced, when it is known that SE stands for standard efficiency (lower than 83% based on higher heating value), IE stands for improved efficiency (at least 83% based on higher heating value) and HE stands for high efficiency (at least 90% based on higher heating value). Thus HE installations are preferred.

District heating, heat pumps and installations including solar thermal collectors are not considered as multisourcing is evaluated with use of the data of G.Mulders about solar energy (Mulders, 2011a).

All investigated installations are marked in green, installations which are left out of scope marked in red. Comparing the seven installations left, the total minimized energy demand is found when “Local gas heating + Tankless heater” is applied; this result is presented in Table 14.

The results of applying the other installations are presented in Appendix A.

Table 14: Results of energy demand minimization.

Demand minimization	Variables	Low-density block	High-density block
Installation applied	-	Local gas heating	Local gas heating
Minimized electricity demand (MJ/year)	D_{EODmin}	133805	909209
Minimized heat demand for warm potable water (MJ/year)	D_{HQ1min}	100014	669113
Minimized heat demand for spatial heating (MJ/year)	D_{HSHmin}	297763	751814
Minimized total energy demand (MJ/year)	D_{TEmin}	531582	2330136

From Table 14 is it found that improving the installation to local gas heating, the total energy demand is reduced by more than 40% at both blocks. The ratio between both heat demands for warm potable water is reduced by applying the same installation at both blocks; now this ratio of 6.7 is more in balance with ratio of both shower demands of 4.9, which contributes to 83% of the energy demand for water heating (Blom et al., 2010).

Building age

As the building age is one of the main parameters with respect to the energy demand of a building (Schremmer et al., 2009), the effect of the building age on the possibilities for demand minimization are evaluated too (Table 15). The demand minimization factor is defined as the ratio between the minimized demand and the baseline assessment demand.

Table 15: Results of energy demand minimization in relation to the building age.

Demand minimization	Low-density block	High-density block
Building age	Demand minimization factor	Demand minimization factor
<1965	0.48	0.57
1966-1975	0.55	0.58
1976-1988	0.58	0.60
1989-2000	0.91	0.87
2001-Present	0.96	0.93

The main reason for the different demand minimization factors is contributed to the different insulation properties of the buildings (appendix A). Thus the largest energy demand reduction can be obtained by insulation. This effect is observed in all buildings, but especially in buildings build before 1989 where the demand for spatial heating can be reduced by more than 50% in the best performing scenarios (appendix A).

4.3.3 Recycling (R)

Recycling techniques

As heat recycling is considered as impossible, heat recycling is not considered in this study.

4.3.4 Multisourcing (M)

Multisourcing techniques

In this research only the multisourcing of solar energy is investigated. According to G.Mulders there are two ways to multisource solar energy (Mulders, 2011a):

1. Electricity collection by photovoltaic cells.
2. Heat collection by solar thermal collectors.

Solar panels can be installed flat on the roof or with a tilt angle (usually 35°). Although installation with a tilt angle has a more efficient conversion, flat installation is preferred due to the shadows on neighbour panels created by the tilt panels (Mulders, 2011a). This reduces the feasible surface area of harvesting. In case of free standing houses with a tilt roof only half the roof area is assumed to be useable for solar panels, as the other half is located in the roof shadow.

Photovoltaic cells

Photovoltaic cells (PV-cells) produce electricity by the conversion of solar radiation into electricity. This is done directly. The efficiency of a PV-cell depends on the absorbing characteristics (light spectrum) of the semi-conductor, usually Silicon (Liu et al., 2009), and set to 14% (Mulders, 2011a). For the generation of electricity at roofs, these cells are connected together in a solar panel.

Electricity obtained from solar panels is direct current electricity (DC), which e.g. can be used in batteries. If the devices (including export of DC to the grid) are connected to the grid the direct current has to be converted to alternating current, this is done by an inverter (Goetzberger and Hoffmann, 2005).

Solar thermal collectors

In solar thermal collectors solar radiation is converted to heat. This heat is captured in water, air or oil. This heat can be either be used directly or stored.

Although there are two types of solar collectors, non-concentrating and concentrating (Kalogirou, 2004), only non-concentrating collectors are investigated as they are more common in urban areas.

There are four different collector types; unglazed, single glazed, double glazed and evacuated tubes. It is found that double glazed collectors are the best heat collectors for spatial heat (25°C), with a yield of $47.70 \text{ m}^3 \text{ gas eq/m}^2$. Evacuated tubes are the best heat collectors for warm potable water, with a yield of $31.85 \text{ m}^3 \text{ gas eq/m}^2$ (Mulders, 2011b). From a yearly perspective, neglecting temporal variations and storage issues, it is concluded that double glazed collectors are preferred as long as the spatial heat demand is not completely fulfilled from renewable sources.

The panel efficiency is found to be temperature dependent (Figure 10)(Kalogirou, 2004), evacuated tubes perform better on cold and cloudy days, but on average 47% for evacuated tubes and 70% for double glazed flat plates.

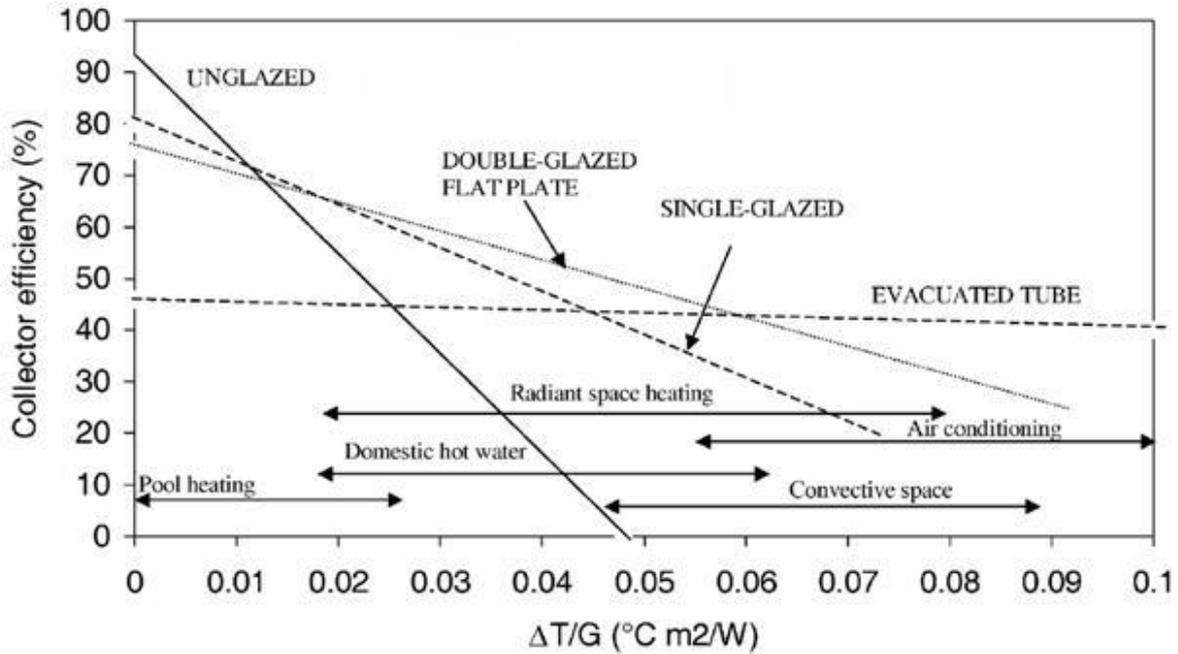


Figure 10: Efficiencies of different solar collectors (Kalogirou, 2004).

Energy storage

Losses due to energy storage are neglected ($E_{f_{ES}}=1$ and $E_{f_{HS}}=1$).

Tables 16 and 17 display the results of the energy multisourcing. As the roof is either used for PV-cells or solar thermal collectors two new variables are included to show the harvesting potential of both electricity as heat ($M_{E_{harp}}$ and $M_{H_{harp}}$). These harvesting potentials include the roof area for harvesting and the efficiency of the panels without considering demand limitations and roof competition.

Table 16: Results of energy multisourcing for the low density block.

Multisourcing		Low-density block				
		BA	D	D+R	D+M	D+R+M
Variables						
Area roof used for electricity generation	A_{EG}	0	0	0	36	36
Empty roof area	A_{empt}	615	615	615	382	382
Area roof used for heat generation	A_{HG}	0	0	0	197	197
Potential electricity multisourcing (MJ/year)	M_{Epot}	11457841	11457841	11457841	11457841	11457841
Harvesting potential of electricity (MJ/year)	M_{Eharp}	122515	122515	122515	122515	122515
Actual electricity multisourcing (MJ/year)	M_E	0	0	0	18849	18849
Potential heat multisourcing (MJ/year)	M_{Hpot}	6545771	6545771	6545771	6545771	6545771
Harvesting potential of heat (MJ/year)	M_{Hharp}	351905	351905	351905	351905	351905
Actual heat multisourcing (MJ/year)	M_H	0	0	0	297763	297763
Potential total energy multisourcing (MJ/year)	M_{TEpot}	18003612	18003612	18003612	18003612	18003612
Actual total energy multisourcing (MJ/year)	M_{TE}	0	0	0	316613	316613
Total energy resources harvested (MJ/year)	RH_{TE}	0	0	0	316613	316613
Overproduced electricity (MJ/year)	O_E	0	0	0	0	0

Table 17: Results of energy multisourcing for the high density block.

Multisourcing		High-density block				
Variables		BA	D	D+R	D+M	D+R+M
Area roof used for electricity generation	A_{Eg}	0	0	0	1025	1025
Empty roof area	A_{empt}	2010	2010	2010	487	487
Area roof used for heat generation	A_{Hg}	0	0	0	498	498
Potential electricity multisourcing (MJ/year)	M_{Epot}	11457841	11457841	11457841	11457841	11457841
Harvesting potential of electricity (MJ/year)	M_{Eharp}	745650	745650	745650	745650	745650
Actual electricity multisourcing (MJ/year)	M_E	0	0	0	501835	501835
Potential heat multisourcing (MJ/year)	M_{Hpot}	6545771	6545771	6545771	6545771	6545771
Harvesting potential of heat (MJ/year)	M_{Hharp}	2299246	2299246	2299246	2299246	2299246
Actual heat multisourcing (MJ/year)	M_H	0	0	0	751814	751814
Potential total energy multisourcing (MJ/year)	M_{TEpot}	18003612	18003612	18003612	18003612	18003612
Actual total energy multisourcing (MJ/year)	M_{TE}	0	0	0	1253649	1253649
Total energy resources harvested (MJ/year)	RH_{TE}	0	0	0	1253649	1253649
Overproduced electricity (MJ/year)	O_E	0	0	0	0	0

In case of the energy collection at the roofs it is found that heat collection is preferred above electricity production, due to a higher harvesting potential ($M_{Hharp} > M_{Eharp}$, for both blocks). As the heat demand for spatial heat can be fully covered from this heat collection, the remaining roof area is used for the collection of electricity.

4.3.5 Evaluation

Finally both blocks from Table 2 are evaluated with use of the indices. The results are presented in Table 18 and 19.

Table 18: Results of energy system evaluation for the low-density block.

Evaluation		Low-density block				
Variables		BA	D	D+R	D+M	D+R+M
Actual total energy demand (MJ/year)	D_{TE}	960689	531582	531582	531582	531582
Total energy resources harvested (MJ/year)	RH_{TE}	0	0	0	316613	316613
Total energy outputs (MJ/year)	O_{TE}	0	0	0	0	0
Total energy demand minimization index (-)	DMI_{TE}	0	0.447	0.447	0.447	0.447
Total energy output index (-)	OI_{TE}	0	0	0	0	0
Total energy self-sufficiency index (-)	SSI_{TE}	0	0	0	0.596	0.596
Electricity self-sufficiency index (-)	SSI_E	0	0	0	0.141	0.141
Heat self-sufficiency index (-)	SSI_H	0	0	0	0.749	0.749

Table 19: Results of energy system evaluation for the high-density block.

Evaluation		High-density block				
Variables		BA	D	D+R	D+M	D+R+M
Actual total energy demand (MJ/year)	D_{TE}	3993489	2330136	2330136	2330136	2330136
Total energy resources harvested (MJ/year)	RH_{TE}	0	0	0	1253649	1253649
Total energy outputs (MJ/year)	O_{TE}	0	0	0	0	0
Total energy demand minimization index (-)	DMI_{TE}	0	0.417	0.417	0.417	0.417
Total energy output index (-)	OI_{TE}	0	0	0	0	0
Total energy self-sufficiency index (-)	SSI_{TE}	0	0	0	0.538	0.538
Electricity self-sufficiency index (-)	SSI_E	0	0	0	0.552	0.552
Heat self-sufficiency index (-)	SSI_H	0	0	0	0.529	0.529

Although there are only minor differences between the three main indices (DMI_{TE} , OI_{TE} and SSI_{TE}) for the total energy system of both blocks, there are large differences between the electricity and heat self-sufficiency indices, as the demand for spatial heating is relatively high in case of free-standing houses and lower in a flat building.

4.4 Combined balances

The combined balances are a result of the integration of the energy and water balances, including their linkages. The energy needed for treatment is included too. As many variables are unaffected, e.g. all variables from the water balances, only the affected variables are presented. As multisourcing of energy and water is independent, multisourcing is not considered in the combined balances.

4.4.1 Baseline assessment (BA)

As only the energy needed for treatment is added to the combined system, the baseline assessment consists out of two variables (Table 20); the energy needed for water treatment and the new total energy demand.

Table 20: Results of combined baseline assessment.

Baseline assessment	Variables	Low-density block	High-density block
Initial energy demand for water treatment (MJ/year)	D_{HTO}	0	0
Initial energy demand (excl. water treatment) (MJ/year)	D_{TEOC}	960689	3993489

Energy needed for water treatment

Used shower water is treated in the treatment unit. This water stream is found to be the cleanest fraction of the residential wastewater and therefore observed as light grey water ($COD < 300 \text{ mg/L}$). This means that chemical treatment by e.g. coagulation or ion exchange is preferred above biological treatment (Li et al., 2009). This chemical treatment step is followed after a pre-treatment step of sedimentation and screening. After treatment a membrane filtration is performed to filter the chemicals from the solution.

As a plug flow system is assumed (Agudelo-Vera et al., 2012b) and the energy needed for pumping is neglected, the total energy input is neglected. The water stream can be applied in unrestricted reuses like washing clothes and toilet flushing (Li et al., 2009).

4.4.2 Demand minimization (D)

Water demand minimization leads to energy demand minimization, as less water needs to be heated (section 3.3.1). The combined minimized heat demand for warm potable is calculated with the combined factor (eq. 3.80) and presented in Table 21.

Table 21: Results of combined demand minimization.

Demand minimization	Variables	Low-density block	High-density block
Installation applied	-	Local gas heating	Local gas heating
Combined factor	CF	0.72	0.84
Minimized heat demand for warm potable water (MJ/year)	$D_{HQ1minC}$	72449	562990
Minimized total energy demand (MJ/year)	D_{TEminC}	504017	2224013

The difference in combined factors is caused by the lower initial shower demand per usage at the high-density block, as the percentage at which gas is used for the heating of showerwater is assumed to be constant (83%) (Blom et al., 2010).

4.4.3 Recovery (R)

Heat can be recovered from warm water, as there is a temperature difference between the water flow and its surroundings. Tables 22 and 23 provides the results of heat recovery from used shower and washing machine water.

Table 22: Results of heat recovery from wastewater for the low-density block.

Recovery		Low-density block				
		BA	D	D+R	D+M	D+R+M
Variables						
Heat recovery from potable water (MJ/year)	R_{HQ1}	0	0	36167	0	36167
Heat recovery from non-potable water (MJ/year)	R_{HQ2}	0	0	8261	0	8261
Actual heat recovered used for spatial heating (MJ/year)	R_{HSHC}	0	0	44428	0	44428
Total energy resources harvested (MJ/year)	R_{HTEC}	0	0	44428	316613	332080
Area roof used for electricity generation in combined system	A_{EGC}	0	0	0	36	65
Area roof used for heat generation in combined system	A_{HGC}	0	0	0	197	168
Combined actual electricity multisourcing	M_{EC}	0	0	0	18849	34317
Combined actual heat multisourcing	M_{HC}	0	0	0	297763	253335

Table 23: Results of heat recovery from wastewater for the high-density block.

Recovery		High-density block				
		BA	D	D+R	D+M	D+R+M
Variables						
Heat recovery from potable water (MJ/year)	R_{HQ1}	0	0	209485	0	209485
Heat recovery from non-potable water (MJ/year)	R_{HQ2}	0	0	51547	0	51547
Actual heat recovered used for spatial heating (MJ/year)	R_{HSHC}	0	0	261032	0	261032
Total energy resources harvested (MJ/year)	R_{HTEC}	0	0	261032	1253649	13380302
Area roof used for electricity generation in combined system	A_{EGC}	0	0	0	1025	1198
Area roof used for heat generation in combined system	A_{HGC}	0	0	0	498	325
Combined actual electricity multisourcing	M_{EC}	0	0	0	501835	586488
Combined actual heat multisourcing	M_{HC}	0	0	0	751814	490782

As expected, as 83% of the gas used for the water heating is used to heat shower water, most heat can be recovered from shower water. Comparing the D+R+M scenario with the D+M scenario leads to the conclusion that due to the heat recovery and the limited heat demand the multisourcing of energy will be changed. This means that it is important to know whether multisourcing or multisourcing with recovery will be applied before the installation of solar panels (PV-cells and/or solar thermal collectors).

4.4.4 Evaluation

Finally both blocks are evaluated with the indices. The results are presented in Tables 24 and 25.

Table 24: Evaluation of the combined system for the low-density block.

Evaluation		Low-density block				
Variables		BA	D	D+R	D+M	D+R+M
Combined demand minimization index (-)	DMI _c	0	0.432	0.432	0.432	0.432
Combined output index (-)	OI _c	- 0.648	- 0.742	- 0.637	- 0.637	- 0.637
Combined self-sufficiency index (-)	SSI _c	0	0	0.148	0.419	0.434

Table 25: Evaluation of the combined system for the low-density block.

Evaluation		High-density block				
Variables		BA	D	D+R	D+M	D+R+M
Combined demand minimization index (-)	DMI _c	0	0.401	0.401	0.401	0.401
Combined output index (-)	OI _c	- 0.575	- 0.617	- 0.502	- 0.508	- 0.502
Combined self-sufficiency index (-)	SSI _c	0	0	0.173	0.391	0.415

Combining both systems leads to a reduced heat demand for warm potable water, as less water needs to be heated, and the possibility of heat recovery from used water streams.

Comparing the combined indices with the water and energy indices is very hard as the combined indices are defined as the averages, although this can easily be changed, if preferred, to e.g. a 40-60% ratio, of both systems including their linkages. Therefore there are 3 merged indices developed from which the combined indices can be compared with, these are called the mean indices (DMI_M, OI_M and SSI_M). The difference between the combined and the mean indices is that within the combined indices, the effects of combining both water and energy systems is taken into account. Within the mean indices these issues (e.g. heat recovery) are not considered.

Mean Demand Minimization Index:

$$DMI_M = \frac{DMI_W + DMI_{TE}}{2} \quad (4.23)$$

Mean Output Index (incl. wastes):

$$OI_M = - \frac{OI_W + OI_{TE}}{2} \quad (4.24)$$

Mean Self-Sufficiency Index:

$$SSI_M = \frac{SSI_W + SSI_{TE}}{2} \quad (4.25)$$

Table 26: Evaluation of the mean indices for the low-density block.

Evaluation		Low-density block				
Variables		BA	D	D+R	D+M	D+R+M
Mean demand minimization index (-)	DMI _M	0	0.418	0.418	0.418	0.418
Mean output index (-)	OI _M	- 0.648	- 0.742	- 0.637	- 0.637	- 0.637
Mean self-sufficiency index (-)	SSI _M	0	0	0.105	0.402	0.402

Table 27: Evaluation of the mean indices for the high-density block.

Evaluation		High-density block				
		BA	D	D+R	D+M	D+R+M
Mean demand minimization index (-)	DMI _M	0	0.388	0.388	0.388	0.388
Mean output index (-)	OI _M	- 0.575	- 0.617	- 0.502	- 0.508	- 0.502
Mean self-sufficiency index (-)	SSI _M	0	0	0.114	0.378	0.383

These mean indices (Tables 26 and 27) are compared with the combined indices (Tables 24 and 25) to evaluate to what extent the energy balances are affected by combining both systems and whether there is a need for creating a combined model.

With respect to the demand minimization indices it is concluded that the energy demand reduction, due to the water demand reduction, considered that the water balances are unaffected, is found to be 2.9% (compared with the initial energy demand) for the low-density block and 2.7% for the high-density block (Compare Tables 24 and 25 with Tables 26 and 27, Percentage = $(DMI_C - DMI_M) * 2$).

The output indices are unaffected by combining both systems, as the water balances are unaffected and the electricity production is insufficient to produce any output.

The largest differences are observed comparing the self-sufficiency indices:

The recovery potential is found to be 8.8% (of the total energy demand) for the low-density block and 11.7% for the high density block. This means that energy recovery is only significant if the demand for spatial heating is comparable with or lower than the heat demand for potable water, as the recovery potential has to be big enough. With respect to this comparability it is important to mention that dynamic aspects will play a key roll here, thus there is a need for e.g. a monthly evaluation.

The underestimation, the combined energy demand is lower without affecting energy multisourcing, of the self-sufficiency made by not combining both systems with respect to multisourcing is found to be less than 4% (3.4% at the LDB and 2.6% at the HDB). In the low density block the mean index is based on a 59.6% energy self-sufficiency (Table 18), as the water self-sufficiency is still 20,9% (Table 11), which is 3.3% lower than the 62.8% self-sufficiency obtained in the combined index (Table 24). This difference is caused by the lower energy demand in the combined system.

As recovered heat is used to fulfil part of the spatial heat demand, the electricity production is increased in the fifth scenario (D+R+M), which increases the amount of resources harvested, compared to the third (D+R) and fourth scenario (D+M). Another reason for the increased self-sufficiency is the lower energy demand as mentioned earlier. The net effect is found to be 6.3% for the low-density block and 6.4% for the high-density block.

Now it can be concluded that combining both systems only makes sense in high-density or young well isolated blocks, if heat is recovered only. With respect to multisourcing combining both systems is found to be insignificant. This is also the case when multisourcing is combined with recovery.

5. Case selection

In the previous chapter the model was evaluated, applying the Urban Harvest Approach, for a low- and a high-density block (Table 2). Now there are two cases selected which are located in Wageningen to show that the model, discussed in previous chapters, can be applied at existing blocks too.

5.1 Cases

Two existing blocks, which are located in Wageningen, are selected to show the feasibility of the developed models. These blocks are selected based on the following criteria and assumptions:

1. The buildings in a certain block should be good representatives of their building period.
2. Only blocks with dwelling houses are evaluated.
3. The two blocks have different building age and building type, as these factors are the most important to determine the gas and electricity demand (Schremmer et al., 2009).
4. There is no district heating applied at these blocks.

5.1.1 Jasmijnplantsoen – Drouwlaan – Bremlaan – Meidoornplantsoen

The first block is a residential building block of which part is built in the early fifties and part in 1990. Table 28 provides an overview of this block; more detailed information is presented in appendix D.

Table 28: Overview of the low-density block in Wageningen.

Street name	House numbers	Type of building	Building period
Bremlaan	1&3,5&7,9&11	Semi-detached	1989-2000
Drouwlaan	2&6, 8&12	Corner house	1946-1965
	4,10	Terraced house	1946-1965
Jasmijnplantsoen	2&4,6&8,10&12 14&16,18&20	Semi-detached	<1965
Meidoornplantsoen	21&23	Semi-detached	<1965
	25&27,29&31 33&35,37&39	Semi-detached	1989-2000

5.1.2 Hollandseweg – Nobelweg – Lorentzstraat – Van 't Hoffstraat

The second case is about a block located in the Bovenbuurt, northeast Wageningen. This block contains 3 apartment buildings built in 1963, and is thus a high-density block. Table 29 provides an overview of this block; more detailed information is presented in appendix D.

Table 29: Overview of the high-density block in Wageningen.

Street name	House numbers	Type of building	Building period
Hollandseweg	2-76,78-152,154-228	Apartment	<1965
Lorentzstraat	No buildings addressed Lorentzstraat built in block		
Nobelweg	No buildings addressed Nobelweg built in block		
Van 't Hoffstraat	No buildings addressed Van 't Hoffstraat built in block		

5.2 Inputs

Both cases are evaluated with use of the combined and mean indices (Tables 33 and 34) to investigate whether applying the Urban Harvest Approach, as applied in chapter 4, leads to some remarkable conclusions for the real cases.

To make sure that the differences between the cases from chapter 4 and the Wageningen cases can be explained the inputs are presented in tables 30, 31 and 32. Intermediate results are presented in appendix E.

Table 30: Overview of all general inputs at the Wageningen blocks.

			
General inputs	Variables	Block Jasmijnplantsoen	Block Hollandseweg
Total block area (m ²)	A _b	9901	14500
Number of building units per block	Bu	32	3
Number of households per building unit	Hhb	1	38
Household occupancy	Occ	4 ^a	2 ^b
Total block population	Tbp	128	228
House typology	-	Varies	Mid-rise apartment/maisonette flat
Roof type	-	Pitched ^c	Flat
Average horizontal roof area per building unit (m ²)	A _{rb}	41	899
Average net roof area per building unit (m ²)	A _{rbn}	49	899
Total horizontal roof area (m ²)	A _r	1297	2698
Total net roof area (m ²)	A _{rn}	1583	2698
Grey water system	-	Single house collection	Shared collection
Rain water collection	-	Single	Shared
Impervious – Pervious percentage	-	13 - 87%	19 - 81%

^a Two adults and two children. ^b Two adults full time working. ^c For a pitched roof a roof angle of 35° is assumed.

A comparison of Table 30 with its theoretical equivalent (Table 2) shows that for both the block 'Jasmijnplantsoen' as the block 'Hollandseweg' the total block area (A_b), the number of building units per block (Bu), the average horizontal roof area per building unit (A_{rb}) and the average net roof area per building unit (A_{rbn}) are increased. At the block 'Jasmijnplantsoen' it is found that the house typology now varies, with semi-detached buildings, corner houses and terraced houses and that the impervious-pervious percentage is slightly different. At the block 'Hollandseweg' the number of households per building unit (Hhb) is increased and the buildings are surrounded by a large green area.

As a result of these inputs, the total block population (Tbp), the total horizontal roof area (A_r) and the total net roof area (A_{rn}) are increased.

Table 31: Overview of all water inputs at the Wageningen blocks.

Water inputs	Variables	Block Jasmijnplantsoen	Block Hollandseweg
Initial shower demand per usage (l)	C_{WSo}	68.7	56.8
Initial toilet demand per usage (l)	C_{WTo}	5.74	5.75
Initial washing machine demand per usage (l)	C_{WWo}	55.6	55.6
Initial potable water demand (m^3 /year)	D_{WQ1o}	3350	5825
Initial non-potable water demand (m^3 /year)	D_{WQ2o}	2051	4502
Initial water demand (m^3 /year)	D_{Wo}	5401	10328
Evapotranspiration coefficient (-)	Et_c	0.38	0.38
Infiltration coefficient (-)	In_c	0.42	0.42
Runoff coefficient (-)	Ro_c	0.20	0.20
Yield of harvesting (-)	Y_h	0.72	0.64

With respect to the water inputs only the initial demands are changed comparing the block ‘Jasmijnplantsoen’ with the low-density block, this difference is caused by the change in total block population.

At the block ‘Hollandseweg’ the precipitation coefficient is changed too, compared with the high density block, due to the changed impervious-pervious percentage.

The initial demands per usage and the yield of harvesting are unaffected as at both blocks, which are assumed to be homogeneous, the household occupancies (Occ) and the roof type are unchanged.

Table 32: Overview of the energy inputs at the Wageningen blocks.

Energy inputs	Variables	Block Jasmijnplantsoen	Block Hollandseweg
Installations (Baseline Assessment)	-	Local gas heating	Central heating (IE-combi)
Initial electricity demand (MJ/year)	D_{EODo}	546066	1312254
Initial heat demand for warm potable water (MJ/year)	D_{HQ1o}	447088	1067998
Initial heat demand for spatial heating (MJ/year)	D_{HSHo}	1705555	4167735
Initial total energy demand (MJ/year)	D_{TEo}	2698709	6547987
External input of district heat (MJ/year)	El_H	0	0

The energy inputs of both blocks differs from the theoretical blocks as the total block population, the building periods (Table 28) and the useable floor area per household (UFA, Appendix D) are different with respect to the theoretical cases. At the block ‘Hollandseweg’ the collective central heating (IE-combi) is replaced by a central heating (IE-combi) system.

As the electricity demand is mainly dependent on the household occupancy, the initial electricity demands can be estimated well with the ratio of the total block population as the household occupancy is constant (e.g. demand low-density block/total block population low-density block*total block population block ‘Jasmijnplantsoen’ ($141840/32*128 = 567360$)).

The heat demand for warm potable water is found to be both dependent on the installation applied as the household occupancy. As at the block ‘Jasmijnplantsoen’ the installation is unaffected, the heat demand can be estimated in the way as the electricity demand. At the block ‘Hollandseweg’ the heat demand can be estimated with less accuracy, as correcting the first estimate (the method used for the electricity demand estimation) with the collective/single ratio of 2,02 from Appendix A gives a result of 887593 MJ/year ($1276698/162*228/(1276698/630658)$).

Estimating the initial heat demand for spatial heating is more difficult, as the building age and the building type are found to be the most important variables, and both variables are adapted in these Wageningen blocks from the theoretical cases. Therefore only a rough reasoning is given for both blocks. At the block 'Jasmijnplantsoen', the demand is increased as there are more buildings involved at this block and decreased as the buildings are not-freestanding. The building ages are both beneficial as disadvantageous as half of the building is younger and half is older. At the block 'Hollandseweg' all apartments are found to be older, compared with the theoretical high-density block, which increases the heat demand for spatial heating. The increased total block population and the decreased amount of apartments at the building centre (apartments not located at the roof, floor or corner) amplify this effect.

5.3 Results

With use of the inputs (section 5.2) and the Urban Harvest Approach applied exactly in the same manner as in chapter 4 the two Wageningen blocks are evaluated comparing the fourteen (water, energy (incl. electricity and heat self-sufficiency), merged and combined) indices (Table 33 and 34) with their equivalents (Tables 11, 18, 19, 24, 25, 26 and 27).

Table 33: Results of the block 'Jasmijnplantsoen'.

Evaluation		Block Jasmijnplantsoen				
Variables		BA	D	D+R	D+M	D+R+M
Water demand minimization index (-)	DMI _W	0	0.390	0.390	0.390	0.390
Water self-sufficiency index (-)	SSI _W	0	0	0.209	0.209	0.209
Water waste output index (-)	WOI _W	-1.293	-1.479	-1.270	-1.270	-1.270
Total energy demand minimization index (-)	DMI _{TE}	0	0.415	0.415	0.415	0.415
Total energy output index (-)	OI _{TE}	0	0	0	0	0
Total energy self-sufficiency index (-)	SSI _{TE}	0	0	0	0.474	0.474
Electricity self-sufficiency index (-)	SSI _E	0	0	0	0.161	0.161
Heat self-sufficiency index (-)	SSI _H	0	0	0	0.628	0.628
Mean demand minimization index (-)	DMI _M	0	0.402	0.402	0.402	0.402
Mean output index (-)	OI _M	-0.646	-0.740	-0.635	-0.635	-0.635
Mean self-sufficiency index (-)	SSI _M	0	0	0.105	0.342	0.342
Combined demand minimization index (-)	DMI _C	0	0.423	0.423	0.423	0.423
Combined output index (-)	OI _C	-0.646	-0.740	-0.635	-0.635	-0.635
Combined self-sufficiency index (-)	SSI _C	0	0	0.165	0.359	0.380

The comparison of the water indices of the block 'Jasmijnplantsoen' (Table 33) with their equivalents from Table 11 shows that both the demand minimization index as the self-sufficiency index remain equal. The water waste output index is slightly higher (the difference is less than 0.5%). These results are in accordance with the expectations:

1. The demand minimization index is unaffected as both the initial water demand as the actual water demand are increased by the total block population factor (the total block population at the block 'Jasmijnplantsoen'/the total block population at the low-density block).
2. The self-sufficiency index is unaffected as the ratio between both water demands (D_{WQ1} and D_{WQ2}) remains equal (see above). Thus the relative amount of water recycled remains the same. The amount of precipitation harvested is still able to fulfil the non-potable demand (D_{WQ2}).
3. The waste output index is changed as the runoff is adapted due to the changed block area. As the block area is less than 4 times (the total block population factor) increased, the

relative runoff is decreased. A decreased relative runoff gives, with a proportional domestic wastewater flow (DWW), a lower relative waste output. Thus the waste output index is increased (closer to 0).

A comparison of the energy indices shows that both the demand minimization indices as the self-sufficiency indices are different between both cases. As there are no energy outputs in this study the output indices remain 0. The demand minimization indices are different as the demands are different (section 5.2 Inputs). The ratio between the demand for spatial heating and the total energy demand is found to be the most important factor, as the demand for spatial heat is the best reducible.

The energy self-sufficiency depends on the roof area from which energy can be harvested. This area, considering the roof type (section 3.2.2 Block: Self-sufficiency units: Multisourcing), can be calculated with the roof conversion factor (CF_r). As the buildings at the block 'Jasmijnplantsoen' do have pitched roofs 50% cannot be used for energy collection. At the other half approx. 75% can be used for harvesting (Mulders, 2011a). As double glazed collectors are used for the multisourcing of heat, the heat yield is limited to the spatial heat demand, the remaining roof area is used for the collection of electricity using PV-cells. As long as the self-sufficiency of electricity is larger than 0, the heat self-sufficiency can be checked by the dividing the minimized heat demand for spatial heating by the minimized total heat demand. The total self-sufficiency index is checked by multiplication of the other self-sufficiency indices (for electricity and heat) with their corresponding demands. Thus the results are in line with the expectations.

As the mean indices are calculated from the energy and water indices, there is no need for any doubt about these numbers. The combined indices applied in this study only affect the energy balances by reducing the energy demand due to water demand reduction and by increasing the self-sufficiency due to heat recovery from water. If demand minimization is combined with multisourcing, the combined self-sufficiency index is increased (compared to the mean self-sufficiency index) due to the demand minimization, as the spatial heating demand is lower. As a consequence of this decreased demand the electricity production is increased. As the ratio of the water demands at both blocks is unaffected in this study, the effect of combining (comparing the mean with the combined indices) both models (the water and energy model) at the block 'Jasmijnplantsoen' is, as expected, comparable and thus small.

Table 34: Results of the block ‘Hollandseweg’.

Evaluation		Block Hollandseweg				
		BA	D	D+R	D+M	D+R+M
Variables						
Water demand minimization index (-)	DMI _W	0	0.359	0.359	0.359	0.359
Water self-sufficiency index (-)	SSI _W	0	0	0.229	0.208	0.229
Water waste output index (-)	WOI _W	-1.224	-1.350	-1.121	-1.141	-1.121
Total energy demand minimization index (-)	DMI _{TE}	0	0.505	0.505	0.505	0.505
Total energy output index (-)	OI _{TE}	0	0	0	0	0
Total energy self-sufficiency index (-)	SSI _{TE}	0	0	0	0.531	0.531
Electricity self-sufficiency index (-)	SSI _E	0	0	0	0.532	0.532
Heat self-sufficiency index (-)	SSI _H	0	0	0	0.531	0.531
Mean demand minimization index (-)	DMI _M	0	0.432	0.432	0.432	0.432
Mean output index (-)	OI _M	-0.612	-0.675	-0.561	-0.571	-0.561
Mean self-sufficiency index (-)	SSI _M	0	0	0.114	0.370	0.380
Combined demand minimization index (-)	DMI _C	0	0.444	0.444	0.444	0.444
Combined output index (-)	OI _C	-0.612	-0.675	-0.561	-0.571	-0.561
Combined self-sufficiency index (-)	SSI _C	0	0	0.174	0.383	0.412

Comparing the water indices of the block ‘Hollandseweg’ (Table 34) with the theoretical high-density block (Table 11), shows that the demand minimization index and the self-sufficiency index (except for the D+M scenario) are equal to each other. These indices are explained with the same arguments as used for the explanation of the differences between the block ‘Jasmijnplantsoen’ and the theoretical low-density block. The difference between the D+M self-sufficiencies stem from the fact that the amount of harvestable rainwater is lower than the demand for non-potable water. The different waste output indices can be explained by changes in both the runoffcoefficient (Ro_c), which is decreased from 0.55 at the low-density block to 0.2 at the block ‘Hollandseweg’, as the total block area (A_b), which is increased stronger than the total block population.

Due to the decreased runoffcoefficient the amount of waste production is decreased by a factor of 2.75 as infiltrated and evapotranspired water are not observed as waste outputs, but to the increased block area by a factor 5.8 the total outputs are increased. Thus the runoff is increased by more than 100%. Although the population is increased, this effect does not cancel the increased runoff; the waste output index is therefore decreased (becomes more negative).

The main difference between the energy indices is located in the demand minimization index, a difference which is caused by the different installations applied at the baseline assessment (collective central heating at the high-density block versus central heating at the low-density block). Comparing collective with central installations (Appendix A) shows that at collective installations there are improvements possible at both the heat demand for warm water as the heat demand for spatial heating. At the central installations the reduction in heat demand for warm water is found to be less.

As at the minimized cases the installation applied is local gas heating, the demand ratio’s become comparable (Appendix A). Thus the heat self-sufficiency indices are comparable. The electricity indices of both cases as more or less equal, this means that the ratio between the minimized total energy demand and the roof area is more or less equal. This is indeed the case (1256 at the block ‘Hollandseweg’ and 1159 at the high-density block).

The combined indices at the block ‘Hollandseweg’ are only in case of the demand minimization including recycling case, significantly different (difference is larger than 5%). This result was also observed at the high-density block.

6. Conclusion/Discussion

The objective of this report is to optimize the energy and water cycles at block level in a yearly balance for different building typologies, by looking at a system in which both cycles are combined.

Currently water is extracted from nature and delivered by (commercial) watercompanies towards households. This water can be characterised as safe and clean. Although there are many different water demands, which can be generalised in potable and non-potable water demands, this distinction is not made by the watercompanies. Thus much of the water currently delivered to the households is in fact too clean for its purpose. At two blocks located in Wageningen, the block 'Jasmijnplantsoen' and the block 'Hollandseweg', it is found that initially respectively 38% and 44% of the total water inputs from the watercompany are overqualified. Finally all used water leaves the houses immediately without recycling.

Factors affecting the water balances significantly are the ratio grey (impervious area) versus green (pervious area) land and the household occupancy. Other factors such as roof area (used for the collection of precipitation) are found to be less significant as the recycling potential is found to be large enough.

With respect to the water cycles it is found that the water demand can be reduced significantly by minimizing the water demand for showering, toilet flushing and mechanically washing of clothes. Combining all these techniques leads to a demand reduction of about 40%. Large households use relatively more water for showering, toilet flushing and washing; this reduction is fractionally higher at the low-density blocks. As both Wageningen blocks are assumed to be homogeneous too, with 2 or 4 people in each household, there are no differences between the demand minimization indices of the two fictional cases and the two Wageningen blocks.

The self-sufficiency of the water cycles is limited to approx. 20% as the potable demand is fulfilled from external water sources. As the roof area for harvesting the precipitation is limited at high-density blocks, it is found that water recycling leads to a slightly higher self-sufficiency index at these blocks. This difference is not found at the low-density blocks. Although a self-sufficiency of 20% is relatively low, this self-sufficiency can be improved by looking at larger scales (e.g. city level) as water treatment plants might be redesigned to water production sites, or by the investigation of non-conventional methods (techniques not considered in this study) for water treatment.

The waste outputs indices of both low-density blocks are almost equal, the waste output indices of the Jasmijnplantsoen are slightly higher as there is less block area per person available, which lowers the runoff per person. The high density blocks show larger differences, as the buildings located at the block 'Hollandseweg' have more green area surrounded; this increases the runoff per person, in spite of the changed distribution of the precipitation coefficients.

The current energy inputs are produced from oil or gas, which are limited resources. This report shows that the demand for these unsustainable resources can be reduced by approx. 70% at a low-density block such as the block 'Jasmijnplantsoen' and by more than 75% at a high-density block such as the block 'Hollandseweg'.

The total energy demand can be split in three groups, the electricity demand, the heat demand for warm water and the heat demand for spatial heating. Energy outputs were not considered in this research.

Evaluating the energy models makes clear that the demand can be reduced by more than 40%. At the Hollandseweg this percentage was found to be more than 50%. In all cases there are no energy outputs due to harvesting limitations. With respect to self-sufficiency approx. 50% of the total energy demand can be covered with renewable sources.

A comparison between the mean and the combined indices shows that only for the demand minimization and recycling/recovery scenarios the self-sufficiency indices can change significantly. The recovered energy potential per person depends on the household occupancy. This does not explain the difference between the theoretical low-density case and the Jasmijnplantsoen, with respect to the significance of the combined self-sufficiency in this scenario. This difference is explained from the combined total energy demand per person, which is lower at the Jasmijnplantsoen, due to the increased insulation levels of the new buildings.

For the other 4 scenarios (the baseline assessment, demand minimization, demand minimization with multisourcing and demand minimization with both recycling/recovery as multisourcing) the mean indices can be used quite accurate and these combined indices does not give any significant results at block scale, as the heat reduction due the water demand reduction contributes to only 5% on the total energy demand. The self-sufficiency in the D+R+M scenario is insignificant due to the shift in energy production from the solar panels, from heat production to electricity production.

The energy demand for water treatment, neglected in this study (section 4.4.1), makes an evaluation with the combined model even worse; it lowers the self-sufficiency and increases the demand.

As the best results can be obtained by both recycling as multisourcing water and energy, which can easily be observed comparing the combined self-sufficiency indices, it is concluded that the added value of the combined indices at block level at yearly basis is small for households at block level. As in this study both low- as high-density blocks were investigated it is not expected that this conclusion has to be adapted for other residential blocks.

As the combined system includes the energy needed for water treatment, the minimized heat demand for warm potable water (due to a decreased water demand) and heat recovery from used water, there is no added value of the combined indices expected if spatial and temporal variations are considered too. Only the value of heat recovery might decrease due to these variations, as the new supply might exceed the current energy demand for spatial heating. This lowers the value of the combined indices at block level. The only way at which this combined model might lead to an added value at a block is by the investigation of non-conventional methods, such as energy recovery from anaerobic digestion.

The development of a model at which water and energy cycles are combined however has to be viewed from a broader perspective. Considering industrial blocks, cities or other scales might lead to different conclusions with respect to a combined model. From that perspective the combined model might be a model with a larger potential.

Finally it should be mentioned that investigating situations at which the energy demand for water heating is relatively high, might lead to significant results in the combined system, as there is more heat to recover. Situations at which a water demand reduction leads to a significant energy demand reduction has to be investigated too. Finally it is found that the energy demand can increase significantly if the energy for treatment cannot be neglected anymore; this is the case when treatable water is heavily polluted or when the amounts of treatable water are that large that pumping have to be considered.

Bibliography

- AGUDELO-VERA, C. M., KEESMAN, K. J., MELS, A. R. & RIJNAARTS, H. H. M. 2012b. Evaluating the potential of improving the residential water cycle at building level.
- AGUDELO-VERA, C. M., KEESMAN, K. J., MELS, A. R. & RIJNAARTS, H. H. M. 2012c. Evaluating the potential of improving the residential water cycles at city block scale.
- AGUDELO-VERA, C. M., MELS, A. R., KEESMAN, K. J. & RIJNAARTS, H. H. M. 2011. Resource management as a key factor for sustainable urban planning. *Journal of Environmental Management*, 92, 2295-2303.
- AGUDELO-VERA, C. M., MELS, A. R., KEESMAN, K. J. & RIJNAARTS, H. H. M. 2012a. The Urban Harvest Approach as an aid for Sustainable Urban Resource Planning. *Journal of Industrial Ecology*.
- ARNOLD JR, C. L. & GIBBONS, C. J. 1996. Impervious surface coverage: The emergence of a key environmental indicator. *Journal of the American Planning Association*, 62, 243-258.
- BLOM, J., TELKAMP, P., SUKKAR, G. & WIT, D. G. 2010. Energie in de waterketen.
- DEWULF, J., VAN LANGENHOVE, H., MUYS, B., BRUERS, S., BAKSHI, B. R., GRUBB, G. F., PAULUS, D. M. & SCIUBBA, E. 2008. Exergy: Its Potential and Limitations in Environmental Science and Technology. *Environmental Science & Technology*, 42, 2221-2232.
- EDUGIS. 2012. Available: www.edugis.nl [Accessed 01-05 2012].
- EEA, E. E. A. 2009. Ensuring quality of life in Europe's cities and towns. . *Tackling the environmental challenges driven by European and global change*.
- FOEKEMA, H. & VAN THIEL, L. 2011. Watergebruik thuis 2010. Available: www.vewin.nl [Accessed 23-07 2012]
- GIRARDIN, L., MARECHAL, F., DUBUIS, M., CALAME-DARBELLAY, N. & FAVRAT, D. 2010. EnerGis: A geographical information based system for the evaluation of integrated energy conversion systems in urban areas. *Energy*, 35, 830-840.
- GOETZBERGER, A. & HOFFMANN, V. 2005. *Photovoltaic solar energy generation*, Freiburg, Springer.
- GOLIĆ, K., KOSORIĆ, V. & FURUNDŽIĆ, A. K. 2011. General model of solar water heating system integration in residential building refurbishment—Potential energy savings and environmental impact. *Renewable and Sustainable Energy Reviews*, 15, 1533-1544.
- GROSSMANN, I. E. & MARTÍN, M. 2010. Energy and Water Optimization in Biofuel Plants. *Chinese Journal of Chemical Engineering*, 18, 914-922.
- HABITAT, U. N. C. F. H. S. 2008. State of the World's Cities 2008/2009 Harmones Cities. XIV.
- HASHIMOTO, S. & MORIGUCHI, Y. 2004. Proposal of six indicators of material cycles for describing society's metabolism: from the viewpoint of material flow analysis. *Resources, Conservation and Recycling*, 40, 185-200.
- HIREMATH, R. B., SHIKHA, S. & RAVINDRANATH, N. H. 2007. Decentralized energy planning; modeling and application-a review. *Renewable and Sustainable Energy Reviews*, 11, 729-752.
- KALOGIROU, S. A. 2004. Solar thermal collectors and applications. *Progress in Energy and Combustion Science*, 30, 231-295.
- KNMI. 2010. *Norm Neerslag* [Online]. Available: www.knmi.nl [Accessed 14-11 2011].
- LI, F., WICHMANN, K. & OTTERPOHL, R. 2009. Review of the technological approaches for grey water treatment and reuses. *Science of the Total Environment*, 407, 3439-3449.
- LIU, Q., YU, G. & LIU, J. J. 2009. Solar radiation as large-scale resource for energy-short world. *Energy and Environment*, 20, 319-329.
- MULDERS, G. 2011a. Urban Solar Energy in Wageningen; Supply and demand of solar energy.
- MULDERS, G. 2011b. Appendix: Urban Solar Energy in Wageningen; Supply and demand of solar energy.

- PEDERSEN, L., STANG, J. & ULSETH, R. 2008. Load prediction method for heat and electricity demand in buildings for the purpose of planning for mixed energy distribution systems. *Energy and Buildings*, 40, 1124-1134.
- ROBERTS, L. 2011. 9 Billion? *Science*, 333, 540-543.
- RUBIN, M. 1982. Calculating heat transfer through windows. *International Journal of Energy Research*, 6, 341-349.
- SCHREMMER, C. E. A. 2009. Urban development and urban metabolism: A spatial approach. *SUME-Sustainable Urban Metabolism in Euroipe (FP7)*.
- SETERNOVEM 2006. Referentiewoningen nieuwbouw. Arnhem: DGMR Bouw BV.
- SETERNOVEM. 2010. *Energiebesparingsverkenner* [Online]. Available: www.energiebesparingsverkenner.nl [Accessed 01-05 2012].
- SHARMA, A., BURN, S., GARDNER, T. & GREGORY, A. 2010. Role of decentralised systems in the transition of urban water systems. *Water Science and Technology: Water Supply* 10, 577-583.
- SØRENSEN, B. 2008. A sustainable energy future: Construction of demand and renewable energy supply scenarios. *International Journal of Energy Research*, 32, 436-470.
- STREMKE, S. 2010. *Designing sustainable energy landscapes: concepts, principles and procedures*.
- STRUCHINER, L. G. 2011. *Designing the circular metabolic building; The case of Biotope in the Sunrise Campus*. Wageningen University.
- TIPSOMTEBESPAREN.NL. 2012. *Koken op gas* [Online]. Available: www.tipsomtebesparen.nl [Accessed 09-03 2012].
- VAN NOPPEN, B. F. J. & VERLINDEN, H. L. F. 1998. *Woningen* [Online]. Available: www.cbs.nl [Accessed 24-02 2012].
- VERSTRAETE, W. & VLAEMINCK, S. E. 2011. ZeroWasteWater: short-cycling of wastewater resources for sustainable cities of the future. *International Journal of Sustainable Development & World Ecology*, 18, 253-264.
- VROM 2003. Het nieuwe waterleidingbesluit; Gevolgen voor eigenaren van collectieve leidingwater-installaties
- WATER4ALL. 2007. *Regenwater, een duurzame oplossing* [Online]. Available: www.water4all.be [Accessed 22-02 2012].
- WCED 1987. Our common future. *World Farmers' Times*, 2, 4-9.

Appendix A: Energy demand tables

Case 1: Low-density block

Table A1: Overview of the minimized energy demand (incl. baseline assessment) at a low-density block (<1965).

<1965	Baseline Assessment (HE-combi)	Local gas heating	HE-combi	HEe	IE-combi incl. tank less heater
D _E (MJ/year)	145526	134525	145526	116813	142589
D _{HQ1} (MJ/year)	92671	100014	92671	92671	100014
D _{HSH} (MJ/year)	880630	304093	305359	334730	362582
D _{TE} (MJ/year)	1118827	538632	543557	544214	605185

Table A2: Overview of the minimized energy demand (incl. baseline assessment) at a low-density block (1966-1975).

1966-1975	Baseline Assessment (IE-combi)	Local gas heating	HE-combi	HEe	IE-combi incl. tank less heater
D _E (MJ/year)	141840	133805	144634	116064	141840
D _{HQ1} (MJ/year)	113434	100014	92671	92671	100014
D _{HSH} (MJ/year)	705415	297763	300042	329160	356252
D _{TE} (MJ/year)	960689	531582	537347	537895	598106

Table A3: Overview of the minimized energy demand (incl. baseline assessment) at a low-density block (1976-1988).

1976-1988	Baseline Assessment (IE-combi)	Local gas heating	HE-combi	HEe	IE-combi incl. tank less heater
D _E (MJ/year)	141840	133805	144634	119117	141840
D _{HQ1} (MJ/year)	113434	100014	92671	92671	100014
D _{HSH} (MJ/year)	592741	258011	264847	290927	314728
D _{TE} (MJ/year)	848015	491830	502152	502715	556582

Table A4: Overview of the minimized energy demand (incl. baseline assessment) at a low-density block (1989-2000).

1989-2000	Baseline Assessment (HE-combi)	Local gas heating	HE-combi	HEe	IE-combi incl. tank less heater
D _E (MJ/year)	163786	152698	163786	137088	160992
D _{HQ1} (MJ/year)	92671	100014	92671	92671	100014
D _{HSH} (MJ/year)	320045	271430	276748	303840	328654
D _{TE} (MJ/year)	576502	524142	533204	533599	589660

Table A5: Overview of the minimized energy demand (incl. baseline assessment) at a low-density block (2001-Present).

2001-Present	Baseline Assessment (HE-combi)	Local gas heating	HE-combi	HEe	IE-combi incl. tank less heater
D _E (MJ/year)	179222	168134	179222	161366	176429
D _{HQ1} (MJ/year)	92671	100014	92671	92671	100014
D _{HSH} (MJ/year)	178253	161795	178253	196230	211675
D _{TE} (MJ/year)	450146	429943	450146	450268	488118

Case 2: High-density block

Table A6: Overview of the minimized energy demand (incl. baseline assessment) at a high-density block (<1965).

<1965	Baseline Assessment (Local gas heating)	Local gas heating	HE-combi	HEe	Col. HE-combi	Col. HE-combi incl. tank less heater	Col. HE-combi incl. elec. boiler
D_E (MJ/year)	893462	893462	971611	891443	962863	962863	1449252
D_{HQ1} (MJ/year)	669113	669113	630658	630658	1276698	669113	0
D_{HSH} (MJ/year)	2404134	688483	759410	838693	802517	802517	802517
D_{TE} (MJ/year)	3966709	2251058	2361679	2360794	3042078	2434493	2251769

Table A7: Overview of the minimized energy demand (incl. baseline assessment) at a high-density block (1966-1975).

1966-1975	Baseline Assessment (Col. IE-combi)	Local gas heating	HE-combi	HEe	Col. HE-combi	Col. HE-combi incl. tank less heater	Col. HE-combi incl. elec. boiler
D_E (MJ/year)	979776	909209	990565	902416	979776	979776	1466165
D_{HQ1} (MJ/year)	1276698	669113	630658	630658	1276698	669113	0
D_{HSH} (MJ/year)	1737015	751814	833946	920730	880282	880282	879902
D_{TE} (MJ/year)	3993489	2330136	2455169	2453804	3136755	2529170	2346066

Table A8: Overview of the minimized energy demand (incl. baseline assessment) at a high-density block (1976-1988).

1976-1988	Baseline Assessment (Col. IE-combi)	Local gas heating	HE-combi	HEe	Col. HE-combi	Col. HE-combi incl. tank less heater	Col. HE-combi incl. elec. boiler
D_E (MJ/year)	979776	909209	990565	910440	979776	979776	1466165
D_{HQ1} (MJ/year)	1276698	669113	630658	630658	1276698	669113	0
D_{HSH} (MJ/year)	1488246	669967	758081	836699	799384	799574	799384
D_{TE} (MJ/year)	3744720	2248289	2379304	2377797	3055858	2448463	2265549

Table A9: Overview of the minimized energy demand (incl. baseline assessment) at a high-density block (1989-2000).

1989-2000	Baseline Assessment (HE-combi)	Local gas heating	HE-combi	HEe	Col. HE-combi	Col. HE-combi incl. tank less heater	Col. HE-combi incl. elec. boiler
D_E (MJ/year)	1066090	987941	1066090	985943	1052676	1052676	1539065
D_{HQ1} (MJ/year)	630658	669113	630658	630658	1276698	669113	0
D_{HSH} (MJ/year)	972573	669303	757796	835940	799099	799479	799099
D_{TE} (MJ/year)	2669320	2326356	2454543	2452541	3128473	2521268	2338164

Table A10: Overview of the minimized energy demand (incl. baseline assessment) at a high-density block (2001-Present).

2001-Present	Baseline Assessment (HE-combi)	Local gas heating	HE-combi	HEe	Col. HE-combi	Col. HE-combi incl. tank less heater	Col. HE-combi incl. elec. boiler
D_E (MJ/year)	1140739	1062882	1140739	1111082	1127617	1127617	1614006
D_{HQ1} (MJ/year)	630658	669113	630658	630658	1276698	669113	0
D_{HSH} (MJ/year)	282381	212973	282381	311626	297004	297953	297004
D_{TE} (MJ/year)	2053778	1944968	2053778	2053366	2701319	2094683	1911010

Block Jasmijnplantsoen:

Table A11: Overview of the minimized energy demand (incl. baseline assessment) at the block Jasmijnplantsoen.

Jasmijnplantsoen	Baseline Assessment (Local gas heating)	Local gas heating	HE-combi	HEe
D_E (MJ/year)	546066	553122	484538	519224
D_{HQ1} (MJ/year)	447088	365558	365558	394359
D_{HSH} (MJ/year)	1705555	680823	749820	664618
D_{TE} (MJ/year)	2698709	1599503	1599916	1578202

Block Hollandseweg:

Table A12: Overview of the minimized energy demand (incl. baseline assessment) at the block Hollandseweg.

Hollandseweg	Baseline Assessment (IE-combi)	Local gas heating	HE-combi	HEe	Col. HE-combi incl. elec. boiler
D_E (MJ/year)	1312254	1231265	1330517	1207343	1995700
D_{HQ1} (MJ/year)	1067998	941714	887593	887593	0
D_{HSH} (MJ/year)	4167735	1065909	1169594	1291320	1234065
D_{TE} (MJ/year)	6547987	3238888	3387704	3386255	3229765

Appendix B: Insulation levels in Energiebesparingsverkenner

Table B1: Overview of the roof insulation levels in the Energiebesparingsverkenner.

Roof insulation	No insulation		Moderate insulation		Good insulation	
	Building age	Insulation thickness (cm)	Rc-value (m ² K/W)	Insulation thickness (cm)	Rc-value (m ² K/W)	Insulation thickness (cm)
< 1966	0	0.22	3	0.97	8	2.22
1966-1975	0	0.22	3	0.97	8	2.22
1976-1988	0	0.22	5	1.47	10	2.72
> 1988	-	-	5	1.47	10	2.72

Table B2: Overview of the outer wall insulation levels in the Energiebesparingsverkenner.

Outer wall insulation	No insulation		Moderate insulation		Good insulation	
	Building age	Insulation thickness (cm)	Rc-value (m ² K/W)	Insulation thickness (cm)	Rc-value (m ² K/W)	Insulation thickness (cm)
< 1966	0	0.36	5	1.61	8	2.36
1966-1975	0	0.36	5	1.61	8	2.36
1976-1988	0	0.36	7	2.11	8	2.36
> 1988	-	-	5	1.61	10	2.86

Table B3: Overview of the floor insulation levels in the Energiebesparingsverkenner.

Floor insulation	No insulation		Moderate insulation		Good insulation	
	Building age	Insulation thickness (cm)	Rc-value (m ² K/W)	Insulation thickness (cm)	Rc-value (m ² K/W)	Insulation thickness (cm)
< 1966	0	0.15	3	0.90	8	2.15
1966-1975	0	0.15	3	0.90	8	2.15
1976-1988	0	0.15	5	1.40	10	2.65
> 1988	-	-	5	1.40	10	2.65

Appendix C: Window types in Energiebesparingsverkenner

Table C1: Overview of the window types in the Energiebesparingsverkenner.

Window type	Heat transfer coefficient (W/m ² K)
Single glazing (Rubin, 1982)	6.0
Insulated glazing	2.8
HR++ glazing	1.2

Appendix D: Detailed overview of both selected blocks

Table D1: Overview of all residential buildings at the block Jasmijnplantsoen – Drouwlaan – Bremlaan – Meidoornplantsoen.

Address	Building type	Building period ^{D1}	Postal code 5	Cadastral area (m ²) ^{D1}	UFA (m ²) ^{D1}	Energy label ^{D1}
Bremlaan 1	Semi-detached	1989-2000	6706 D	435	119	Unknown
Bremlaan 3	Semi-detached	1989-2000	6706 D	565	133	Unknown
Bremlaan 5	Semi-detached	1989-2000	6706 D	550	119	Unknown
Bremlaan 7	Semi-detached	1989-2000	6706 D	530	119	Unknown
Bremlaan 9	Semi-detached	1989-2000	6706 D	515	159	Unknown
Bremlaan 11	Semi-detached	1989-2000	6706 D	655	127	Unknown
Drouwlaan 2	Corner house	<1965	6706 D	1268	90	G
Drouwlaan 4	Terraced house	<1965	6706 D		90	E
Drouwlaan 6	Corner house	<1965	6706 D		90	E
Drouwlaan 8	Corner house	<1965	6706 D		90	F
Drouwlaan 10	Terraced house	<1965	6706 D		90	D
Drouwlaan 12	Corner house	<1965	6706 D		90	E
Jasmijnplantsoen 2	Semi-detached	<1965	6706 D	958	98	G
Jasmijnplantsoen 4	Semi-detached	<1965	6706 D		93	E
Jasmijnplantsoen 6	Semi-detached	<1965	6706 D		93	E
Jasmijnplantsoen 8	Semi-detached	<1965	6706 D		93	G
Jasmijnplantsoen 10	Semi-detached	<1965	6706 D		108	F
Jasmijnplantsoen 12	Semi-detached	<1965	6706 D	1490	92	G
Jasmijnplantsoen 14	Semi-detached	<1965	6706 D		92	G
Jasmijnplantsoen 16	Semi-detached	<1965	6706 D		92	E
Jasmijnplantsoen 18	Semi-detached	<1965	6706 D		92	G
Jasmijnplantsoen 20	Semi-detached	<1965	6706 D		92	G
Meidoornplantsoen 21	Semi-detached	<1965	6706 D	255	143	Unknown
Meidoornplantsoen 23	Semi-detached	<1965	6706 D	255	105	Unknown
Meidoornplantsoen 25	Semi-detached	1989-2000	6706 D	430	141	Unknown
Meidoornplantsoen 27	Semi-detached	1989-2000	6706 D	310	120	Unknown
Meidoornplantsoen 29	Semi-detached	1989-2000	6706 D	270	120	Unknown
Meidoornplantsoen 31	Semi-detached	1989-2000	6706 D	275	129	Unknown
Meidoornplantsoen 33	Semi-detached	1989-2000	6706 D	275	120	Unknown
Meidoornplantsoen 35	Semi-detached	1989-2000	6706 D	275	120	Unknown
Meidoornplantsoen 37	Semi-detached	1989-2000	6706 D	275	120	Unknown
Meidoornplantsoen 39	Semi-detached	1989-2000	6706 D	315	120	Unknown

Table D2: Overview of all residential buildings at the block Hollandseweg – Nobelweg – Lorentzstraat – Van 't Hoffstraat.

Address	Building type	Location	Building period ^{D1}	Postal code	Cadastral area (m ²) ^{D1}	UFA (m ²) ^{D1}	Energy label ^{D1}
Hollandseweg 2	Maisonette	First floor, Corner	<1965	6706 K	Unknown	78	F
Hollandseweg 4	Maisonette	First floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 6	Maisonette	First floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 8	Maisonette	First floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 10	Maisonette	First floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 12	Maisonette	First floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 14	Maisonette	First floor, Corner	<1965	6706 K	Unknown	78	F
Hollandseweg 16	Maisonette	Third floor, Corner	<1965	6706 K	Unknown	78	F
Hollandseweg 18	Maisonette	Third floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 20	Maisonette	Third floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 22	Maisonette	Third floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 24	Maisonette	Third floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 26	Maisonette	Third floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 28	Maisonette	Third floor, Corner	<1965	6706 K	Unknown	78	F
Hollandseweg 30	Apartment	First floor, Terraced	<1965	6706 K	Unknown	40	F
Hollandseweg 32	Apartment	First floor, Terraced	<1965	6706 K	Unknown	40	F
Hollandseweg 34	Apartment	First floor, Terraced	<1965	6706 K	Unknown	40	F
Hollandseweg 36	Apartment	First floor, Terraced	<1965	6706 K	Unknown	40	F
Hollandseweg 38	Apartment	First floor, Terraced	<1965	6706 K	Unknown	40	F
Hollandseweg 40	Maisonette	Second floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 42	Maisonette	Second floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 44	Maisonette	Second floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 46	Maisonette	Second floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 48	Maisonette	Second floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 50	Maisonette	First floor, Corner	<1965	6706 K	Unknown	78	F
Hollandseweg 52	Maisonette	First floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 54	Maisonette	First floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 56	Maisonette	First floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 58	Maisonette	First floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 60	Maisonette	First floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 62	Maisonette	First floor, Corner	<1965	6706 K	Unknown	78	F
Hollandseweg 64	Maisonette	Third floor, Corner	<1965	6706 K	Unknown	78	F
Hollandseweg 66	Maisonette	Third floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 68	Maisonette	Third floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 70	Maisonette	Third floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 72	Maisonette	Third floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 74	Maisonette	Third floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 76	Maisonette	Third floor, Corner	<1965	6706 K	Unknown	78	F
Hollandseweg 78	Maisonette	First floor, Corner	<1965	6706 K	Unknown	78	F
Hollandseweg 80	Maisonette	First floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 82	Maisonette	First floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 84	Maisonette	First floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 86	Maisonette	First floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 88	Maisonette	First floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 90	Maisonette	First floor, Corner	<1965	6706 K	Unknown	78	F
Hollandseweg 92	Maisonette	Third floor, Corner	<1965	6706 K	Unknown	78	F
Hollandseweg 94	Maisonette	Third floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 96	Maisonette	Third floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 98	Maisonette	Third floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 100	Maisonette	Third floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 102	Maisonette	Third floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 104	Maisonette	Third floor, Corner	<1965	6706 K	Unknown	78	F
Hollandseweg 106	Apartment	First floor, Terraced	<1965	6706 K	Unknown	40	F
Hollandseweg 108	Apartment	First floor, Terraced	<1965	6706 K	Unknown	40	F
Hollandseweg 110	Apartment	First floor, Terraced	<1965	6706 K	Unknown	40	F
Hollandseweg 112	Apartment	First floor, Terraced	<1965	6706 K	Unknown	40	F
Hollandseweg 114	Apartment	First floor, Terraced	<1965	6706 K	Unknown	40	F
Hollandseweg 116	Maisonette	Second floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 118	Maisonette	Second floor, Terraced	<1965	6706 K	Unknown	78	F
Hollandseweg 120	Maisonette	Second floor, Terraced	<1965	6706 K	Unknown	78	F

Appendix E: Detailed overview of the intermediate results of both Wageningen blocks

Table E1: Overview of the water outputs at the block 'Jasmijnplantsoen'.

Evaluation		Block Jasmijnplantsoen				
Variables		BA	D	D+R	D+M	D+R+M
Actual water demand (m ³ /year)	D _w	5401	3297	3297	3297	3297
Water resources harvested (m ³ /year)	RH _w	0	0	690	690	690
Water waste outputs (m ³ /year)	WO _w	6981	4877	4187	4187	4187

Table E2: Overview of the water outputs at the block 'Hollandseweg'.

Evaluation		Block Hollandseweg				
Variables		BA	D	D+R	D+M	D+R+M
Actual water demand (m ³ /year)	D _w	10328	6619	6619	6619	6619
Water resources harvested (m ³ /year)	RH _w	0	0	1513	1378	1513
Water waste outputs (m ³ /year)	WO _w	12642	8933	7420	7555	7420

Table E3: Overview of the energy outputs at the block 'Jasmijnplantsoen'.

Evaluation		Block Jasmijnplantsoen				
Variables		BA	D	D+R	D+M	D+R+M
Installation applied	-	Central heating (IE-combi)	Local gas heating	Local gas heating	Local gas heating	Local gas heating
Actual total energy demand (MJ/year)	D _{TE}	2698709	1578202	1578202	1578202	1578202
Total energy resources harvested (MJ/year)	RH _{TE}	0	0	0	748439	748439
Total energy outputs (MJ/year)	O _{TE}	0	0	0	0	0

Table E4: Overview of the energy outputs at the block 'Hollandseweg'.

Evaluation		Block Hollandseweg				
Variables		BA	D	D+R	D+M	D+R+M
Installation applied	-	Central heating (IE-combi)	Local gas heating	Local gas heating	Local gas heating	Local gas heating
Actual total energy demand (MJ/year)	D _{TE}	6547987	3238888	3238888	3238888	3238888
Total energy resources harvested (MJ/year)	RH _{TE}	0	0	0	1721186	1721186
Total energy outputs (MJ/year)	O _{TE}	0	0	0	0	0

Table E5: Overview of the combined outputs of both blocks.

Combined outputs	Variables	Block Jasmijnplantsoen	Block Hollandseweg
Initial energy demand for water treatment (MJ/year)	D _{HTo}	0	0
Initial energy demand (excl. water treatment) (MJ/year)	D _{TEoC}	2698709	6547987
Minimized heat demand for warm potable water (MJ/year)	D _{HQ1minC}	285668	1067998
Minimized heat demand for spatial heating (MJ/year)	D _{HSHminC}	664618	4167735
Minimized total energy demand (MJ/year)	D _{TEminC}	1469510	6547987

Appendix F: List of all Word variables

Table F1: List of all variables used in Word.

Variables used in Word		
Variable	Variable name	Unit
α	Roof slope	$^{\circ}$
A_b	Total block area	m^2
A_{empt}	Empty roof area	m^2
A_r	Total roof area available for harvesting	m^2
A_{rb}	Roof area of a building unit	m^2
A_{rbn}	Net roof area of a building unit	m^2
A_{rn}	Net roof area	m^2
A_{rs}	Shadowed roof area	m^2
A_{EG}	Roof area used for electricity generators	m^2
A_{EGC}	Roof area used for electricity generators in combined system	m^2
A_{Hg}	Roof area used for heat generators	m^2
A_{HgC}	Roof area used for heat generators in combined system	m^2
B_u	Number of building units in the block	-
C_{WSmin}	Minimized water demand shower per usage	l
C_{WSo}	Initial water demand shower per usage	l
C_{WTmin}	Minimized water demand toilet per usage	l
C_{WTo}	Initial water demand toilet per usage	l
C_{WWmin}	Minimized water demand washing machine per usage	l
C_{WWo}	Initial water demand washing machine per usage	l
CF_r	Conversion factor roof	-
CF_{Q1}	Combined factor potable water	-
D	Actual demand	Varies
D_o	Initial demand	Varies
D_c	Actual energy demand for cooking	MJ/year
D_E	Actual electricity demand	MJ/year
D_{EC}	Actual electricity demand for cooking	MJ/year
D_{EOD}	Actual electricity demand for other electrical devises	MJ/year
D_{EODmin}	Minimized electricity demand for other electrical devises	MJ/year
$D_{EODminC}$	Combined minimized electricity demand for other electrical devises	MJ/year
D_{EODo}	Initial electricity demand for other electrical devises	MJ/year
D_{EQ2}	Actual electricity demand for heating water	MJ/year
D_{EWD}	Actual electricity demand for waterless electrical devises	MJ/year
D_{GC}	Actual gas demand for cooking	MJ/year
D_H	Actual heat demand (incl. gas)	MJ/year
D_{HQ1}	Actual heat demand for warm potable water	MJ/year
D_{HQ1min}	Minimized heat demand for warm potable water	MJ/year
$D_{HQ1minC}$	Combined minimized heat demand for warm potable water	MJ/year
D_{HQ1o}	Initial heat demand for warm potable water	MJ/year
D_{HSH}	Actual heat demand for spatial heating	MJ/year
D_{HSHmin}	Minimized heat demand for spatial heating	MJ/year
$D_{HSHminC}$	Combined minimized heat demand for spatial heating	MJ/year
D_{HSHo}	Initial heat demand for spatial heating	MJ/year
D_{HT}	Actual heat demand for water treatment	MJ/year
D_{HTo}	Initial heat demand for water treatment	MJ/year
D_{TE}	Actual total energy demand	MJ/year
D_{TEC}	Combined actual total energy demand	MJ/year
D_{TEmin}	Minimized total energy demand	MJ/year
D_{TEminC}	Combined minimized total energy demand	MJ/year
D_{TEo}	Initial total energy demand	MJ/year
D_{TEoC}	Combined initial total energy demand	MJ/year
D_W	Actual water demand	m^3 /year
D_{WC}	Combined actual water demand	m^3 /year
D_{Wmin}	Minimized water demand	m^3 /year
D_{Wo}	Initial water demand	m^3 /year
D_{Woc}	Combined initial water demand	m^3 /year

D _{WQ1}	Actual potable water demand	m ³ /year
D _{WQ1min}	Minimized potable water demand	m ³ /year
D _{WQ1minC}	Combined minimized potable water demand	m ³ /year
D _{WQ1o}	Initial potable water demand	m ³ /year
D _{WQ2}	Actual non-potable water demand	m ³ /year
D _{WQ2min}	Minimized non-potable water demand	m ³ /year
D _{WQ2minC}	Combined minimized non-potable water demand	m ³ /year
D _{WQ2o}	Initial non-potable water demand	m ³ /year
D _{WS}	Actual water demand for shower	m ³ /year
D _{WSmin}	Minimized water demand for shower	m ³ /year
D _{WSo}	Initial water demand for shower	m ³ /year
D _{WTmin}	Minimized water demand for toilet	m ³ /year
D _{WTo}	Initial water demand for toilet	m ³ /year
D _{WW}	Actual water demand for washing machine	m ³ /year
D _{WWmin}	Minimized water demand for washing machine	m ³ /year
D _{WWo}	Initial water demand for washing machine	m ³ /year
DMI	Demand minimization index	-
DMI _C	Combined demand minimization index	-
DMI _M	Mean demand minimization index	-
DMI _{TE}	Total energy demand minimization index	-
DMI _W	Water demand minimization index	-
DWW	Flow of domestic wastewater	m ³ /year
DWW _{Q1}	Flow of domestic wastewater from potable water demand	m ³ /year
DWW _{Q1ut}	Flow of untreatable domestic wastewater from potable water demand (excl. overflow)	m ³ /year
DWW _{Q2}	Flow of domestic wastewater from non-potable water demand	m ³ /year
E _{Eh}	Efficiency of the electricity heater	-
E _{Es}	Efficiency of the electricity storage unit	-
E _{Gh}	Efficiency of the gas heater	-
E _{Hr}	Heat recovery efficiency of the heat recovery unit	-
E _{Hs}	Efficiency of the heat storage unit	-
E _t	Evapotranspired precipitation	m ³ /year
E _{t_c}	Evapotranspiration coefficient	-
EC _O	Energy content of other gas heated water flows	MJ
EC _S	Energy content of shower water	MJ
EC _T	Total energy content all gas heated water streams	MJ
EC _{WS}	Energy concentration of shower water	MJ/m ³
EC _{WW}	Energy concentration of washing machine water	MJ/m ³
EI	Total external input of water	m ³ /year
E _E	External input of electricity from supplier	MJ/year
E _G	External input of gas from supplier	MJ/year
E _{Gh}	External input of gas from supplier to heater	MJ/year
E _{GC}	External input of gas from supplier used for cooking	MJ/year
E _H	External input of district heat	MJ/year
E _{Q1}	External inputs to fulfil potable water demand	m ³ /year
E _{Q2}	External inputs to fulfil non-potable water demand	m ³ /year
H _{Eh}	Heat obtained from electricity heater	MJ/year
H _{Gh}	Heat obtained from gas heater	MJ/year
H _{hb}	Amount of households per building unit	-
HC _C	Heat consumption from cooking	MJ/year
HC _{Eg}	Heat consumption from electricity generator	MJ/year
HC _{Eh}	Heat consumption from electricity heater	MJ/year
HC _{Es}	Heat consumption from electricity storage unit	MJ/year
HC _{EOD}	Heat consumption from other electrical devises	MJ/year
HC _{EQ2}	Heat consumption from electrical heated water	MJ/year
HC _{EWD}	Heat consumption from waterless electrical devises	MJ/year
HC _{Gh}	Heat consumption from gas heater	MJ/year
HC _{Hg}	Heat consumption from heat generator	MJ/year
HC _{Hr}	Heat consumption from heat recovery unit	MJ/year
HC _{Hs}	Heat consumption from heat storage unit	MJ/year
HC _{HQ1}	Heat consumption from potable warm water	MJ/year
HC _{HSH}	Heat consumption from spatial heat	MJ/year
HC _{HT}	Heat consumption from wastewater treatment	MJ/year
HC _{TE}	Total heat consumption	MJ/year
HC _{TEg}	Total heat consumption in generation units	MJ/year

HC _{TEh}	Total heat consumption in heating units	MJ/year
HC _{TEr}	Total heat consumption in recovery units	MJ/year
HC _{TEs}	Total heat consumption in storage units	MJ/year
HC _{TEu}	Total heat consumption after energy usage	MJ/year
I _{Eh}	Input of electricity to heater	MJ/year
I _{EC}	Input of electricity used for cooking	MJ/year
I _{EOD}	Input of electricity used for other electrical devises	MJ/year
I _{EQ2}	Input of electricity used for water heating	MJ/year
I _{EWD}	Input of electricity used for waterless devises	MJ/year
I _{HQ1}	Input of heat used for heating potable water	MJ/year
I _{HSH}	Input of heat used for spatial heating (excl. recovery)	MJ/year
I _{HT}	Input of heat used for water treatment	MJ/year
In	Infiltrated precipitation	m ³ /year
In _c	Infiltration coefficient	-
K	Treatment capacity treatment unit S ₂	m ³ /year
M _{har}	Harvested water multisourcing	m ³ /year
M _{pot}	Potential water multisourcing	m ³ /year
M _E	Actual electricity multisourcing	MJ/year
M _{EC}	Combined actual electricity multisourcing	MJ/year
M _{Ehar}	Harvested electricity multisourcing	MJ/year
M _{Eharp}	Harvesting potential electricity multisourcing	MJ/year
M _{Epot}	Potential electricity multisourcing	MJ/year
M _H	Actual heat multisourcing	MJ/year
M _{HC}	Combined actual heat multisourcing	MJ/year
M _{Hhar}	Harvested heat multisourcing	MJ/year
M _{Hharp}	Harvesting potential heat multisourcing	MJ/year
M _{Hpot}	Potential heat multisourcing	MJ/year
M _{TE}	Actual total energy multisourcing	MJ/year
M _{TEpot}	Potential total energy multisourcing	MJ/year
MF _S	Minimization factor shower	-
MF _T	Minimization factor toilet	-
MF _W	Minimization factor washing machine	-
O	Outputs	Varies
O _E	Overproduced electricity	MJ/year
O _{TE}	Total energy outputs	MJ/year
O _{TEC}	Combined total energy outputs	MJ/year
OCC	Occupancy of a household	-
OF	Overflow from storage & treatment units	m ³ /year
OF ₁	Overflow from storage unit S ₁	m ³ /year
OF ₃	Overflow from storage unit S ₃	m ³ /year
OI	Output index	-
OI _C	Combined output index	-
OI _M	Mean output index	-
OI _{TE}	Total energy output index	-
R ₁	Recycled used potable water from storage unit S1	m ³ /year
R ₂	Recycled used potable water from treatment unit S2	m ³ /year
R _{pot}	Potential recycling from used potable water	m ³ /year
R _{HQ1}	Heat recovery from potable water	MJ/year
R _{HQ2}	Heat recovery from non-potable water	MJ/year
R _{HSH}	Actual heat recovered used for spatial heating	MJ/year
R _{HSHC}	Combined actual heat recovered used for spatial heating	MJ/year
Ro	Total runoff	m ³ /year
Ro _c	Runoff coefficient	-
RH	Resources harvested	Varies
RH _E	Total electricity resources harvested	MJ/year
RH _H	Total heat resources harvested	MJ/year
RH _{TE}	Total energy resources harvested	MJ/year
RH _{TEC}	Total energy resources harvested in combined system	MJ/year
RH _W	Water resources harvested	m ³ /year
RH _{WC}	Water resources harvested in combined system	m ³ /year
SSI	Self-sufficiency index	-
SSI _C	Combined self-sufficiency index	-
SSI _E	Electricity self-sufficiency index	-
SSI _H	Heat self-sufficiency index	-

SSI _M	Mean self-sufficiency index	-
SSI _{FE}	Total energy self-sufficiency index	-
SSI _W	Water self-sufficiency index	-
T _{bp}	Total block population	-
UFA	Useable floor area per household	m ²
WO	Waste outputs	Varies
WO _W	Water waste outputs	m ³ /year
WO _{WC}	Water waste outputs in combined system	m ³ /year
WOI	Waste output index	-
WOI _W	Water waste output index	-
Y _h	Yield of water harvesting	-
Y _{EG}	Yield of the electricity generator	MJ/m ²
Y _{Hg}	Yield of the heat generator	MJ/m ²

Appendix G: List of all MATLAB variables

Table G3: List of all variables used in MATLAB.

Variables used in MATLAB		
a	Roof slope	rad
t	Time step	year
y1	Recycling yes/no matrix	-
y2	Multisourcing yes/no matrix	-
y3	Excel matrix needed to obtain results matrix	-
Ab	Total block area	m ²
Aeg	Roof area used for electricity generators	m ²
Aegc	Roof area used for electricity generators in combined system	m ²
Aempt	Empty roof area	m ²
Ahg	Roof area used for heat generators	m ²
Ahgc	Roof area used for heat generators in combined system	m ²
Ar	Total roof area available for harvesting	m ²
Arb	Roof area of a building unit	m ²
Arbn	Net roof area of a building unit	m ²
Arn	Net roof area	m ²
Ars	Shadowed roof area	m ²
Bu	Number of building units in the block	-
BP	Building period	-
Cwsmin	Minimized water demand shower per usage	l
Cwso	Initial water demand shower per usage	l
Cwtmin	Minimized water demand toilet per usage	l
Cwto	Initial water demand toilet per usage	l
Cwwmin	Minimized water demand washing machine per usage	l
Cwwo	Initial water demand washing machine per usage	l
CFq1	Combined factor potable water	-
CFr	Conversion factor roof	-
De	Actual electricity demand	MJ/year
Dec	Combined actual electricity demand	MJ/year
Demin	Minimized electricity demand	MJ/year
Deo	Initial electricity demand	MJ/year
Deod	Actual electricity demand for other electrical devises	MJ/year
Deoda	Actual electricity demand for other electrical devises (all years)	MJ/year
Deodc	Combined actual electricity demand for other electrical devises	MJ/year
Deodmin	Minimized electricity demand for other electrical devises	MJ/year
Deodminc	Combined minimized electricity demand for other electrical devises	MJ/year
Deodo	Initial electricity demand for other electrical devises	MJ/year
Dh	Actual heat demand (incl. gas)	MJ/year
Dhc	Combined actual heat demand (incl. gas)	MJ/year
Dhmin	Minimized heat demand (incl. gas)	MJ/year
Dho	Initial total heat demand (incl. gas)	MJ/year
Dhq1	Actual heat demand for warm potable water	MJ/year
Dhq1a	Actual heat demand for warm potable water (all years)	MJ/year
Dhq1c	Combined actual heat demand for warm potable water	MJ/year
Dhq1min	Minimized heat demand for warm potable water	MJ/year
Dhq1minc	Combined minimized heat demand for warm potable water	MJ/year
Dhq1o	Initial heat demand for warm potable water	MJ/year
Dhsh	Actual heat demand for spatial heating	MJ/year
Dhsha	Actual heat demand for spatial heating (all years)	MJ/year
Dhshc	Combined actual heat demand for spatial heating	MJ/year
Dhshmin	Minimized heat demand for spatial heating	MJ/year
Dhshminc	Combined minimized heat demand for spatial heating	MJ/year
Dhsho	Initial heat demand for spatial heating	MJ/year
Dte	Actual total energy demand	MJ/year
Dtec	Combined actual total energy demand	MJ/year
Dtemin	Minimized total energy demand	MJ/year

Dteo	Initial total energy demand	MJ/year
Dteoc	Combined initial total energy demand	MJ/year
Dw	Actual water demand	m ³ /year
Dwc	Combined actual water demand	m ³ /year
Dwmin	Minimized water demand	m ³ /year
Dwminc	Combined minimized water demand	m ³ /year
Dwo	Initial water demand	m ³ /year
Dwoc	Combined initial water demand	m ³ /year
Dwq1	Actual potable water demand	m ³ /year
Dwq1c	Combined actual potable water demand	m ³ /year
Dwq1min	Minimized potable water demand	m ³ /year
Dwq1minc	Combined minimized potable water demand	m ³ /year
Dwq1o	Initial potable water demand	m ³ /year
Dwq2	Actual non-potable water demand	m ³ /year
Dwq2c	Combined actual non-potable water demand	m ³ /year
Dwq2min	Minimized non-potable water demand	m ³ /year
Dwq2minc	Combined minimized non-potable water demand	m ³ /year
Dwq2o	Initial non-potable water demand	m ³ /year
Dws	Actual water demand for shower	m ³ /year
Dwsmin	Minimized water demand for shower	m ³ /year
Dwso	Initial water demand for shower	m ³ /year
Dwt	Actual water demand for toilet	m ³ /year
Dwtmin	Minimized water demand for toilet	m ³ /year
Dwto	Initial water demand for toilet	m ³ /year
Dww	Actual water demand for washing machine	m ³ /year
Dwwmin	Minimized water demand for washing machine	m ³ /year
Dwwo	Initial water demand for washing machine	m ³ /year
DMlc	Combined demand minimization index	-
DMIm	Mean demand minimization index	-
DMlte	Total energy demand minimization index	-
DMLw	Water demand minimization index	-
DWW	Flow of domestic wastewater	m ³ /year
DWWq1	Flow of domestic wastewater from potable water demand	m ³ /year
DWWq1ut	Flow of untreatable domestic wastewater from potable water demand (excl. overflow)	m ³ /year
DWWq2	Flow of domestic wastewater from non-potable water demand	m ³ /year
Efeh	Efficiency of the electricity heater	-
Efes	Efficiency of the electricity storage unit	-
Efgh	Efficiency of the gas heater	-
Efhr	Heat recovery efficiency of the heat recovery unit	-
Efhs	Efficiency of the heat storage unit	-
Et	Evapotranspired precipitation	m ³ /year
Etc	Evapotranspiration coefficient	-
ECo	Energy content of other gas heated water flows	MJ
ECs	Energy content of shower water	MJ
ECt	Total energy content all gas heated water streams	MJ
ECws	Energy concentration of shower water	MJ/m ³
ECww	Energy concentration of washing machine water	MJ/m ³
El	Total external input of water	m ³ /year
Ele	External input of electricity from supplier	MJ/year
Elg	External input of gas from supplier	MJ/year
Elgh	External input of gas from supplier to heater	MJ/year
Elh	External input of district heat	MJ/year
Elq1	External inputs to fulfil potable water demand	m ³ /year
Elq2	External inputs to fulfil non-potable water demand	m ³ /year
Ginputs	Matrix of general inputs exported to excel	-
Heh	Heat obtained from electricity heater	MJ/year
Hgh	Heat obtained from gas heater	MJ/year
Hhb	Amount of households per building unit	-
HCeg	Heat consumption from electricity generator	MJ/year
HCeh	Heat consumption from electricity heater	MJ/year
HCeod	Heat consumption from other electrical devises	MJ/year
HCes	Heat consumption from electricity storage unit	MJ/year
HCgh	Heat consumption from gas heater	MJ/year
HChg	Heat consumption from heat generator	MJ/year

HChq1	Heat consumption from potable warm water	MJ/year
HChr	Heat consumption from heat recovery unit	MJ/year
HChs	Heat consumption from heat storage unit	MJ/year
HChsh	Heat consumption from spatial heat	MJ/year
HCte	Total heat consumption	MJ/year
HCteg	Total heat consumption in generation units	MJ/year
HCteh	Total heat consumption in heating units	MJ/year
HCter	Total heat consumption in recovery units	MJ/year
HCtes	Total heat consumption in storage units	MJ/year
HCteu	Total heat consumption after energy usage	MJ/year
I	Type of installation	-
leh	Input of electricity to heater	MJ/year
leod	Input of electricity used for other electrical devises	MJ/year
lhq1	Input of heat used for heating potable water	MJ/year
lhsh	Input of heat used for spatial heating (excl. recovery)	MJ/year
In	Infiltrated precipitation	m ³ /year
Inc	Infiltration coefficient	-
K	Treatment capacity treatment unit S ₂	m ³ /year
Me	Actual electricity multisourcing	MJ/year
Mec	Combined actual electricity multisourcing	MJ/year
Mehar	Harvested electricity multisourcing	MJ/year
Meharc	Combined harvested electricity multisourcing	MJ/year
Meharp	Harvesting potential electricity multisourcing	MJ/year
Mepot	Potential electricity multisourcing	MJ/year
Mh	Actual heat multisourcing	MJ/year
Mhc	Combined actual heat multisourcing	MJ/year
Mhar	Harvested water multisourcing	m ³ /year
Mhar2	Used harvested water multisourcing	m ³ /year
Mhhar	Harvested heat multisourcing	MJ/year
Mhharc	Combined harvested heat multisourcing	MJ/year
Mhharp	Harvesting potential heat multisourcing	MJ/year
Mhpot	Potential heat multisourcing	MJ/year
Mi	Intermediate water multisourcing variable	m ³ /year
Mpot	Potential water multisourcing	m ³ /year
Mte	Actual total energy multisourcing	MJ/year
Mtepot	Potential total energy multisourcing	MJ/year
MFs	Minimization factor shower	-
Mft	Minimization factor toilet	-
MFw	Minimization factor washing machine	-
Occ	Occupancy of a household	-
Oe	Overproduced electricity	MJ/year
Ote	Total energy outputs	MJ/year
Otec	Combined total energy outputs	MJ/year
OF	Overflow from storage & treatment units	m ³ /year
OF ₁	Overflow from storage unit S ₁	m ³ /year
OF ₃	Overflow from storage unit S ₃	m ³ /year
Olc	Combined output index	-
Olm	Mean output index	-
Olte	Total energy output index	-
Precip	Matrix of precipitation data exported to excel	-
R1	Recycled used potable water from storage unit S1	m ³ /year
R2	Recycled used potable water from treatment unit S2	m ³ /year
Resultsc	Matrix of combined results exported to excel	-
Resultse	Matrix of energy results exported to excel	-
Resultsw	Matrix of water results exported to excel	-
Rhci	Heat recovery intermediate variable in combined system	m ³ /year
Rhq1	Heat recovery from potable water	MJ/year
Rhq2	Heat recovery from non-potable water	MJ/year
Rhsh	Actual heat recovered used for spatial heating	MJ/year
Rhshc	Combined actual heat recovered used for spatial heating	MJ/year
Ri	Water recycling intermediate variable	m ³ /year
Ro	Total runoff	m ³ /year
Roc	Runoff coefficient	-
Rpot	Potential recycling from used potable water	m ³ /year

RHe	Total electricity resources harvested	MJ/year
RHh	Total heat resources harvested	MJ/year
RHte	Total energy resources harvested	MJ/year
RHtec	Total energy resources harvested in combined system	MJ/year
RHw	Water resources harvested	m ³ /year
RHwc	Water resources harvested in combined system	m ³ /year
RT	Roof type	-
SSic	Combined self-sufficiency index	-
SSle	Electricity self-sufficiency index	-
SSlh	Heat self-sufficiency index	-
SSIm	Mean self-sufficiency index	-
SSite	Total energy self-sufficiency index	-
SSlw	Water self-sufficiency index	-
Tbp	Total block population	-
TEInputs	Matrix of energy inputs exported to excel	-
TEMult	Matrix of energy multisourcing data exported to excel	-
TEUHA	Matrix of total energy UHA results exported to excel	-
UFA	Useable floor area per household	m ²
Vectore	Vector of all energy indices exported to excel	-
Vectorw	Vector of all water indices exported to excel	-
WOw	Water waste outputs	m ³ /year
WOwc	Water waste outputs in combined system	m ³ /year
WOlw	Water waste output index	-
WUHA	Matrix of waterUHA results exported to excel	-
Yeg	Yield of the electricity generator	-
Yh	Yield of water harvesting	-
Yhgd	Yield of the heat generator (double glazed collector)	-
Yhge	Yield of the heat generator (evacuated tube)	-