Sustainable design of building's installations by taking into account real drinking water use

Ilse Pieterse-Quirijns, ilse.pieterse@kwrwater.nl
KWR Watercycle Research Institute, Nieuwegein, The Netherlands

Andreas Moerman, andreas.moerman@kwrwater.nl
KWR Watercycle Research Institute, Nieuwegein, The Netherlands

Ewald Slingerland, E.Slingerland@ecofys.com
Ecofys, Utrecht, The Netherlands

Wim de Groote, wimdegroote@e-ster.be
e-ster, Gent, Belgium

Mirjam Blokker, mirjam.blokker@kwrwater.nl
KWR Watercycle Research Institute, Nieuwegein, The Netherlands

Abstract

Climate change and depletion of resources challenge to promote sustainability in the design of buildings. Important indicators for sustainable buildings are water and energy efficiency. Examples of these indicators in a building's water system are saving of water and energy in the supply of cold and hot water, in reuse of wastewater, and in heat and resources recovery from wastewater. These applications require insight in the cold and hot water demand of a building or in the characteristics of the drainage loads. SIMDEUM®, an end-use model to simulate residential and non-residential cold and hot water demand patterns, can provide this information. In this paper, the contribution of SIMDEUM is illustrated in two cases: in the energy efficient design of several water heaters for various scenarios in household characteristics and appliances and secondly, to investigate the feasibility of alternative sanitation concepts. SIMDEUM forms an essential element to evaluate building's sustainability concepts.

Keywords: SIMDEUM, cold and hot water demand, energy efficiency, alternative sanitation concepts, sustainability

1 Introduction

Sustainability is a global issue that has worldwide attention. Climate change and depletion of natural resources challenge to promote sustainability in the design of buildings. Buildings are responsible for a large amount of energy and water consumption, raw material employment and usage of land. They generate considerable amounts of greenhouse and ozone-depleting gases throughout their life cycles for the services they provide, such as lighting, water and climate control, leading to enormous impacts on nature (Melchert 2007). A sustainable building is a building that has minimum adverse impacts on the built and natural environment, in terms of the buildings themselves, their immediate surroundings and the broader regional and global settings (Azhar et al 2011; John et al 2005).

Five objectives for sustainable buildings are identified: resource efficiency, energy efficiency, pollution prevention, harmonisation with environment and integrated and systematic approaches (John et al 2005; Motawa & Carter 2013). This includes the elimination and control of hazardous substances, use of renewable and biological materials and added functionality in materials and structures, indoor environmental quality (John et al 2005; Azhar et al 2011).

The most important decisions regarding a building's sustainable features are made during the design and preconstruction stages. Aspects of sustainable design are building orientation, building massing, daylight analysis, water harvesting, energy modelling, sustainable materials, site and logistics management (Azhar et al 2005; Huat & Abidin bin Akasah 2011). Also other factors, not related to design, play an important role in energy use like the intensity of building occupancy, type of activity, user attitude and behaviour, management and organisation, the desired air temperature and climate (Huat & Abidin bin Akasah 2011).

In the sustainable building concept, water and energy efficiency play a role. This paper reflects the sustainability in the design of a building's installation for water supply and drainage. As far as the authors know, not much attention is paid to the construction of the building's indoor installation in the current sustainability concepts. In view of the building's installation for water supply and drainage, sustainability can refer to several aspects.

First of all, sustainability can be achieved by saving of water, materials and energy in the supply of water to a building. Water use can be reduced by using other types of appliances, such as water-saving shower heads instead of rain showers or by influencing the behaviour of users. For example, residents can be encouraged to shower less frequent or take shorter showers. This will save water and energy to heat the water, since the residential water use (specifically in the Netherlands) is dominated by the water used for showering.

The residential energy use for hot water varies between 9-27% of the total energy use, depending on the country. Since buildings become more energy efficient, for example due to improved insulation, this percentage will increase in future. Therefore, efficient design of water heating systems becomes more crucial for sustainable design of buildings.

In general, pipe diameters and water heating systems in buildings are oversized to guarantee a high expected water demand and to meet the desired comfort wish (Pieterse-Quirijns et al 2013). Badly designed systems can cause stagnant water with health risks, and are less energy efficient and therefore more expensive to operate. The main reason for the bad designs are the outdated guidelines with extra safety factors to warrantee no lack of comfort, that generally overestimate the peak demand values required for design and that do not give any insight into the hot water demand. Recently, new guidelines were developed and they prove to result in a reliable prediction of peak values for cold and hot water in various buildings. The application of these guidelines lead to selection of smaller diameters. Also the heater capacity could be reduced with a factor 2 to 4 compared to suppliers proposals, while still meeting the desired need and comfort (Pieterse-Quirijns et al 2013). Therefore, applying guidelines with reliable predictions of water demand result in saving both materials (of pipes and water heater) and energy.

Secondly, sustainability can be realised by reusing or recycling wastewater and rainwater. Rain and wastewater are seen as a nuisance and as such removed from cities. Only a small percentage of high quality (potable) water is used for drinking and cooking. The rest is used for non-potable purposes, mainly for personal hygiene and cleaning, which require lower quality than water that is fit for human consumption. This means that grey water coming from the shower and bath, and rainwater can be (re) used as non-potable water, such as for toilet flushing or the washing machine. This leads to less low-grade use of drinking water, reuse of waste water, waste water which needs to be cleaned less and useful use of rainwater. This promotes sustainability in the water cycle (Agudelo-Vera 2012).

Thirdly, recovery of heat and resources from wastewater promotes sustainability as well. Wastewater contains thermal energy (60% of residential water in the Netherlands is heated to 40 °C) and nutrients that can potentially be harvested (Blokker et al 2013). The temperature of the discharged water is raised when households heat their drinking water for bathing and cleaning or when the water in the drinking water installation has ample time to approach room temperature, especially in the winter (Moerman et al 2014). Nitrates from discharged urine can be used to harvest struvite, as sustainable fertilizer or sustainable source of phosphate. Locally, the energy can be harvested from shower discharge. A shower-heat-recovery system can have an overall energy efficiency of 65%.

To study these concepts of sustainability, understanding the cold and hot water demand of a building on the fixture level or the characteristics of the drainage loads is required. SIMDEUM is a model that supports this understanding. SIMDEUM is an end-use model which simulates residential and non-residential water demand patterns (Blokker et al 2011). In this paper, the role of SIMDEUM in sustainable design of buildings is illustrated in two case studies:

a) energy efficient design of several water heaters
b) alternative sanitation concepts

2 Background of SIMDEUM

2.1 Philosophy of water demand modelling in SIMDEUM

SIMDEUM stands for "**SIM**ulation of water **D**emand, an **E**nd-**U**se **M**odel." It is a stochastic model based on statistical information of end uses, including statistical data on water appliances and users (Blokker et al 2010). SIMDEUM's philosophy is that people's behaviour regarding water use is modelled, taking into account the differences in installation and water-using appliances. This means that in each building, whether it is residential, like a house or non-residential, like an office, hotel or nursing home, the characteristics of the present water-using appliances and taps are considered as well as the water-using behaviour of the users who are present (i.e. presence, time of use, frequency of use).

For each person, his presence is modelled and when he uses water and for which reason. The characteristics of each appliance are defined, like the flow rate, duration of use, frequency of use and the desired temperature. The duration and frequency may vary depending on the users: a teenager showers more frequently and longer than an elderly person. Moreover, the duration, frequency and the desired temperature of an appliance depends on the type of appliance (e.g. particular type of washing machine) and the particular application. For example, a kitchen tap can be used for filling a glass (15 s, 0.167 l/s, 10℃) or for washing dishes (45 s, 0.25 l/s, 55℃). SIMDEUM calculates for each appliance at what time it is used, by whom and for which purpose. This results in a demand pattern for cold and hot water at each appliance on a second base. By the addition of the demand patterns of all appliances, the demand pattern of a house, office, hotel or nursing home is obtained. The characteristics of the users and the appliances are different for each type of building and are extensively described in Blokker et al (2010 and 2011) and Pieterse-Quirijns et al (2013).

Measurements of cold and hot water patterns on a per second base in different types of buildings show that SIMDEUM renders a reliable prediction of both cold and hot water demand, as well in average water use, as in the diurnal water demand patterns (or variation during the day) and the variation in days. New design-demand-equations based on SIMDEUM give a better prediction of the measured peak values for cold water flow than the existing guidelines. Moreover, they can predict hot water use well. The new design-demand-equations lead to reliable and improved designs of building installations and water heater capacity, resulting in more hygienic and economical installations (Pieterse-Quirijns et al 2013).

2.2 Extending SIMDEUM to energy and wastewater: SIMDEUM-HW and SIMDEUM-WW

2.2.1 SIMDEUM-HW: SIMDEUM-HotWater for calculating energy related to heating drinking water

During the last decades the share of water heating in the total building heat demand increased due to better insulation of buildings. In passive buildings this increase is even larger since these buildings require very little energy for space heating. Therefore, the water and energy nexus becomes increasingly important. SIMDEUM-HW enables the calculation of energy demand patterns for heating of drinking water at end-use level.

SIMDEUM simulates the cold and hot water demand patterns at each tap or appliance. SIMDEUM-HW is a post-processing, that calculates the corresponding energy for the desired hot water at the tap based on energy balance (for example for the shower, bath or kitchen tap). Additionally, SIMDEUM simulates the water use of the washing machine and dishwasher. These appliances use energy to heat water to the desired set programme temperature. Based on this temperature, the electrical energy is calculated to reach this temperature. Together with information on the supply system layout, causing energy losses in the building drinking water system due to hot water supply from a central heater, the total energy demand patters per appliance is calculated.

Alternative concepts as hot-fill washing machine, hot-fill dishwasher and a shower heat recovery system, use alternative energy sources as hot water or shower wastewater. SIMDEUM-HW calculates the related amount of decentral energy use during the day.

In this way, SIMDEUM-HW simulates total and decentralised energy demand patterns for each appliance and tap, and by summation for a building. This knowledge can be used in design of efficient water heaters. Efficient heating of drinking water is crucial for sustainable design of buildings.

2.2.2 SIMDEUM-WW: SIMDEUM-WasteWater for calculating discharge patterns

SIMDEUM's basis gives insight in the reason for which the water is used and at what temperature this water needs to be at each tap. This demanded water will also be discharged per tap. Therefore, it also provides information of the wastewater quantity, temperature and quality that will leave the building through the sewage system (e.g. shower water at 35℃ with soap residue, or toilet water at 15℃ with medicines, hormones and nitrates). For residential buildings SIMDEUM is transformed from a demand model into a discharge model, called SIMDEUM-WW.

In SIMDEUM-WW, the behaviour of the users regarding a tap will be the same as in SIMDEUM, like time and frequency of use. However, the characteristics of the discharge can be different, like the discharge flow rate and duration. For the bathroom tap, kitchen tap (except for the sub end use "doing dishes") and shower, the discharge characteristics are the same as for the demand. The discharge from WC, bath, washing machine, dishwasher and water for manual dish washing are different. For example, flushing the toilet is shorter and at higher flow rate than filling the reservoir (the demand).

The time of discharge is not always equal to the time of the demand. The bath tub can be emptied 10 minutes to 1 hour after it is being filled. The intake and discharge of washing machine, dishwasher and emptying the sink after doing the dishes also shows a shift in time.

In SIMDEUM-WW, the expected temperature of the discharged water is introduced and the temperature of the cold water. It is assumed that the cold water is heated during use and transport in the housing to an average of 20℃. This temperature depends on the season and the residence time in the drinking water installation. The expected temperature of the discharged heated water of points is obtained from measurements, and varies between 35 and 55℃, dependent on the use and programme of washing machine and dishwasher.

The final temperature of the total discharge volume leaving a building is calculated by mixing the discharged volumes of the appliances with the corresponding temperature using an energy balance. For a detailed description of the discharge characteristics of appliances is referred to Pieterse-Quirijns et al (2012).

3 Case I: SIMDEUM to calculate total efficiency, yearly cost and carbon emission of domestic hot water use

3.1 Introduction (background and purpose)

In the Netherlands the level of comfort for domestic hot water is generally expressed in so-called comfort classes, ranging from 1 (kitchen only) to 6 (simultaneous use of kitchen and shower/bath). To determine the most efficient appliances, or to maximise efficiency and minimise (hot water generation) costs, the relatively coarse character of these comfort classes does not suffice. The purpose of this case is to apply the finer modelling results of SIMDEUM and SIMDEUM-HW in a heater efficiency model, as basis for determining the overall efficiency of heaters, as well as related costs and carbon emissions from generating hot water (Figure 1).

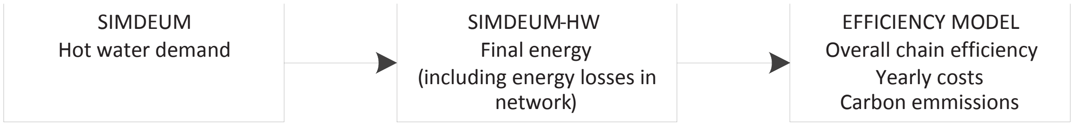

Figure 1 Model layout to calculate total efficiencies, yearly costs and carbon emissions based on SIMDEUM modelling data.

3.2 Approach

3.2.1 Considered water heaters

In this case, local water heaters were considered (Table 1), i.e. collective solutions like district heating or collective heat pumps are not included this case study.

The heat pump (HP) series are electrical and vary on the heat source used. For all heat pump systems a large storage tank has been assumed due to the relatively strong desire for continuous heat production by heat pumps.

For the condensing boilers (CB) two variants are taken into account; one in which 50% of the hot water demand is supplied by solar collectors (or an energy roof) and one in which a small part of hot water demand is supplied locally by a small electrical close-in boiler in the kitchen. Geysers (instantaneous water heaters) and boilers (storage tank water heaters) can be both electrical and gas-driven. Subsequently both small and large storage tanks were used. The micro CHP simultaneously produces heat and power by means of a Stirling engine (or fuel cell) and requires a large tank to store the heat that becomes available during power production.

Table 1 Heaters for domestic hot water in in case I (SIMDEUM to calculate total efficiency, yearly cost and carbon emission of domestic hot water use)

Water heater type	**Size of storage tank**	**Fuel**	**Heat source**	Short name (see results)
(Combi) heat pump (HP)	Large	Electricity	Ambient air	HP-air
HP (or heat pump boiler)	Large	Electricity	Ventilation air	HP-vent
HP	Large	Electricity	Closed loop, vertical	HP-closed
HP	Large	Electricity	Open loop, groundwater, recirculation	HP-open1
HP	Large	Electricity	Open loop, groundwater, heat and cold storage	HP-open2
HP	Large	Electricity	District heating	HP-DH
HP	Large	Electricity	Waste heat	HP-waste
Condensing boiler (CB)	None	Gas	n/a	CB
CB with solar collectors / energy roof	Large	Gas	n/a	CB-solar
CB with close-in boiler at kitchen	Small	Gas	n/a	CB-kitchen
Geyser	None	Gas	n/a	Geyser-gas
Geyser	None	Electricity	n/a	Geyser-elec
Boiler	Large	Gas	n/a	Boiler-large-gas
Boiler	Large	Electricity	n/a	Boiler-large-elec
Boiler	Small	Gas	n/a	Boiler-small-gas
Boiler	Small	Electricity	n/a	Boiler-small-elec
Micro CHP	Large	Gas	n/a	Micro CHP

3.2.2 Determination of overall system efficiencies

In efficiency model, the heat supply chain was broken down into the following elements:

- S1 – Efficiency of heat transfer during production
- S2 – Start-up losses
- S3 – Storage tank losses
- S4 – Auxiliary electrical energy needed for functioning of water heater

The combination of S1 through S4 gives the total amount of primary energy needed to heat the hot water volume calculated by SIMDEUM to the desired hot water temperature, based on the final energy calculated by SIMDEUM-HW.

For data on **S1**, a number of recent quality statements based on the Dutch standard for Energy performance of buildings NEN 7120 was used. The number of available statements varies with the type of appliance, but in all cases the arithmetic average of the figures in the statements was taken as the generation efficiency. For heat pumps delivering heat at 65 °C (instead of 55 - 58 °C), a correction factor is applied to account for the larger temperature difference between heat source and hot water temperature. It should be noted that NEN 7120 is based on a standardised test cycle of 49 (hot) water withdrawals.

S2 is only relevant for condensing boilers and gas geyser and based on SIMDEUM-HW's output for various amounts of (hot) water withdrawals per day. Based on supplier data, we used an average start-up loss for each (hot) water use, based on the effective waiting periods and thermal capacities. In case of large storage tanks, start-up losses are negligible because the water heaters are assumed not to produce demand-driven in that case. Storage tanks gradually lose heat to their environments (**S3**). Based on data extracted from product sheets of well-known suppliers, the heat loss was parameterised as a function of tank size. Subsequently, the necessary size of the tank was calculated with SIMDEUM modelling data, based on a Dutch installation guideline (ISSO publication 30). Auxiliary energy (**S4**) is already part of the efficiencies reported in NEN 7120. In case the fuel for hot water production is electricity, a power generation efficiency of 39% was applied to calculate primary energy, in accordance with NEN 7120.

3.2.3 Description of scenarios

With SIMDEUM and SIMDEUM-HW several scenarios were defined to study the impact of building type, household size (1-2 person, 3-4 person), seasonal differences (temperature of drinking water taken in from the drinking water distribution network; 10°C during winter, 20°C during summer), hot water temperature at tap level (55 or 65°C) and shower heat recovery (present or absent) on the total efficiency, yearly costs and carbon emissions of several hot water appliances (Table 1). The outcomes were compared to a base scenario (1-2 person household, hot water temperature 55°C, no shower heat recovery).

3.3 Results and discussion

The results for overall chain efficiency, costs and carbon emissions of hot water production for the base scenario with varying consumer behaviour are shown in Figure 2. The figure shows that the outcomes of the efficiency model vary considerably for the various heaters. Moreover, SIMDEUM allows to study variable customer behaviour, which appear to influence the energy efficiency factors (Figure 2). Especially in systems with large storage tanks the influence on efficiency is substantial.

The impact of the different scenarios, compared to the base scenario, is described in Table 2.

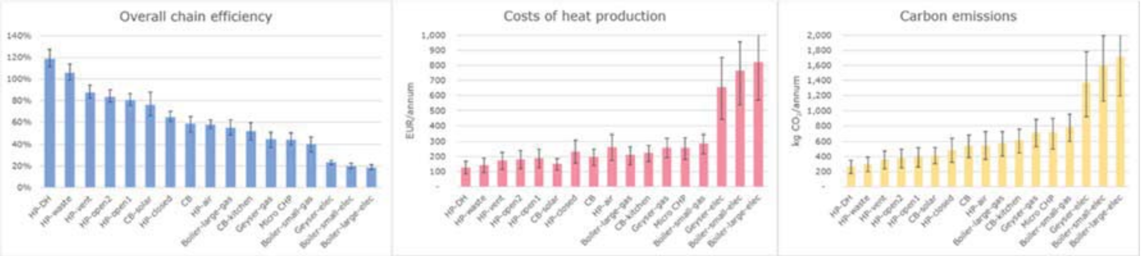

Figure 2 Overall chain efficiencies, costs of heat production and carbon emission of the water heaters considered for base scenario. For meaning of abbreviated names, see **Table 1**. Bars show average consumer, error bars represent economical (low) and uneconomical (high) consumers. Costs are based on 2014 average energy prices: gas 0.65 EUR/Nm3, electricity 0.22 EUR/kWh.

Table 2 Effects of different scenarios, simulated with SIMDEUM(-HW), on chain efficiency and costs of heat production.

Scenario	**Impact on:**	
	Chain efficiencies	Costs of heat production
Hot water temperature 65 °C	Only for heat pumps up to 20% lower efficiencies	For heat pumps some tens of euros a year more expensive
Shower heat recovery	Negligible effect on average, but error bars decrease	Saves some tens to hundreds of euros a year
Large household / luxury house	1.2 to 1.6 times higher efficiencies, error bars closer to average	2 to 3 times higher costs; only heat pumps with district/waste heat cheaper than condensing boiler

With SIMDEUM, natural variation of user hot water demand was modelled and studied, leading to realistic demand patterns of energy and corresponding realistic designs, where standard guidelines (with rules of thumbs) can result in oversized systems. Moreover, a model as SIMDEUM is essential to study the effect of different scenarios on heater performance in terms of total chain efficiency, costs and carbon emissions.

As follow-up, the model can be used as an online tool for consumers, e.g. to calculate the savings potential of taking shorter showers, using water-saving shower heads or lower temperatures.

4 Case II: SIMDEUM in alternative sanitation concepts

4.1 Introduction (background and purpose)

In the coming years, the old port in Ghent, Belgium, will be converted into a new sustainable neighbourhood on the waterfront, Oude Dokken. An alternative sanitation concept for this area has been developed. Within the concept, the domestic wastewater is discharged in two separate streams: light polluted (light grey) water and heavily polluted (black) water. The grey water flow remains marginally contaminated and easy to treat. The black water is purified along with the kitchen waste with the aid of new treatment techniques, where biogas is formed. This biogas can then be used to heat water for local use. Also, nutrients can be reclaimed as struvite.

Within this new concept, the wastewater and organic waste provide the energy, which is used for local sanitary hot water supply. Under the new concept, the aim is to shift from electric energy use to warm water use: washing machine and dishwasher are supplied with hot water (hot fill).

To investigate the feasibility of this concept, a good indication of the hot water demand under varying conditions and the (potential) hot water consumption of certain devices, such as the washing machine and the dishwasher, are required. The purpose of this case study is to calculate the hot water demand as well as the energy-use (central and decentralised) in several building scenarios, varying in home occupancy and presence of alternative appliances. Moreover, drainage characteristics as temperature and flow are determined.

4.2 Approach

Four area scenarios are defined (Table 3), varying in expected water use and in the use of alternative concepts. Because of the tight constraints of the number and types of houses, the variation in the (annual) household water use is restricted. Variation in the water use is obtained by increasing the family size in the larger apartments and the number of teenagers (using more water than small children). Data that characterise the water use are based on the Dutch situation and adapted to the Belgium situation and culture, where statistics are available. Employment rate and percentage of part-time workers differ from the Netherlands as well as the penetration rate and frequency of use of some appliances in households, like presence of bathtub and frequency of bathing are higher than in The Netherlands, shower frequency is lower and frequency of dishwasher use is higher.

The assumed temperatures at the tap are 10℃ for cold water and 45℃ for hot water. The temperature of hot water is determined by the biogas system. For some applications, additional (electrical) heating is required, as for example higher temperature at the kitchen tap is required for washing the dishes. For the calculation of energy requirement, a loss of 5℃ inside the building is assumed.

For each scenario, the water use and the associated energy requirements were calculated for three sizes of the area, 200, 435 and 866 households. For each area size, 100 diurnal demand patterns were simulated with SIMDEUM and SIMDEUM-HW. From these demand patterns, characteristic numbers were derived for average cold and hot water use, average energy requirement (central and decentralised) of the area, as well as the maximum water and energy use, defined as the 99-percentile of the 100 values of the different characteristic parameters. The hot water and energy use (average and maximum) were also calculated for the washing machines and dishwashers in the area separately.

For each district scenario, 100 discharge patterns were generated with SIMDEUM-WW. The average temperature in the discharge flow was determined.

Table 3 Description of four district scenarios, varying in family size and use of alternative sanitation concepts.

Name scenario	Average householdsize	Appliances	Average water use per household per day [l.day^{-1}]
scen 1_min_normal	2.3	Normal	248.9
scen 2_max_normal	2.7		286.5
scen 3_min_alternative	2.3	• All toilets are vacuum toilet • 60% of households with hot-fill washing machine (1st cycle uses hot water) • 95% of households with hot-fill dish washer (4 cycles use hot water)	213.4
scen 4_max_alternative	2.7		244.9

4.3 Results and discussion

The total average water and energy use for the four scenarios is shown in Figure 3. The figure illustrates that the water use is higher in the larger households (scenario 2 and 4). The total water use in the scenarios with alternative sanitation concepts use is lower, due to the presence of vacuum toilets. However, the hot water use in those scenarios is higher due to the hot-fill washing machines and dishwashers: 60% of the total water use against 48% in the scenarios with normal appliances. In the latter scenarios a larger part of the energy is supplied by the central energy supply, through the hot water. More than 90% of the total energy demand is supplied by hot water, against 80% in the normal scenarios 1 and 2.

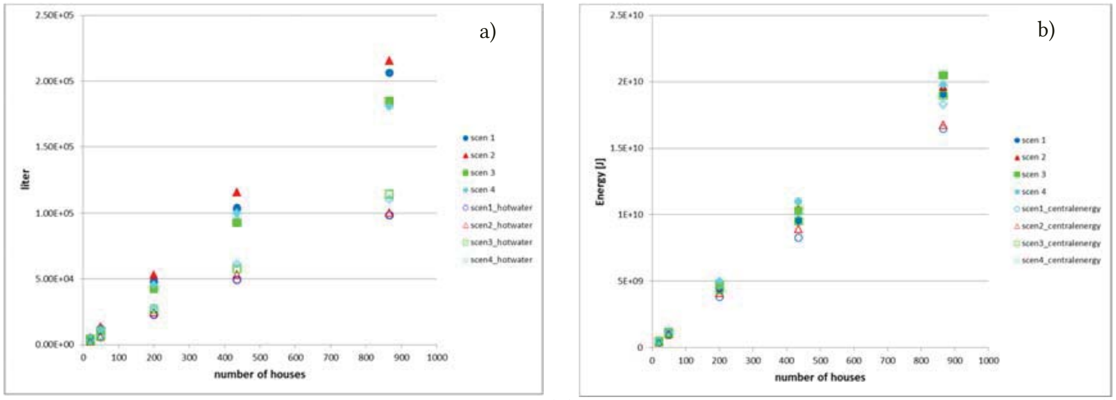

Figure 3 Total average water and hot water use (a) and total and centralized average energy use (b) in the four scenarios as function of the number of houses.

With SIMDEUM, the hot water demand and energy use can be determined for each appliance in the building. As an example, the hot water and energy use of the washing machines in the districts are shown in Figure 4. Only the hot-fill washing machines in scenario 3 and 4 use hot water (figure a), that provides 50% of the total required energy (figure b).

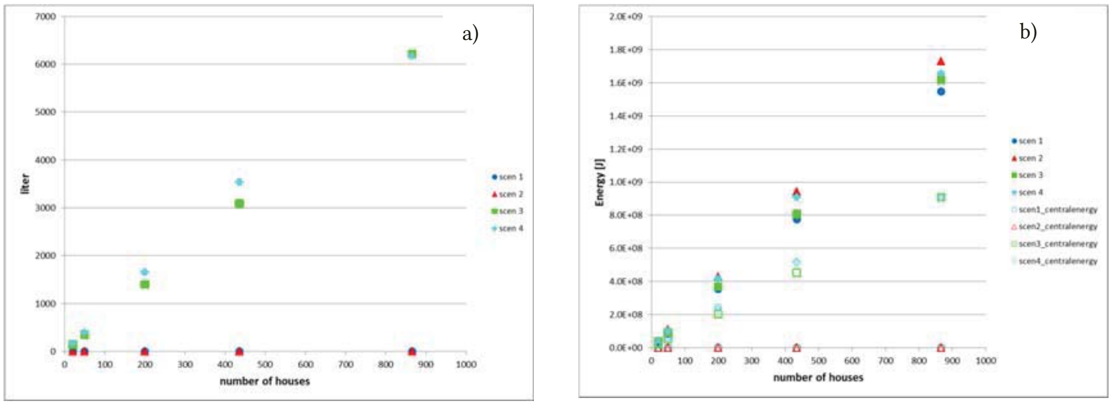

Figure 4 Average hot water use (a) and total and centralized average energy use (b) by the washing

machines in the four scenarios as function of the number of houses.

From the discharge characteristics, determined with SIMDEUM-WW, it appears that the application of vacuum toilets in scenario 3 and 4 reduces the discharge volume considerably, a reduction of 25% of the average flow and of 60% of the maximum discharge flow rate. Moreover, the temperature of the wastewater in these scenarios is approximately 2-2.5℃ higher (Figure 5). Since the vacuum toilets in these scenarios have no toilet flushing, they do not cause dilution of the discharge stream, causing higher temperatures. Also, in the hot-fill dishwasher all washing cycles are warm, causing a higher discharge temperature. However, the total contribution of the dishwasher is small (3% of total water consumption). This is reflected in the small impact of the increase in the model of the discharge temperature of the dishwasher (only 0.2℃).

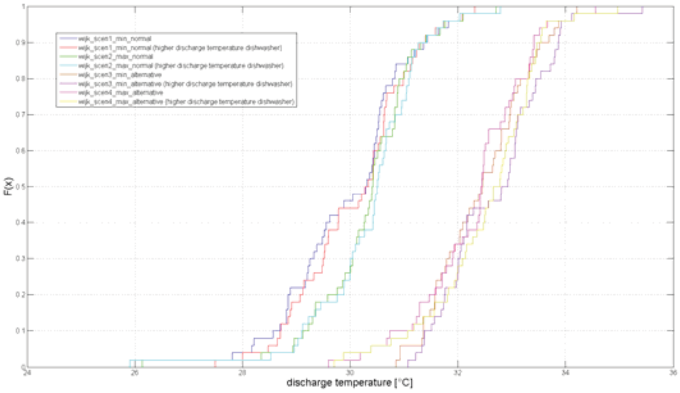

Figure 5 The average temperature of the discharge displayed as cumulative frequency distribution for the four scenarios with measured discharge temperature of dishwasher (35°C) and discharge temperature related to the programme of the dishwasher.

SIMDEUM gives the possibility to investigate the consequences for water and energy efficiency of variations in households, types of appliances and the application of alternative concepts. Simulations show that the application of hot-fill washing machines and dishwashers reduce the need of decentralised energy with more than 10%.

Also other sustainability issues can be studied with simulations, like the recovery of thermal energy from wastewater. Replacing toilets with vacuum toilets increases the temperature of waste water with 2-2.5℃. Application of hot-fill dishwashers barely has any effect on the temperature of wastewater and is not beneficial from the viewpoint of the recovery of energy.

Simulations of the water use at taps and appliances show that the energy for washing machine, dishwasher and kitchen tap account for only 30% of the total energy demand. Most energy is required for shower or bath. The highest gain in energy savings can be achieved by using water saving showerheads or shower heat recovery systems. With SIMDEUM the contribution of the shower heat recovery is analysed in the first case of this paper.

5 Conclusion

SIMDEUM simulates residential and non-residential cold and hot water demand patterns as well as characteristics of a building's discharge. The model can be used to reliably estimate the cold and hot water use in various buildings, in for example existing BIM software, and in scenario studies, where the effect of measures on water and energy use of a building can be investigated. Possible recovery of energy and nutrients from wastewater under various conditions can be investigated as well.

Case studies illustrate that SIMDEUM forms an essential element to evaluate building's sustainability concepts, since the model provides insight in (variation in) water and energy demand patterns in various concepts. Due to the dynamics in water use and the present large variation, this information can never be obtained from measurements only. A physically based model is required to understand the water use.

Due to its physical basis, SIMDEUM can be used for other countries, buildings and purposes, when specific information on users and appliances is available. Influences of future developments, like behavioural changes, demographic changes, technical progress, legislative control, climate changes, can be easily investigated with scenario studies based on SIMDEUM.

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