Water and energy nexus at the building level

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Introduction

In recent years, the attention given to the water-energy nexus has grown. Although insight in the energy needed to run our water systems has gained, little is known about the water-energy nexus at the building level, specifically, regarding hot water use. For the Netherlands, total water consumption per capita and residential water consumption is well known, see **Figure 1**. However, reference to

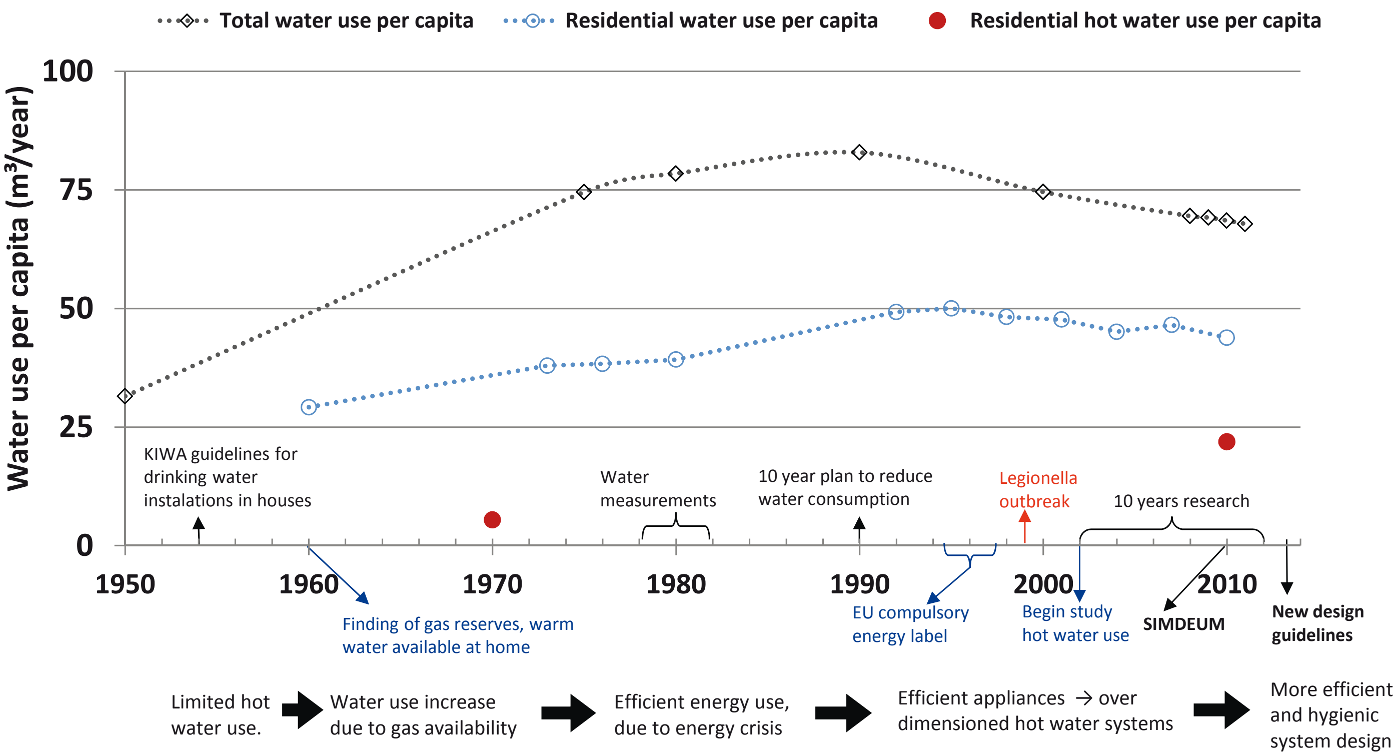

Figure 1. Overview of the changes in the total and residential water consumption per person per year, in the Netherlands.

hot water use is often not reported. In 1970, hot water consumption was estimated at 15 litres per person per day (l/pd). Currently it is estimated that a person uses about 60 l/d of hot water of 40°–60°C, for personal cleaning and kitchen use. Additionally, 13 l/pd of hot water is heated in the washing machine and dishwasher (Blokker et al., 2013). For non-residential buildings, there are no comparable estimates available. Until 2013, the design of the drinking water and hot water system of non-residential buildings was based on outdated assumptions on peak water demand and on unfounded assumptions on hot water demand. In this article we describe the influence of changes in (hot) water use at the building level in the last decades, in the Netherlands. Results show the close interdependency between water and energy over time, and describe an integrated approach towards a more efficient design considering water and energy flows at building level simultaneously.

Introduction of hot water

In the Netherlands, piped drinking water supply began in 1853 and in 1950 the ratification of the Water Supply Act, made nation-wide coverage mandatory. In 1954, the guidelines for the construction of drinking water installations adopted the method to calculate the peak consumption from the German Guidelines[1]. In the 1960s, a period characterized by rapid growth, prosperity and social changes began, driven by the discovery of large quantities of natural gas. Within a few years, almost all Dutch households started to use natural gas, pushing the development of new appliances, and stimulating the adoption of showers. Low gas prices and national campaigns to promote hygienic practices, led to changes in routines by increasing showering frequency. By 1970, 99% coverage of piped drinking water was achieved and 97% of the new houses had hot water and a shower or a bath, see **Figure 1.** Such historical development data for non-residential buildings are not available.

Towards a more efficient water and energy use

Changes in technology penetration and in user behaviour, led to an increase in the water demand, with a peak in the 1990s. In 1991 the government established the third 10 year plan to slow down this trend. Transitions after the 1990s can be logically related to technological development such as water saving devices, where, National and European regulations have been a catalyst. To slow down the increasing hot water use, the National Consultation for Hot Water Platform[2] was formed. In 1994 guidelines for drinking water systems in households[3] was published considering the reduction of water and energy consumption and the consequences for the design of drinking water systems. In 1995 the government, water companies, energy companies and other relevant market parties signed a cooperation declaration Approach for Hot Water Conservation[4]. In 1997 European legislation made energy labelling mandatory for washing machines, and for dish washers in 1999, which specifies the energy and water consumption of an appliance and grades overall energy performance. As a consequence, the average consumption per washing load of washing machines is almost halved starting from 100 litres in 1992 (**Figure 2a**). Most of the energy consumption of washing machines is for heating water, thus less water per cycle means lower energy use. Furthermore, new European norms of sanitary fixtures were developed that take specific water consumption into account, e.g. NEN-EN 1112 of 1997. Energy efficiency has been a constant driver in the last two decades, as shown in the transition towards more energy-efficient systems to heat water at residential level (**Figure 2b**). This transition has been supported by technological developments while comfort and user behaviour were not affected.

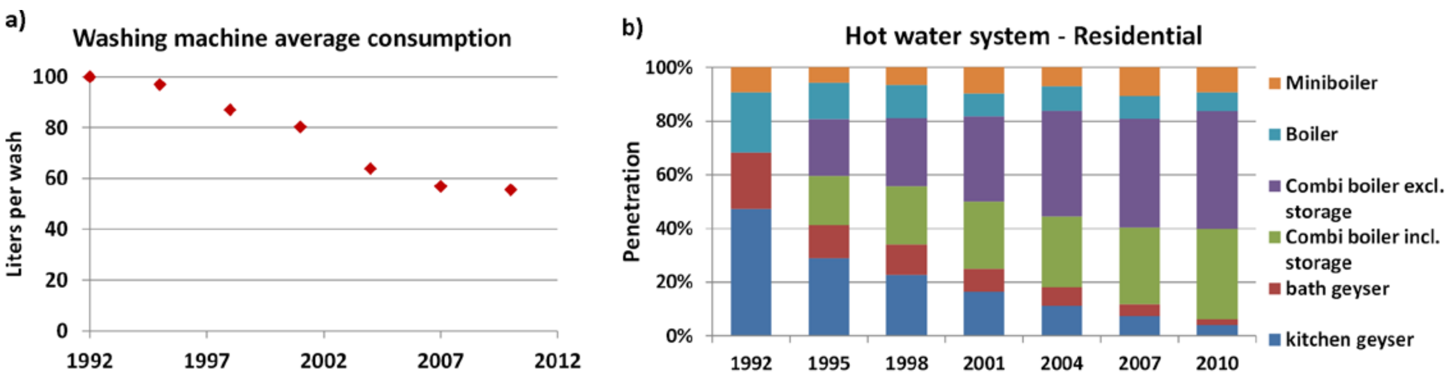

Figure 2. Transition towards more efficient energy efficient appliances in the last two decades a) average water consumption per wash, b) penetration of different hot water systems at residential level.

1 Richtlijnen voor de aanleg van drinkwaterinstallaties
2 Nationaal Overlegplatform Warmwater
3 ISSO - 30 Tapwaterinstallaties in woningen
4 Aanpak Warmwaterbesparing

Despite all these changes in appliances and increasing hot water use, Dutch guidelines on design of drinking water installations for non-residential buildings were, until recently, based on measurements carried out between 1976 and 1980 and there were no guidelines for predicting hot water use. As a result, suppliers of heating systems use company specific guidelines. In general, these old guidelines overestimate the peak demand values. These peak values are crucial for the optimal design of the water system. Badly designed systems are not only less efficient and therefore more expensive, but can also cause stagnant water, possibly leading to increasing health risks.

Determining design rules for efficient water-energy design at the building level

In the late 1970s, it was found that the "new" dangerous *Legionella* bacteria could grow in hot water. It was only after 1999, after a catastrophic outbreak, that strict regulations for *Legionella* prevention in drinking water were introduced in The Netherlands. Audits of water companies made clear that a lot of water systems were not safe enough. The need for safe and reliable (hot) water systems was recognized, giving a boost to the development of new insights for the design and implementation of hot water installations. In 2001, guidelines for drinking water installation for buildings ISSO-55 were published, in which (hot) water use was still based on old measurements and calculation methods.

Understanding hot water demand is essential to select the correct type of water heater as well as the design capacity of the hot water device. For a proper design of (hot) water systems, the instantaneous peak demand or maximum momentary flow (MMF_{cold}), the peak demand of hot water, i.e. maximum momentary flow (MMF_{hot}) and the hot water use (HWU) need to be determined. A reliable estimation of these values for an arbitrary building (type and size) by on-site measuring would require an intensive and expensive measuring campaign and would consume a lot of time. Therefore, in 2003, the water companies and the installation sector (TVVL / Uneto - VNI) commissioned KWR Watercylce Research Institute to investigate the possibilities of simulating the (hot) water demand patterns. This led to the development of SIMDEUM® (SIMulation of water Demand, and End-Use Model). SIMDEUM simulates water demand over the course of the day on a per-second basis, based on information on end uses, fixture characteristics and user behaviour.

Approach to simulate (hot) water use patterns

SIMDEUM for non-residential water demand follows a modular approach. Each building is composed of functional rooms, characterised by its typical users and water-using appliances. The characteristics of the users and the appliances are different for each type of building are extensively described (Blokker et al., 2010; Blokker et al., 2011). Different categories were researched viz. office, hotel, nursing home. Within each category different typologies were defined. The typologies vary in types of appliances, like types of toilets, flow of showers, and in the type of users, like business or tourist hotel guests. With this approach, water demand patterns over the day for cold and hot water demand were simulated for a specific building. From these daily water demand patterns, the characteristic peak demand values of cold and hot water during various time steps were derived. These characteristics formed the basis for new design guidelines. A more detailed description and validation of the method is described in Pieterse-Quirijns et al., (2013). The validation shows that the model predicts the cold and hot water daily demand patterns reasonably well to good. **Figure 3** shows the validation for a nursing home.

With this 10 year study, more insight into the actual (hot) water consumption was gained. Simulating the water demand patterns with SIMDEUM showed to be a reliable method to predict water peaks and daily water patterns, leading to an update in the guidelines for design of hot water systems. Detailed insight into water use per functional room was also gained, allowing for a customized design per building. **Figure 4** shows the variation of (hot) water consumption per bedroom for a business hotel with two different shower types and for different hotel size. It shows 40–50% of total water use in hotels is heated.

Based on the results, new design rules were determined and better understanding of the water and energy nexus at building level according its function was gained. The design rules allow a better choice of the hot water system, resulting in smaller systems using less energy. Additionally, the stagnancy of water is reduced, thus less hygienic problems are expected. In the revised version of the ISSO 55 guidelines, the new design rules based on SIMDEUM are included.

Integrated approach for water and energy

The end-use approach of SIMDEUM allows simulating and understanding hot water demand for different buildings. SIMDEUM determines (hot) water use as well as the energy use related to water-use activities, providing a better understanding of the water-energy nexus at

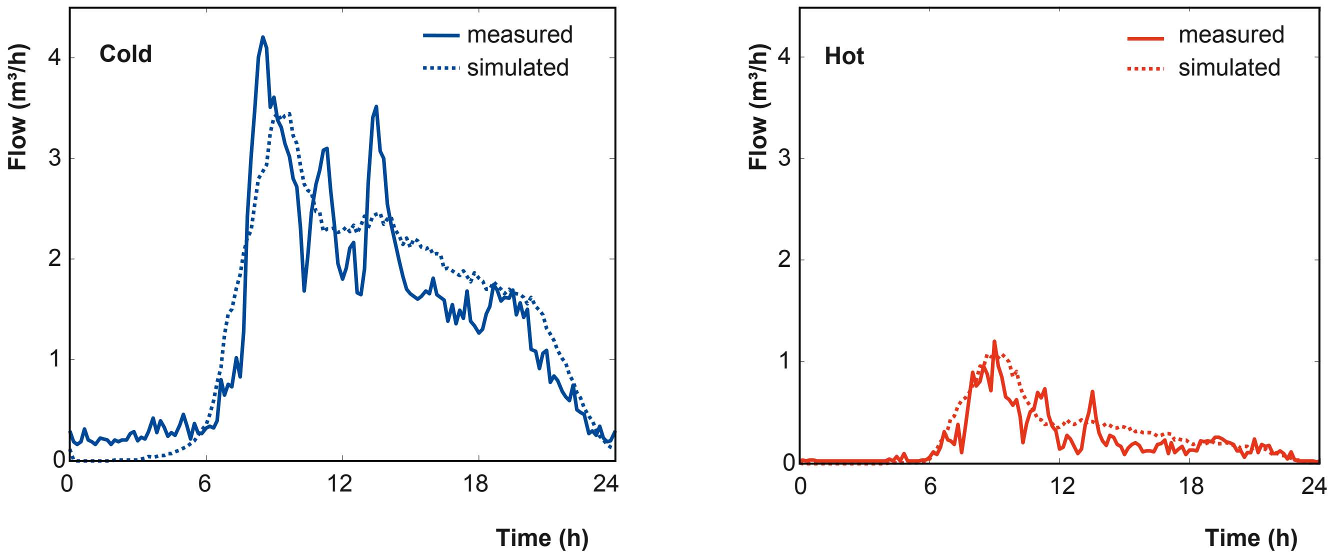

Figure 3. Validation of the design rules for cold and hot water use in a nursing home.

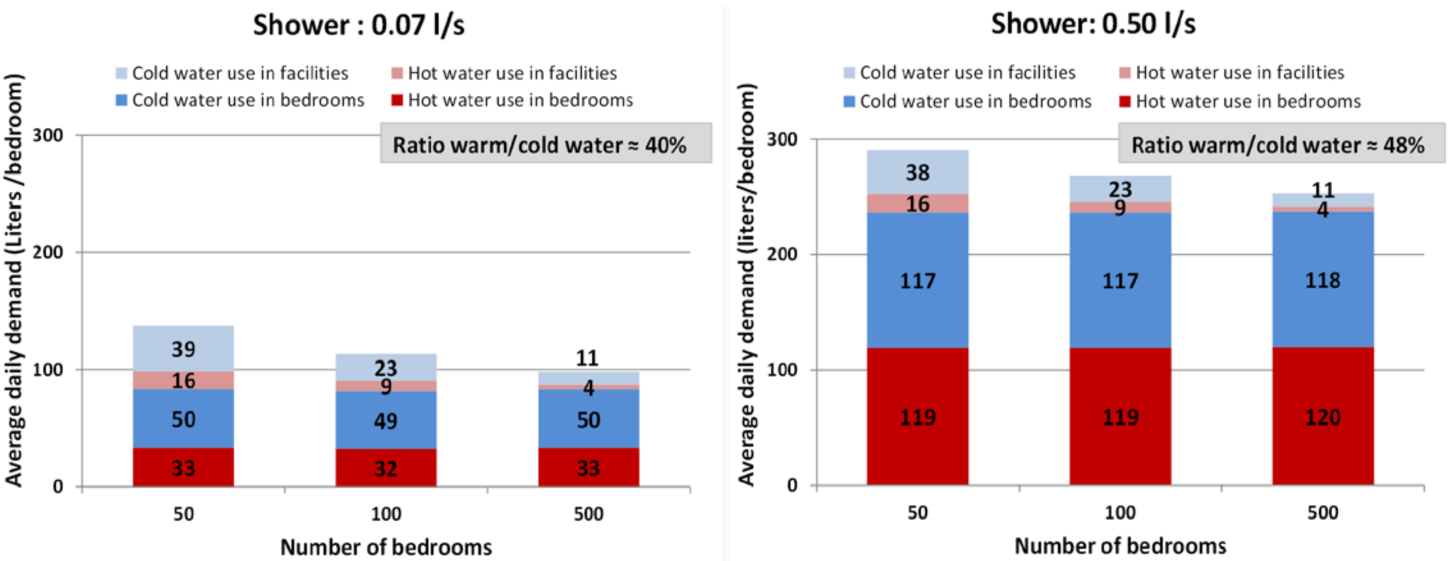

Figure 4. Variations in the daily water use in a business hotel according number of bedrooms. a) for a water saving shower head and b) for a luxurious shower head.

the building level. Furthermore, recent technological developments such as drain water heat recovery systems, require insight into the characteristics of the drainage loads. SIMDEUM is being extended to calculate discharge characteristics, which can be used for instance to design these new systems. Moreover, SIMDEUM's approach facilitates scenario studies considering changes of fixture characteristics, legislations or user behaviour, to predict future water and energy use of buildings.

Conclusions

Water-energy nexus at the building level is strong but complex since it is specific for each building type. Moreover, it depends on user behaviour and fixture characteristics, which change over time driven by different factors, from legislation to comfort. New flexible approaches such as SIMDEUM, which consider water and energy simultaneously, support the design of more efficient resource use at building level. ■

References: See the complete list of references of the article in the html-version at **www.rehva.eu** -> REHVA Journal