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La Torre Rapp, V., Knutsson, J., Wallin, J. (2024). Stakeholder-driven development of a decision support framework targeting sustainable water
supply systems. Energy Reports, 12: 2306-2320. http://dx.doi.org/10.1016/j.egyr.2024.08.030

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Energy Reports 12 (2024) 2306–2320

Contents lists available at ScienceDirect

Energy Reports

journal homepage: www.elsevier.com/locate/egyr

Research paper

Stakeholder-driven development of a decision support framework targeting sustainable water supply systems

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ARTICLE INFO

Keywords:
Rainwater
Greywater
Blackwater
Condensate
Cold water
Energy potential

ABSTRACT

The energy and water demand are expected to increase as a consequence of industrial development. The water streams in a typical building could however be used in a more energy and water efficient way to mitigate these challenges. Unfortunately, there are limited ways to evaluate and compare these system solutions. Thus, this study aims to identify the potential of different water streams within a typical building, their energy and volumetric potential and the areas of interest that can serve as a basis for a framework used for the evaluation of a system solution. A literature study will be performed to identify possible aspects of interest and to identify prevailing water stream within a building. Semi-structured interviews will also be conducted with stakeholders operating within the field which will work as a basis to develop the framework of areas and parameters of interest. Eight water streams were identified within a building where the stream with the largest volume was cold water, greywater and blackwater and the streams containing the largest energy content where cold water, rainwater and condensate. The interview produced several issues where, after processing, three different general aspects and 10 areas of interest were identified. Rainwater has shown to have the potential to work as an energy source for evaporative cooling due to the volume and high quality. By separating the sensible energy from the grey water and utilizing both, both resources enable proper use for higher acceptance amongst tenants.

1. Introduction

It is estimated that over 2.2 billion people do not have access to clean water and a further 2 billion live in areas subjected to high water stress (Bhushan, 2020). In addition, the population is expected to grow to around 10 billion people by 2050, which will further increase the demand for resources such as food and water. Burek et al. (2016) estimated an increase in water demand of 20–30 % globally by 2050 compared with 2010, while OECD projected global water demand to increase to 55 % by 2050 from 2000 (OECD, 2012). Even if much of the water demand increase is expected to mostly occur in Africa, South America, and Asia, Europe is expected to increase its water demand by 9–35 % as a result of technological development. The main driving force for increased water demand are the industrial- and energy sectors, but significant increases are also expected in domestic and municipal demand as a consequence of industrial development (Burek, et al., 2016).

Looking at Sweden, the situation in the south and the central regions as well as the coast of Sweden is typically more challenging due to low groundwater levels and dense population. This also includes regions such as the islands Öland, and Gotland (Statistiska centralbyrån, 2017). Locally stressed water situations can also occur where the groundwater deposits are low and often occur during the summer when the agricultural water demand increases in combination with the sudden increase in population when people leave the cities in favor of the countryside (Statistiska centralbyrån, 2017).

As the global temperature increases, the water situation will likely further exacerbate, as extreme weather events such as monsoon and heat waves, resulting in floods, drought forest fires, etc. have become more likely. These increased chances of compound extreme events have likely been influenced by human activities (IPCC, 2021). Climate change will ultimately result in an increased risk of affecting access to water, forest fire, health, floods, health, economic growth, food supply, and supply capability. Society needs to adapt to climate change and secure a long-term sustainable and robust society in the future. To enable climate adaptation, the Swedish National Council for Climate Adaption states that the focus must shift from problem-oriented toward solutions-oriented and enhance intercommunication between the public and the private sector to overcome future challenges (Nationella expertrådet för klimatanpassning, 2022).

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https://doi.org/10.1016/j.egyr.2024.08.030
Received 29 April 2024; Received in revised form 9 August 2024; Accepted 10 August 2024
Available online 22 August 2024
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Nomenclature and Abbreviations

BOD	Biological oxygen demand
BW	Blackwater
COD	Chemical oxygen demand
DHW	Domestic hot water
GW	Greywater
GWP	Global warming potential
HVAC	Heating, ventilation and air conditioning
RW	Rainwater
RWH	Rainwater harvesting

The International Energy Agency states in the World Energy Outlook report that the path to mitigating climate change using lower carbon technology could aggravate water stress if not properly managed. The growing water demand also puts pressure on existing infrastructure and energy systems (IEA, 2022). The existing water system is obsolete and lacks sufficient financial support for proper maintenance.

In 2014, around four percent of the global electricity consumption was used within the water sector for extraction, wastewater treatment, water distribution and around 50 million tons of oil (IEA, 2016) posing a big challenge ahead in order to achieve an energy system solely using renewable energy sources. IEA (2022) also states that expanding the use of electricity within this sector could be a way to mitigate the carbon emission. However, the energy demand within the water sector is projected to double by 2040 which entails further challenges to the expected electricity-dependent future. By looking at the different streams of water within the built environment itself, the energy in the water could also be seen as a potential resource that could be utilized. For example, studies have shown that the chemical content of wastewater is many times larger than the energy used for treatment (Korth et al., 2013; Shizas and Bagley, 2004). To achieve this, several different system solutions have been investigated such as wastewater recirculation, water-efficient appliances, and using alternative water resources (Knutsson and Knutsson, 2020; Stephan and Stephan, 2017; Villarreal and Dixon, 2004; Upshaw et al., 2017; Jin An et al., 2015). Here performance may depend on different parameters, such as building system structure, type of building, geographical location, season, etc. (Al-Quasi et al., 2020). In addition, by expanding the system boundaries to include streams of water handled by the infrastructure such as stormwater, potential extraction of energy and cost reduction can also be achieved, for example utilizing stormwater for a pumped stormwater system in combination with PV (Coban, 2023).

As lower carbon emission does not necessarily mean lower water use it is important to carefully evaluate every system solution and implement an adequate sustainable water demand in such a way that, mitigation of water use, energy intensity, and environmental impacts can be achieved (Lee and Tansel, 2012). In addition, performance criteria will vary depending on the type of stakeholder involved, and therefore a holistic perspective is important in demonstrating strengths and weaknesses of various solutions. Unfortunately, there are limited ways to evaluate and compare these system solutions from a general point of view, which causes challenges associated with the decision-making of the most suitable system. A life cycle assessment method is often used to assess the impact of a different system designs and estimate energy, water, cost or environmental impact (Stephan and Stephan, 2017; Leong et al., 2019; Bonoli, et al., 2019). Opher et al., (2019) integrated an analytical hierarchy process (AHP), a multi-criteria decision analysis (MCDA) to the LCA to improve the analysis. Other studies may include only one aspect such as economic feasibility (Rodríguez, et al., 2020; Friedler and Hadari, 2006; Oviedo-Ocaña et al., 2018), water saving potential (Muthukumaran et al., 2011; Villarreal and Dixon, 2004; Jin An et al., 2015) or energy savings (Hviid et al., 2020; Vieira et al., 2014; Kalz et al., 2010; Gao et al., 2019). Some studies may instead include two or more aspects (Matos et al., 2014; Licina and Sekhar, 2012; Knutsson and Knutsson, 2020). This creates an inconsistency in terms of evaluation and ultimately leads to difficulties for decision makers to perform comparisons. A holistic and dynamic evaluation framework could therefore constitute a foundation for a better understanding of the potential of different system solutions, and thus help stakeholders to make more adequate decisions.

Today, such a holistic evaluation framework for water system solutions is largely absent. Thus, the objective of this study is to identify the potential of different water stream within a typical building and the areas of interest that can serve as a basis for a framework used for the evaluation of a system solution of a building from a water-energy perspective to provide a versatile reflection to facilitate further decision-making and assessment of various system solutions, ultimately create a framework for evaluation categories. Furthermore, this study aims to display possible obstacles between the interest of stakeholders and the potential of different streams of water to in terms of the energy content, quality and volume.

2. Material and methods

To develop the framework the methodology follows a structure of three separate steps: to identify possible streams of water, determine parameters of interest and analyze the generated results from stakeholders. The ultimate formulation of the framework follows a bottom-up structure where specific parameters of interest are identified and then used as a basis to establish a general framework for evaluation, thus identifying areas of interest from a broad spectrum of stakeholders operating with a different point of view within the area. Ultimately creating a framework with a similar structure as in the Sustainability Index and Smart Readiness Indicator but focusing on the water supply system linked to buildings and society. A view of the process for shaping the framework is seen in Fig. 1. In addition, to determine the volume and energy potential simultaneous processing and evaluation of each water stream will be done in a more qualitative manner by classifying the water stream in terms of volume, energy content, and quality.

2.1. Literature review

Since it is critical to first understand the system outline of the water streams in the built environment, an extensive literature review was conducted. The review included identification of streams of as well as state of the art system design for identified water streams for reduction of water and/or energy demand or consumption. In addition, the literature review also aimed to identify aspects that in previous research individually have been addressed; thus, creating a portfolio of different aspects of interest. Simultaneously the literature review aims to identify different water streams (or streams of water) in a building, to try to categorize them in order facilitate identification of parameter of interest for each water system during the semi structured interview.

To perform the review, a set of criteria were used, including already known types of water streams within buildings such as cold water, domestic hot water, greywater and blackwater, rainwater and condensate. If other water streams where identified, they were included as well. This was in general based upon already existing vocabulary used within the research field and in turn is based upon difference in quality and purpose of the water stream. To narrow down number of papers, only papers including state of the art system so utilize water, with a clear energy perspective where addressed, including evaluations of such system to identify possible evaluation parameters. I addition, consumption pattern, and papers addressing the properties of the water streams were also included. The procedure followed a snowball process where a set of papers where used to generate other papers.

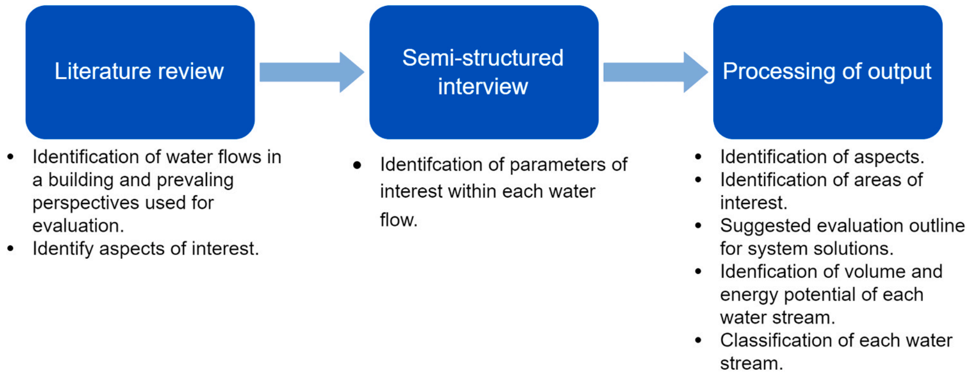

Fig. 1. Process for the shaping of evaluation framework.

2.2. Semi-structured interview

The objective of the interview was to achieve an as comprehensive of a view as possible within all the different actors in the field. This includes the national board of housing building and planning, that is the administrative authority regarding built environment, construction and management of buildings etc., property owners, that own and manage a large fleet of different kinds of building, water supply companies, that supply water and treat wastewater within a region (or municipality), municipalities, that have the outmost responsibility for the growth of the water infrastructure and the building environment, and consultants, playing a part in designing and plan energy- and water systems within buildings. By including at least one in each category, the aim was that this would be enough to attain such a versatile view that the identify the most important factors from all stakeholders involved could be identified, thus limiting the possibility that any interesting factors were neglected.

The criteria used to identify the organization was size, previous project with a clear water perspective involved in and proximity either Stockholm or Gothenburg, where the interview would take place. Thus 12 organizations where identified and consequently an invitation was sent to. This includes consultants within energy and environmental issues and grey water reuse in buildings (6), representatives from water supply sector (2), municipalities (1), property owners (2) and the national board of housing building and planning (1). The stakeholders consisted of one representative from 13 different stakeholders (were two represented the same organization from different cities).

The structure of the interview was based upon two pillars: To sort out and identify parameters of interest for each water stream and specific potential issues and demands related to each water stream and discuss both potential new system solutions and potential issues using that specific water flow as a foundation. The participants were given a few minutes to note each issue (i.e., parameter of interest) themselves to enhance their tendency to be able to contribute by participating in the discussion.

2.3. Processing of output – cross-comparing of parameters and aspects and formulation of framework

By using the output of the semi-structured interviews, a portfolio of different parameters in interest were identified. To further narrow down these parameters and present a clear set of aspects, a clustering was performed. This clustering was done for all parameters identified at the same time since all streams of water are well integrated and connected and related to each other in such a way that many of the parameters of interest are applicable for all streams. This enables the ability to cluster parameters across the earlier division, creating areas of interest based upon one or several parameters. Each area of interest is supposed to be distinctive and descriptive, and ultimately deliver a clear view of each relevant parameter that can be used as a guidance to determine how a proposed system solution performs within that specific area of interest. The criteria for such an aspect are to be easily measurable, easy to comprehend, and used within existing literature to measure performance in any way to facilitate identification of measurable parameters.

In addition, an effort to further cluster each parameter of interest is to be performed, based upon similarities. This was done to generate overall aspects and in turn facilitate decision making and categorizing to display the effect of each parameter of interest from a broader perspective.

2.4. Estimation of volumetric and energy potential

To estimate the corresponding volumes for each water stream identified, several assumptions are made to get a general estimation. These are predominantly based on statistics, in data used for energy simulations, and common practice used within the Swedish building fleet, see Table 1 for more details. In addition, precipitation and temperature data have been collected from the Swedish Metrological and Hydrological Institute for the year 2022 for Stockholm (SMHI, 2023).

3. Theory

This literature review resulted in a total of 125 papers divided into 8 categories, see Table 2. These worked as a basis to perform identify possible parameters of interest, potential issues and state of the art system solutions that in turn was used as a basis to help the stakeholders during the interview.

3.1. Investigation of different water streams in a typical building

Water serves as a conduit for the transfer of thermal energy and waste materials, playing a crucial role in various building systems beyond its primary usage as a resource of consumption. Expanding on this concept, utilizing the diverse water streams as an initial step can aid in pinpointing and cultivating potential energy-saving solutions within the sector. This includes innovations like heat recovery and wastewater sludge incineration (Frijnis et al., 2013), which not only enhance efficiency but also lessens the overall dependency on the resource itself. The water system in a typical building consists of several different water streams, each with different purposes; here divided into 9 different streams, Rainwater, Humidity, Heating, Cooling, Mains water, Greywater, Blackwater, Condensate and Stormwater.

In turn, these can be divided further depending upon how they act and behave. Rainwater, stormwater and humidity are typically parameters linked to geographical and seasonal characteristics, even though requirements regarding humidity can be demand dependent. These will hereby be seen as *natural water streams*. To make a building comfortable to live in, an adequate temperature must be maintained; this results in

Table 1
Data used for estimation volumes of each water stream for an office and for a multifamily building.

Office			
Parameter		Unit	Reference
Area	1000	m^2	-
Number of occupants	20	m^2/p	(SVEBY, 2012)
Min indoor temp	21	°C	(Boverket, 2018)
Max indoor temp	25	°C	(SVEBY, 2012)
Ventilation hours	07–18		Assumed based on common practice
Number of floors	6		-
Roof area	166.7	m^2	-
Ventilation flow	1 + 7	l/(s m^2)+ l/p	Based on common recommendations
(Total) Water demand	14	l/(p d)	
GW production	6.3	l/two-empl., day	(Moslemi Sadeh et al., 2013)
BW production	21.6	l/two-empl, day	(Moslemi Sadeh et al., 2013)
Supply temp, air	20	°C	Assumed based on common practice
Cooling circuit	10	°C	Assumed based on common practice
DHW	2.5	L/empl. day	(Fuentes et al., 2018)
Multifamily building			
Parameter		Unit	Reference
Area	1000	m^2	-
Number of occupants	33	m^2/p	(SVEBY, 2013)
Min indoor temp	21	°C	(Boverket, 2018)
Max indoor temp	-	°C	(SVEBY, 2013)
Ventilation hours	At all times		Assumed based on regulations
Number of floors	6		-
Roof area	166.7	m^2	-
Ventilation flow	0.35	l/(s m^2)	Based on common recommendations
(Total) cold water demand	138	l/(p d)	(Svenskt vatten, 2023a, 2023b)
Share of GW	78.5	%	(Knutsson and Knutsson, 2020)
Share of BW	21.5	%	(Knutsson and Knutsson, 2020)
DHW	34	l/(p d)	(Ahmed et al., 2015)

Table 2
Number of papers included in the review divided per water stream. Note that some papers include aspects from multiple water streams but are only counted once.

Category	Number of relevant papers
Rainwater and stormwater	32
Humidity	8
Heating system	11
Cooling system	5
Cold water	11
Greywater	36
Condensate	12
Blackwater	10

heating and/or cooling of some sort. In addition, potable water is also expected to be provided within the building; thus, it constitutes the *demand-dependent water streams*. As a consequence of these services, and since water is used as a medium for transportation, water has to be discharged from the building. These are therefore hereby called *released water streams* and include greywater from showers, taps, etc., blackwater from WC, condensate from cooling units, and stormwater.

Since each water stream provides different services, temperatures, flow patterns, qualities, and is bounded by different regulations, they may as well provide different opportunities and limitations when developing novel system solutions (Lopez Zavala et al., 2002; Willis et al., 2013). A summary view of these streams and their interface are presented in Fig. 2 below.

3.2. Rainwater and stormwater

Rainwater usually starts as ice crystals that melt through the different atmospheric layers falling toward earth. The temperature differences between the rain droplets and the air are usually 1° C but can be larger during the initial phase before the maximum rainfall rate has been reached (Moses et al., 1949).

Rainwater is a very promising water resource and rainwater harvesting (RWH) systems are usually simple to install and have low running costs and may reduce the maintenance and operational problems compared to a centralized water supply system (Lee et al., 2010). Rainwater has generally been used to replace mains water for toilet flushing (Vieira and Ghisi, 2016), laundry machines (Vieira and Ghisi, 2016), showering (Talebpour et al., 2014) and irrigation (Talebpour et al., 2014). However, the availability of rainwater can vary greatly depending on location and season, and to be able to harvest sufficient quantities of rainwater to meet the demand, large collection surfaces may be needed, as well as significant storage capacities. Other ways to use rainwater is for evaporative cooling due to low mineral content (Hviid et al., 2020) or as thermal storage for cooling purposes (Upshaw et al., 2017).

The quality of rainwater may depend on several parameters, including the catchment areas and region (Zdeb et al., 2018; Schets et al., 2010). Furthermore, the condition of the catchment area depends on human/animal activity, geographical location, proximity to various pollutants, number of proceeding dry days, and season (Lee et al., 2010).

In terms of energy, using rainwater may increase the overall energy usage if the system boundaries are set to the building envelope, since the energy intensive treatment of the effluents at the wastewater treatment facility would otherwise offset the consumption of pumps and other components of the rainwater handling and treatment (Vieira et al., 2014). On the other hand, using rainwater can potentially reduce electricity cost and replace cooling delivered by refrigeration units (Upshaw et al., 2017; Hviid et al., 2020).

Stormwater is a broad term that includes rainwater as well as snow, melted ice, and runoff water from different surfaces such as paved areas, roofs etc (International Organization for Standardization [ISO], 2016). Since urban areas commonly contain a high proportion of paved areas and impervious surfaces it alters the volume, velocity, and the timing of surface runoff water (Hollis, 1975; McCuen, 1979). This also increase the concentration of pollutants in the water but using Low Impact Development (LID) techniques can greatly reduce these impacts on water bodies downstream (Dietz and Clausen, 2008).

There are many techniques today to manage these water flows, including detention-, retention- and infiltration management, but in recent years more focus also lies on local treatment. In addition, in areas that experience water shortages and excess storm water, due to large number of impervious surfaces, storm water management as well as sustainable urban drainage can help to provide water and renewable energy from the resource (Jones and Macdonald, 2007; Coban, 2023). The proportion of stormwater ending up in the wastewater system may as well decrease which in turn decreases the volume of water that has to be treated (Statistiska centralbyrån, 2017).

Generally, one of the best ways to keep the system safe and clean and to help treat potential harmful water is to install first flush filters or diverters. This will help to avoid substances that degrade the quality and can give an unpleasant odor or color (Lee et al., 2010).

3.3. Humidity

Depending on climate, the humidity can vary significantly which in turn affects the energy demand for a building. High humidity results in higher energy content of the air, which means that more energy must be

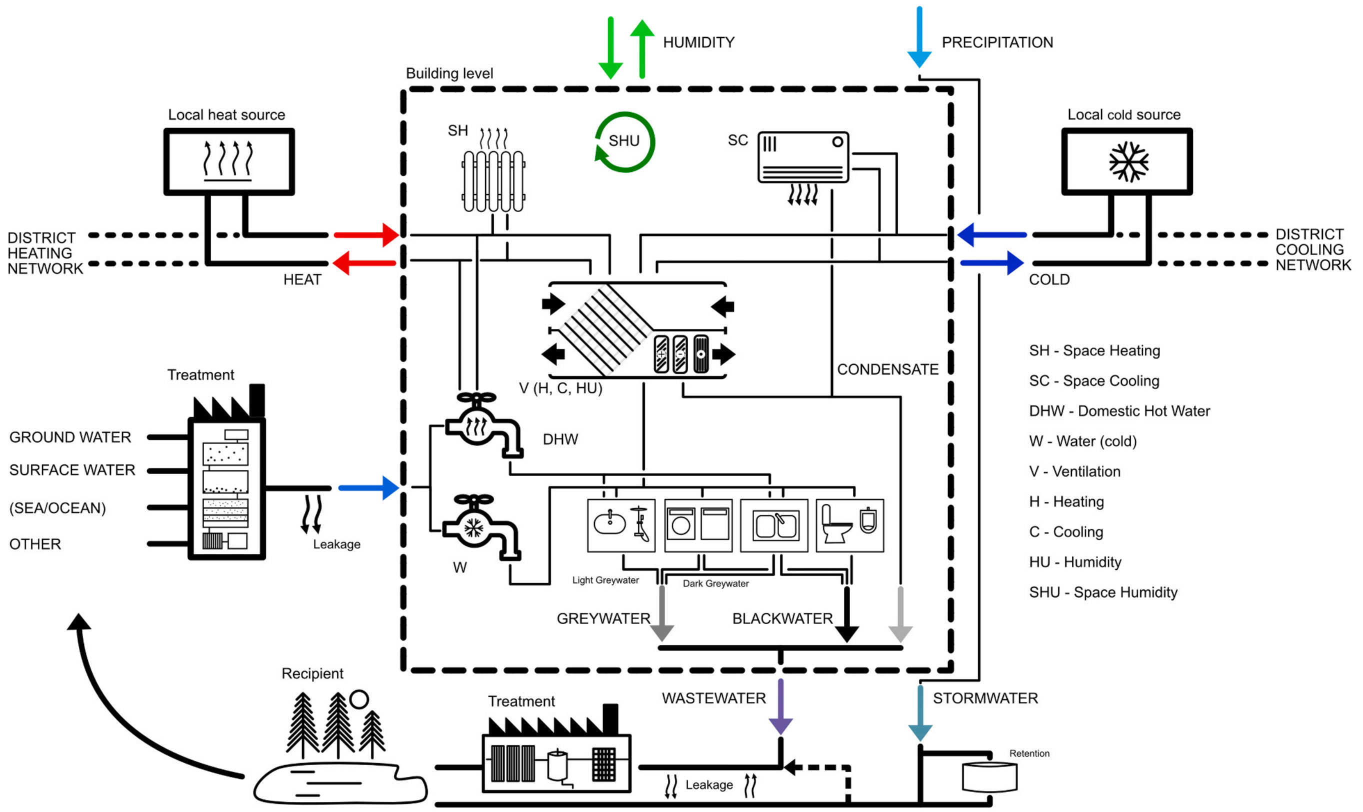

Fig. 2. A holistic view of the 9 water streams identified in or in the proximity of a building.

supplied to the body of air to cool or heat it. This especially affects the cooling demand since the system also must cover the latent heat while condensing the water. In Sweden, the humid air state is generally not controlled indoors which results in a high relative humidity during the summer season and a low relative humidity during the winter season as a consequence of heating of the supply air.

Change of humidity can be done either by cooling down the air to a lower temperature than the atmospheric dew point, or by extracting water vapor using a solid sorbent (or a concentrated liquid) (Wang et al., 2017) where energy sources such as wind, solar, heat sinks, or deep-sea water can be utilized. However, the energy used for condensing water (counteract the latent heat) would be an order of magnitude larger than water purification methods (Bergmair et al., 2014), but in remote areas where the accessibility of freshwater may be limited, water extraction from the air may be a way to avoid long transportation of water (Bergmair et al., 2014). In such cases, renewable energy resources such as solar should be used (Bardi, 2008).

3.4. Heating system

Common heating sources in Sweden include district heating, were biomass is the main fuel used, ground source-, or air source heat pump, but other sources are also utilized (Energimyndigheten, 2022). The main energy carrier is water, and the demand can usually be divided into three distinct demands: space heating, heating of ventilation, and domestic hot water (DHW) corresponding to 55,2 % (space heating and ventilation) and 14,2 % (DHW) of the total energy consumption of a residential building in Sweden (Eurostat, 2020).

According to the Swedish building codes and regulations, domestic hot water should be heated to at least 50 °C but it is not unusual that the eater it heated to 55 °C) or 60 °C in accumulator tanks to avoid the growth of Legionella Pneumophilia (Boverket, 2020) which is well above the required temperature for typical end-uses like showering, cleaning etc. The hot water consumption pattern varies depending on the type of building, region, country, and culture but it usually exhibits peak usages during the day, for example one in the morning and one in the afternoon or evening (Fuentes et al., 2018), but also variations throughout the course of the week such as in Fig. 3.

The total DWH consumption may vary from 20 liters per person and day (lppd) in the UK to, 34 lppd in Sweden (authors own data) and 94 lppd in Canada in households. Studies show that a majority of the DHW is used for shower purposes (Knutsson and Knutsson, 2020; Harvey, 2006 as cited in Fuentes, et al., 2018).

Aa a consequence of the conventional system design and regulations prevailing in Sweden, a recirculation system of the DHW system is

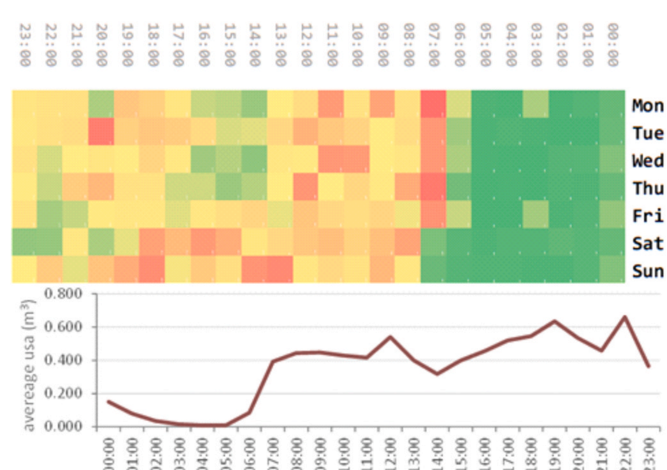

Fig. 3. Heatmap showing hot water usage pattern in a apartment building in Gothenburg, Sweden comprising 29 apartments. Average consumption per hour and weekday. Data was collected for one full year. dark green = lowest usage (0.001 m3/h), dark red = highest usage (0.798 m3/h). (previously unpublished data of the authors).

typically used, aiming to provide hot water very quickly at each use point. These DHW circuits cause heat losses which further increase the heating demand.

3.5. Cooling system

Like the heating system, the cooling system provides cooling for space and ventilation to meet the temperature set points. Cooling is commonly supplied using cooling units (air-to-air) but can also be supplied by a district cooling system. Due to the relatively moderate climate in Sweden, cooling systems are mostly used in commercial buildings (Wernes, 2017). The cooling demand depends on outdoor temperature, internal gains, solar radiation, and the heat island effect.

From a thermal point of view, the purpose of the system is to remove excess heat from the system. This heat can sometimes be utilized to reduce heating demand by heating up ventilation, space or DHW directly and simultaneously reduce the energy demand. The heat can also be distributed into the district heating network and supply nearby buildings. Typical buildings where the excess heat can be utilized are supermarkets or data centers where the cooling demand usually is high (Dorotić et al., 2022), and the energy can be shared with neighboring buildings to increase energy efficiency within that district (Hachem-Vermette and Singh, 2022).

3.6. Cold water (mains water)

Of the total withdrawal of freshwater in Sweden in 2015 (including all sectors), 80 % of the potable water supplied to buildings originates from surface water such as lakes; 13 % originates from groundwater sources while 7 % is not specified. Of the total water used, 23 % is used for residential purposes and 61 % within industry. A majority, 88 % of the water to residential buildings, receives water from a municipal treatment plant. In addition, an equal amount is also connected to the communal waste treatment network. The treatment plants also take care of wastewater from the industries, especially from the food industry (Statistiska centralbyrån, 2017). The energy intensity of the water, i.e. the energy needed to provide water are greatly influenced by origin of the water and can differ from approximately 0.22 kWh/m^3 to up to 20 kWh/m^3 (Vieira et al., 2014; Svenskt vatten, 2023a, 2023b).

Mains water can be utilized for evaporative cooling to reduce the use of heat pumps or district heating but may have to be purified of mineral matter in order to avoid clogging in spray nozzles (Hviid et al., 2020).

3.7. Greywater

Greywater describes the effluents from services using water, such as showering, bathtubs, clothes washing and wash basins (ISO, 2018) and it is generally less polluted than blackwater. Even if the concentration of organic matter is lower in greywater than in wastewater, the concentration of some pollutants can be higher compared to wastewater since the water is not diluted with water from toilets or urinals. Such pollutants include detergent and boron. The characteristics of the effluent also vary depending on the services used, cultural habits, and the behaviors of the occupants (Gross et al., 2015) but also by detergent used and climatic conditions (Oteng-Peprah et al., 2018). Greywater can contain more nitrate, specifically the kitchen sink effluents if included in the greywater stream, than blackwater even if blackwater contains a majority of the total amount of nitrogen, but in the form of ammonia (Lopez Zavala et al., 2002).

Greywater can be further divided into streams which is usually done depending on the degree of pollution. Common divisions are high-load and lower-load, or black greywater and light greywater. Lower load or light greywater consists of streams originating from bath, showers, and wash basins while the rest of the streams, kitchen sink and washing machines, are allocated as high-load or black greywater (Lopez Zavala et al., 2002; Friedler and Hadari, 2006). The high-load greywater may also be defined as blackwater in combination with effluents from toilets and urinals.

In a study published by Knutsson and Knutsson (2020) the bathroom sink used 11.8 % of the total hot water and the shower used 51.9 % (63.7 % combined), while sink and shower comprised 54.6 % of the total greywater produced (including kitchen greywater) which reveals that most of the greywater is the effluents of showering water. Toilet flushing represented 33.1 % of the cold-water consumption (21.5 % of total water consumption).

The temperature of greywater may differ depending on the service it originates from, but effluents from showers usually are warmer than other uses. Studies show that the temperature can differ from 18 to 35 °C (Oteng-Peprah et al., 2018) or 15–42 °C (Oron, et al., 2014) but the average temperature is usually 27 °C. Consequently, greywater can act as a foundation for energy savings, by recirculating the water or taking care of the thermal or chemical energy in other ways (Frijnis et al., 2013; Knutsson and Knutsson, 2020).

3.8. Condensate

If a surface or a body of air has a temperature below the dewpoint, water will precipitate in the form of droplets. These may occur as a natural phenomenon (dew) but also within the heat, ventilation and the air conditioning (HVAC) system in a building, more specifically in the ventilation system and in the cooling system. The condensed water is then either discharged into the sewer or into the storm water system. Chemical analysis of condensed water from cooing units reveals that the quality is affected by geographical location, type of unit and periodic maintenance procedures, but generally its properties are close to distilled water or of good quality with low content of minerals and metals. With low-polish treatment the water could hence be used in the industries and relatively simple post-treatment could be utilized to make it potable (Loveless et al., 2012; Al-Quasi et al., 2020; Gandhidasan and Abualhamayel, 2005).

The volume of condensed water produced by cooling units and dehumidifiers strongly correlates with geographical location and volume of air. Regions especially suited for condensate water utilization would include the Arabian Peninsula, West Africa, Southeast Asia, and Central and South America (Loveless et al., 2012). However, the potentially accessible volume might be significantly lower than from other streams of water. A study by Stephan and Stephan (2017) showed that condensate water harvesting (CWH) covered <1 % of the base water demand of a building with a Mediterranean climate, while rainwater harvesting (RWH) could cover 4.8 %. However, a study have shown that CWH for flushing and irrigational purposes could be a viable solution in strained water supply systems (Loveless et al., 2012). Considering the high quality of condensate water also suggests that other reuse scenarios could be of interest.

3.9. Black water

Black water constitutes of wastewater from sanitary use and drainage from utensils cleaning activities and food preparation like dishwasher and kitchen sinks (ISO, 2018) but in some cases black water may however only refer to wastewater from sanitary use while drainage from food preparation and utensils cleaning are referred to as higher-load greywater or dark greywater (Friedler, 2004; Lopez Zavala et al., 2002). Of all the effluents leaving a building, wastewater originating from toilets is the most contaminated. It contains high levels of nitrogen and phosphorus, in the form of ammonia and phosphate, and has a high chemical oxygen demand (COD) and a high total suspended solids in relation to other effluents. It also contains high levels of nitrate even if greywater from kitchen sink may contain higher levels (Lopez Zavala et al., 2002; Sievers et al., 2016). Traditionally, potable water is used for flushing which means that reducing the water consumption of flushing or replacing the water resource will displace potable water demand to services where potable water is a necessity. In addition, due to the high content of organic matter and other pollutant, blackwater may as well be utilized as an energy source (Xue et al., 2016). By anaerobic digestion, the blackwater can be converted into methane gas and used in a combined heat and power plant. A study by Gao et al. (2019) showed that a higher biochemical methane potential (BMP) was achieved from conventional toilets (9 l and 6 l flushing volume) compared to vacuum-toilets, indicating that there may be a tradeoff between water saving and energy recovery potential. To access the energy content from a chemical point of view, the COD and the BOD can be used as a parameter to estimate the energy content from a theoretical point of view (McCarty et al., 2011).

Another approach could be to install separate piping systems for greywater and blackwater. However, a potential risk for cross-connection will prevail which may influence the characteristics of both streams and the uncertainty of the characteristics is much higher. These will in turn affect the treatment process (Tolksdorf and Cornel, 2017). Moreover, by treating kitchen waste and blackwater together in the anaerobic process, the methanogens efficiency could increase, which makes it a suitable method for biogas production on a decentralized scale (Wang et al., 2020).

3.10. Temperature signatures thought the year

By the change of season, temperatures of each stream of water may as well be affected. The cold stream usually has fixed operating temperatures meaning that the temperatures of the supply and return are going to be constant. The same applies to the heating stream. However, since the heating demand would decrease with increasing temperature, the supply temperatures within the building would decrease until it eventually reached the balance point of its energy signature. An important note is that with increasing temperatures, the water demand of other sectors increases, such as in the agriculture sector, but also the water demand for irrigation of gardens and ornaments. The increase in water demand may intensify by long periods of droughts leading to municipal injunction of limited water use from the. As people tend to leave larger cities during the summer month, higher restraints on the water infrastructure on the countryside tend to occur. (Willis et al., 2013; Mahmoudi, 2017) As the ground temperature increases the supply temperature of the cold water will also increase during summer month (Fuentes et al., 2018).

3.11. Evaluation frameworks

There are already several evaluation systems used today within buildings or the water system, including many certification systems such as LEED, BREEAM, and energy star. LEED is a certification system developed by the U.S. Green Building Council that focus on air quality, material selection, energy and atmosphere rainwater management water reuse etc. (v4.1). There are also some regional priority credits that can be achieved depending on the location of construction. Credits regarding energy and water constitute around 40 % (30 % +10 %) of the total credit achievable for new construction (USGBC, 2024). A new version focusing on decarbonization, quality of life and ecological conservation and restoration is set to be published in 2025. BREEAM is a certification system developed by the in the UK that is one of the oldest certification systems. Compared to LEED some countries have locally adapted versions of BREEAM. Credits regarding energy and water constitute around 28 % (22 %+6 %) of the total credit achievable for new construction. In addition, there is a predefined weighting factor for each are of impact result in a which may impact the total impact of the energy and water category (Building Research Establishment, 2021). Energy star is a certification system developed by The US environmental Protection Agency (EPA) focusing on construction that are more energy efficient. The certification system only focuses on the energy use intensity in relation to a predicted energy intensity, and gives a score passed on the national distribution (Energy Star, 2021).

3.11.1. Sustainability index

Svenskt vatten, has developed an index called sustainability index. The tool is used to evaluate the water supply and wastewater management from a long-term perspective in aspects such as accessibility to water and emergency-readiness, to enable long-term planning and needs for investments for the municipalities responsible for providing water to consumers. The tool does however only focus on facilities and the infrastructure rather than the buildings and premises using the services even though limited evaluation of energy efficiency is done in terms of energy use to provide the services and energy produced from the wastewater. The index is based upon three pillars; Sustainable services for consumers that focus on quality and health aspects of the water, assurance of delivery, satisfaction of consumers etc. Environmental stability focuses on the use of energy and finite resources, environmental regulations and water availability. Sustainable resources focus on the operational stability and status of the treatment facilities and competence of personnel. Each subcategory can receive either a score of "good", "should be reviewed" or "must be addressed" to indicate the severity, where within each subcategory there are multiple parameters that in turn receive separate grades and that make up to the total grade within each subcategory. These parameters are specific to each subcategory and can be based on measurable values such as "proportion of routine tests on mains water where water is unserviceable" or if there exist policies and planning regarding water shortages. Each municipality is evaluated individually on an annual basis and an aggregated result is achieved for each sub category in terms of proportion receiving each grade. The objective of the index it to provide an overview for municipalities what to focus on for future investments (Svenskt vatten, 2021b, 2021a, 2023a, 2023b).

3.11.2. Smart readiness indicator

Smart readiness indicator (SRI) is a tool used and developed within European union to estimate the accommodation of smart ready services. The tool asses different energy systems within a building including the control system and the building envelope. SRI-scores are displayed depending on domain and impact, creating a matrix like scoreboard for each specc (European Commission, et al., 2020).

4. Results

4.1. Energy and volumetric potential

The temperature of each water stream usually follows a signature resembling the outdoor temperature. Since the ground temperature lags, the temperature change of the mains water would also lag reaching its minimum and the maximum temperature after the minimum and the maximum outdoor temperature are reached respectively. Both the condensate and the rainwater temperature follow the outdoor temperature quite consistently while greywater in general would be a function of proportions between DHW and cold water as well as which type of appliance or service the water has served. Although it has a slight dependance of main water temperature, which can be seen in Fig. 4. In addition, data used for grey water is normalized per hour, hence it reaches even higher temperatures for shorter periods. From an exergy point of view condensate and rainwater are comparable to mains water while blackwater and greywater lies within the comfortable indoor temperature interval. It is evident that these streams would have a higher temperature due to their origin.

As the temperature plays an important role in the possibility of recovering energy, the quality of the water stream is critical as well as which type of treatment process is necessary depending on the purpose of the recycled water. For that purpose, it is important to distinguish the stream depending on the degree of pollution. As the water streams in general contain biological or chemical compounds, the biological

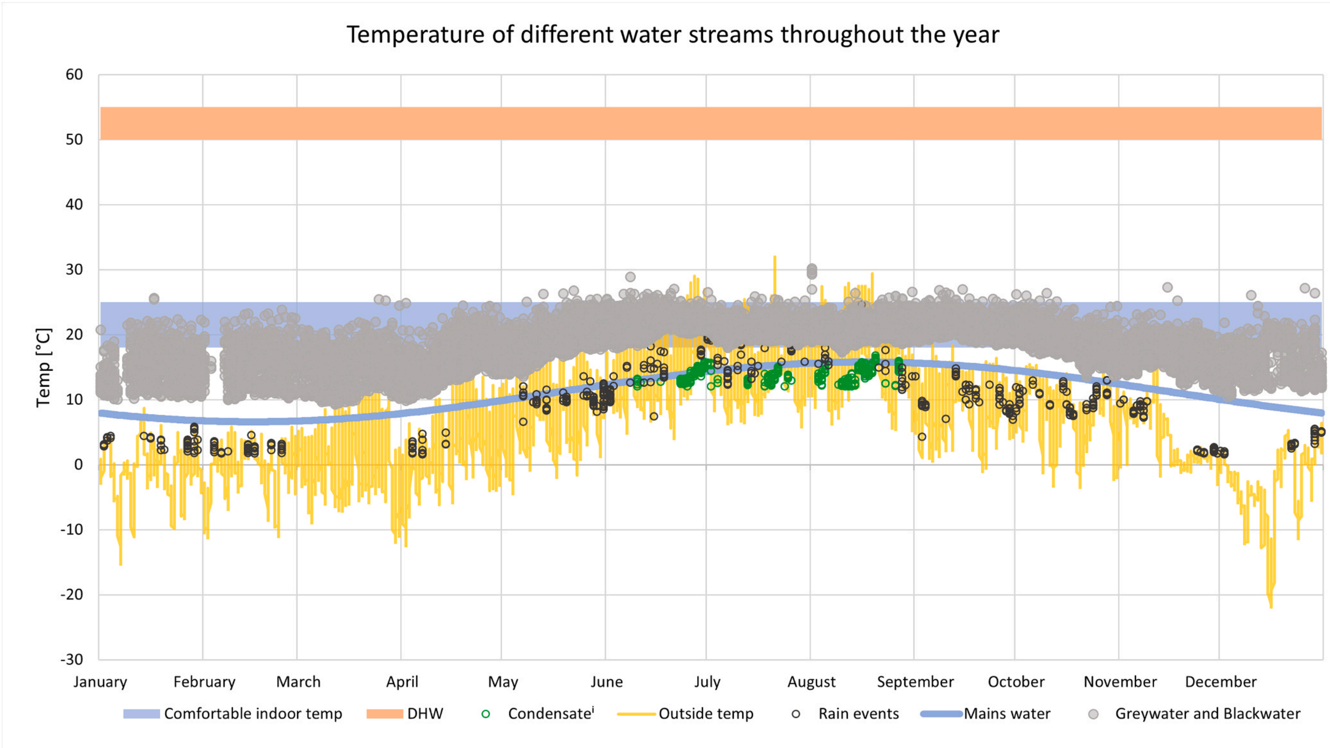

Fig. 4. Typical temperatures of different water streams thought the year (2022) from a Swedish context. Here, all precipitation events occurring when the outdoor temperature is 1.5 °C or higher are considered rain events.

oxygen demand (BOD) and the chemical oxygen demand (COD) are thus hereby used as a measure of degree of pollution. Based on this, 5 degrees of pollution (Table 3) are hereby defined for the purpose of this article, where 1 corresponds to heavily polluted water that can cause health issues and 5 corresponds to potable water.

Energy extraction is here divided into three different types, chemical, sensible, and latent heat, referring to the chemical and biological oxygen demand content of the water, change of temperature or phase transition respectively. As the COD and BOD are usually used to assess the energy content of wastewater (McCarty et al., 2011) it will therefore be used as a measure of the energy potential of blackwater. However, the nature of how the wastewater is dried (oven dried, freeze-dried, etc) to determine the theoretical energy content very much influence the maximum potential (Korth et al., 2013) so for the purpose of this article an energy content of 3.86 kWh/kgCOD is used (McCarty et al., 2011).

Since the energy content from a sensible point of view can vary depending on what the energy is used for, i.e. pre-heating of mains water, as a heat sink for a heat pump etc. it may not me entirely clear how energy could be extracted. Municipalities in Sweden that collect wastewater for treatment however have restrictions of minimum temperature of wastewater leaving the buildings. Hence, the sensible energy content of greywater would be considered as the difference of incoming cold water and outgoing greywater. From a latent energy point of view, phase change of water can be utilized to cool down air by evaporative cooling. Since other water sources, such as rainwater have been used for the same purpose (Hviid et al., 2020), both mains water, rainwater are viewed upon their latent heat. In addition, due to the quality of condensate and the relative simple treatment methods needed to make it potable, it is as well seen through the lens of its latent heat content (Loveless et al., 2012; Al-Quasi et al., 2020; Gandhidasan and Abualhamayel, 2005). A compilation of the potential uses of the water stream evaluated and total energy potential energy that can be extracted are shown in Tables 4 and 5.

Table 3
Categorization depending on quality.

Quality	Description
1	Water containing bacteria, high values of BOD and COD that can cause health issues if in contact with
2	Moderate values of COD and BOD
3	Water with low values of COD and BOD
4	Minor impurities and pollutants that can be treated with relatively simple methods to make it potable.
5	Potable water

The water stream with the largest volume is cold water, constituting a total of 1 526 m^3 based on 1 000 m^2 residential building which would approximately be the sum of greywater, blackwater and DWH. Condensate would make up the smallest potion of the total water volume in both residential buildings and office buildings, see Table 6.

The classification of each water stream based upon volume, energy content and quality can then be seen in Fig. 5. Here the three water streams with the highest energy content are rainwater, condensate, and mains water. These, including DHW, also constitute the water streams with the greatest quality. However, the largest volume would originate from cold water followed by greywater and blackwater and DHW.

4.2. Aspects of interest

Response frequency for the interview was 83 % with representatives from the Swedish National Board of Housing, Building and Planning, municipalities, water suppliers, technical consultants, property owners and water treatment companies. The interview was conducted as a hybrid meeting where the stakeholder where obligated to answer questions at first and then discuss their answers together. The outcome of the interview is shown below in Table 7. Here, the participants were responding with which aspects with respect to each water stream where of greatest importance when focusing on recycling, reducing or reuse.

Table 4
Suggested type of energy extraction from each water stream.

Water stream	Chemical	Sensible		Latent		Comment
		Heating	Cooling	Heating	Cooling	
Rainwater			X		X	Evaporative (and sensible) cooling of air
DWH		X				Heating of cold water
Cold water			X		X	Evaporative (and sensible) cooling of air
Greywater		X				Heating of cold water
Condensate			X		X	Evaporative (and sensible) cooling of air
Blackwater	X	X				Methanogenic + heating of cold water

Table 5
Energy content based on extraction possibility of each water stream.in kWh/m^3.

Water stream	Energy content [kWh/m^3]		Comments
	Residential building	Office building	
Rainwater	639	639	Enthalpy of vaporization 2257 kJ/kg water.
DWH	54	54	Based on annual mean temperature between DHW and cold water
Cold water	639	639	Enthalpy of vaporization 2257 kJ/kg water
Greywater	25	19	Based on annual mean temperature between greywater and cold water (authors own data and based upon volumes from Moslemi Zadeh et al. (2013)
Condensate	NA	639	Enthalpy of vaporization 2257 kJ/kg water
Blackwater	34	34	Based on annual mean temperature between greywater and cold water (authors own data) and 3.86 kWh/kgCOD (McCarty et al., 2011) with a COD concentration of 6 liter flushing (Gao et al., 2019)

Table 6
Annual estimated volume consumed in Sweden in a typical residential or office building of 1000 m^2 based upon assumption made in Section 2.4.

Water stream	Annual estimated volume [m^3]	
	Residential building	Office building
Rainwater	48	48
DWH	376	31
Cold water	1 526	215
Greywater	1198	80
Condensate	-	1.5
Blackwater	328	135

4.3. *Suggested areas of interest*

Due to the interconnection between the different water streams, a change of one stream may result in synergy effects, thus the parameters of interest may not only be of interest for one specific water stream but for all. It is therefore suggested that all parameters of interest are valid for all streams. To conceptualize all parameters and identify issues or performance for a separate stream Fig. 6 suggest an outline that should be used as a framework. In addition, since each stream can be assigned to a certain type of stream (*natural, demand driven, or released*) this enables further sectioning and summing of a final performance.

4.3.1. *Total flow*

Due to a linear water supply system (including use of further water stream) it is obvious that energy and water will be released to the environment (i.e., recipient), thus potentially causing effect on the surroundings. Hence, a parameter of estimating released volume is identified. This is, using a linear system, referring to the total water demand, which is common to evaluate measures reducing the total water demand such as water saving fixtures (Stephan and Stephan, 2017).

4.3.2. *Effect on climate*

All energy and resource consumption upon creating and operating the water supply infrastructure, including the supply of domestic hot water may ultimately affect emission of greenhouse gases. To constrain these and mitigate the effect on climate, a system design intended to act upon that principle may create additional important value for consideration. This aspect of very common to use in existing literature when evaluating these kind of systems (Matos et al., 2014; Xue et al., 2016; Leong et al., 2019)

4.3.3. *Used flow*

The prevailing linear water supply system does not facilitate recirculation of water or energy which results in low incentives from the system itself. In addition, energy and water may be lost along the way. To enhance the utilization of water resources a parameter that advocates for the actual use of water may be useful. In addition to recirculating water, or redirecting from another stream, a decoupling between actual demand and the total amount of withdrawal is created. This has especially of interest for GW recovery- and RWH systems where recovered greywater can cover a portion of the total water demand (Knutsson and Knutsson, 2020; Domènech and Saurí, 2010; Alsulaili et al., 2017).

4.3.4. *Monetary burden*

It is obvious that any resource is coupled to monetary matters through the whole distribution chain, from production to waste treatment, and that this possesses a critical influence on both operation and installation of a certain system. Evaluating the financial aspect of a system solution is already used, either my LCA (Stephan and Stephan, 2017; Leong et al., 2019) or by other means (Ni, et al., 2012; Devkota et al., 2013) to improve the view of the feasibility of a system design. Thus, 7 parameters of interest can thus be assembled to represent a monetary area of interest.

4.3.5. *Energy Load*

There is a strong water-energy nexus and a change in the linear water supply system as well as the in their water streams may initiate other synergies, affecting the overall energy demand. Energy demand is also common aspects evaluated besides the actual water use of an alternative water source (Hviid et al., 2020; Kalz et al., 2010; Matos et al., 2014).

4.3.6. *Share of demand*

When recirculating water, or redirecting from another stream, a decoupling between actual demand and amount of available potential resource due geographical, seasonal, or behavioral factors, often achieved when a released water source such as grey water is recovered and recirculated (Knutsson and Knutsson, 2020). The potential for using such a resource is therefore a product of the system design.

4.3.7. *Acceptance of system solution*

Incentives for developing and utilizing novel system solutions could

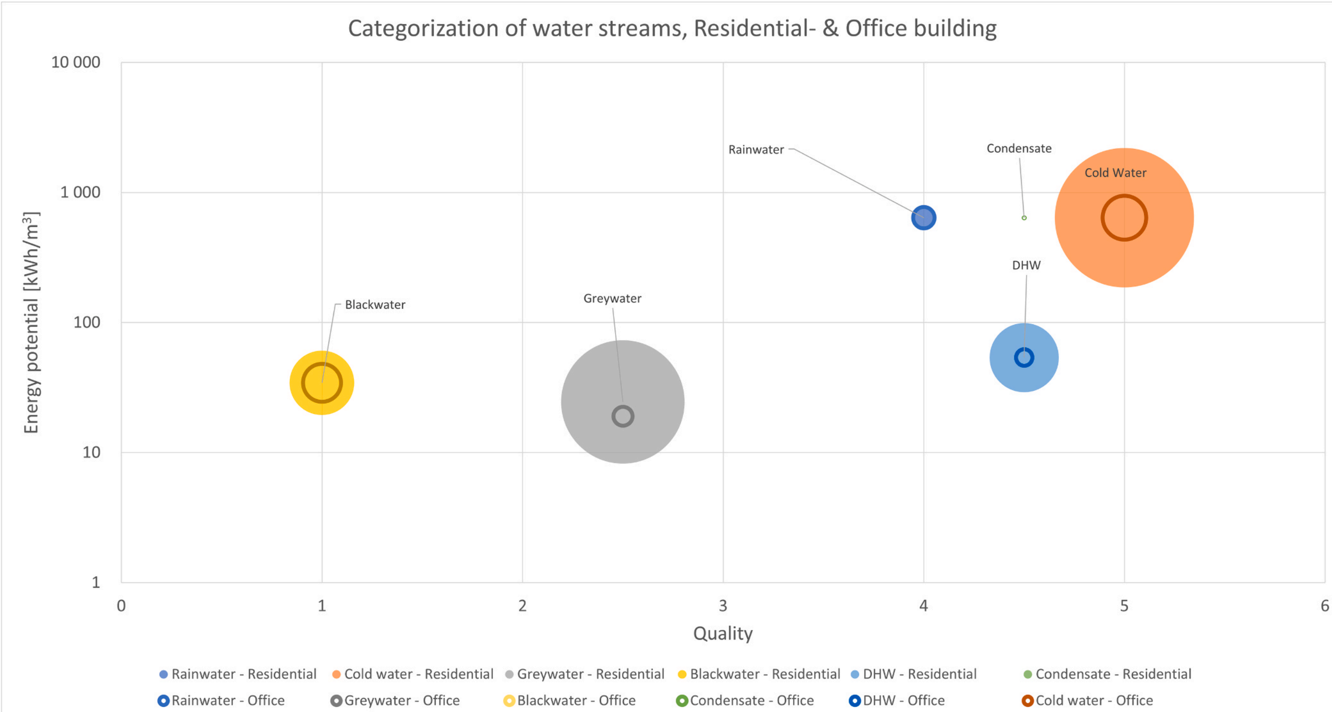

Fig. 5. Graph showing the schematical classification of the identified water streams relative energy potential, typical relative water quality and suggested potentially available volume for a typical building of 1000 m^2. This classification was made for a Swedish context. In this figure, Blackwater, Greywater and DHW are not seen as water resources that could potentially be used for evaporative cooling, hence the lower energy potential. The area of the circle represents the annual volume.

Table 7
Each water stream generated several parameters of interest because of the discussions during the interview.

	Aspect 1	Aspect 2	Aspect 3	Aspect 4	Aspect 5	Aspect 6
Rainwater	Storage	Attitude of occupants when replacing water	Volume of rainwater	Avoid release to recipient	Use of water resource	Retention
Humidity	Demand for optimal humidity	Volume generated from condensation	Degree of technological difficulty			
Heating	DWH recirculation losses	Temperature of DWH	Microbiological security	Installed heating power		
Cooling	Possibility to utilize other resources	Cooling demand				
Mains water	Investment cost	Leakage in water network	Water consumption behavior of occupants/tenants	Social consequence of taxonomy		
Greywater	Energy content of greywater	Losses of heating	Reuse water resource	Adaptation to rules and regulations		
Blackwater	Impact of treatment	Impact of treatment facility	Energy content	Use of resource		
Stormwater	Social aspect of volume to recipient	Quality of water	Complexity of system in relation to potential	Sharing resource between building		
Condensate	Cost in relation to potential	Available volume	Share of treatment necessary to utilize resource			
Other/ General	Life cycle assessment	Global warming potential	Resilience	Reduction of water consumption	Energy used for system solution	Place for future technological solutions.

be constrained by prevailing regulations. The occupants expected to utilize such systems may as well oppose certain system designs and in turn create further barriers for a system to be successful. Previous studies have shown that the acceptance of utilization of different streams of water can vary and have also been used to evaluate a system design (Lambert and Lee, 2018; Muthukumaran et al., 2011; Oteng-Peprah et al., 2018).

4.3.8. Microbiological quality

The quality of each water stream largely influences the possibility to use a stream for a certain function. Today there are directives that classify the quality of potable water. The microbiological quality may as well affect the treatment process of the water, but also acceptance and ultimately lead to a worse performance of a system design due to increased means of treatment method employed (Zdeb et al., 2018; Oteng-Peprah et al., 2018).

4.3.9. Health

By deviating from current building regulations or common practice, or increasing pressure to further develop these, further challenges on health or health related issues that regulations are intended to prevent may arise. Thus, addressing potential health risk have been investigated by some studies (Domènech and Saurí, 2010; Schets et al., 2010).

4.3.10. Resilience and flexibility

Future extreme weather events and other types of single events may

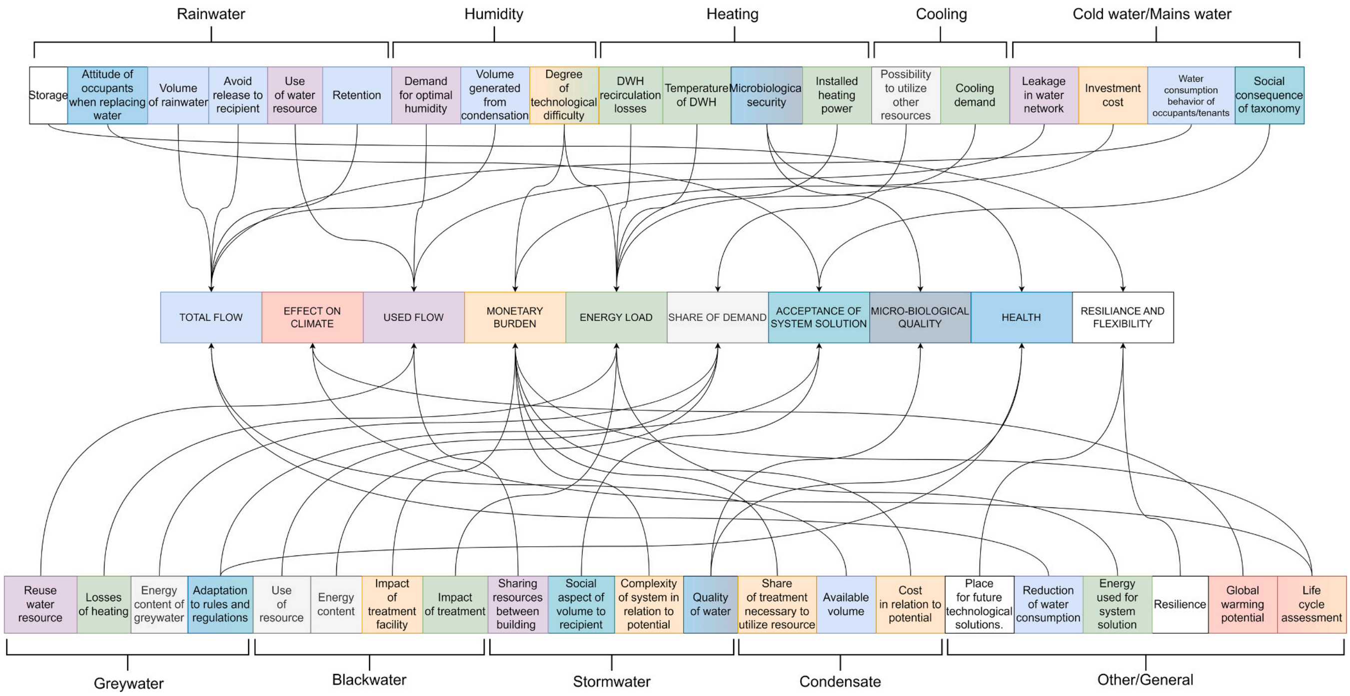

Fig. 6. Suggested Areas of Interest based on all aspects identified by the stakeholders.

generate further challenges on the infrastructure demand and performance. A system that improves resilience and acts as a support to the overall infrastructure can thus create a positive synergy effect outside the system boundaries or for the society as a whole (Malinowski et al., 2015). Some evaluated system solutions aim to provide a peak shaving effect to reduce price or stress on existing a system and thus create value by reducing the load (Upshaw et al., 2017). Moreover, a system that enables future technology to be incorporated into already existing technology will also be an important factor to consider.

4.4. Structure of framework

Since some of the identified parameters of interest can be interpreted from multiple perspectives, they may be expected to contain several factors of consideration, or in this case, critical parameters. Hence, several parameters may have to be evaluated to assess each Area of interest.

In addition, to further facilitate decision-making, a clustering of all the areas of interest is made depending on characteristics of what is measured in different areas. Three different areas are identified, here constituting for "Use of resources", "Social aspects" and "Resilience and Flexibility". Consequently, the structure of the framework is divided into three different levels: Aspects, Area of Interest, and Parameters according to Fig. 7.

In practice, the framework enables the user to specify which areas of interest are valid for each water stream and adapt to prevailing conditions, ultimately receiving an evaluation outlined specified for each case, see Fig. 8.

5. Discussion

Even though the total energy content is highest for water streams such as mains water, condensate, and rainwater, they may not in practice have the highest potential for energy extraction. Since the cold-water stream is not a resource available as a consequence of other services provided, such as the effluents or condensate, the use of cold water for an additional purpose could instead intensify the demand of potable water, thus being counterproductive. Rainwater with similar energy content and quality may instead work as potential resources in practice for such purposes with the possibility to address both energy and water aspects. In addition, a study of a system utilizing rainwater in such may have shown that it is practically possible albeit with energetic challenges to become feasible (Hviid et al., 2020). In a Swedish context, condensate would only be available in commercial building, yet providing a modest volume compared to rainwater. However, the proportions between these volumes may differ depending on the shape of the building and may in some cases provide a better case for condensate rather than rainwater in terms of volume, thus it is important to evaluate the volume of each water stream depending on the actual case, in accordance with aspects mentioned by the stakeholders. Since the precipitation as well as

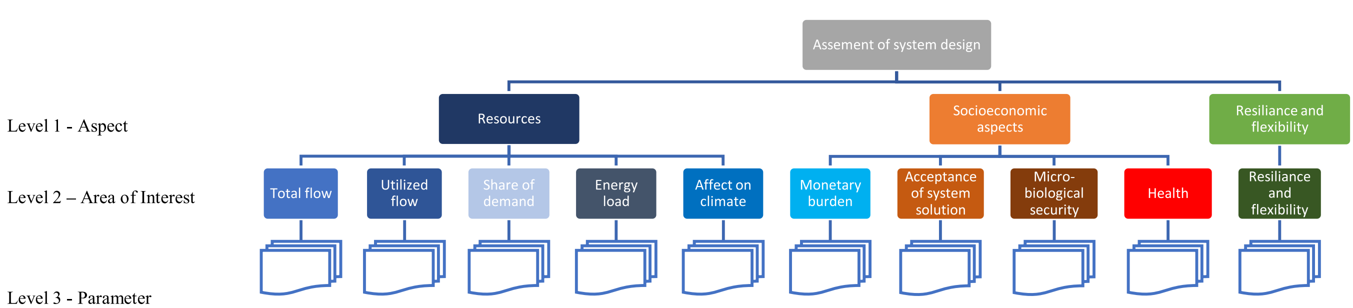

Fig. 7. Suggested structure and evaluation considerations within each level.

Aspect	Area of interest \ Type / Water stream	Natural water streams			Demand dependent water streams			Released water streams			Accumulated value
		Rainwater	Humidity	Storm water	Mains water	Heating	Cooling	Grey water	Black water	Condensate	
Resources	Total flow	X	X	X	X	X	X	X	X	X	-
	Used flow	X	X	X	X	X	X	X	X	X	-
	Share of demand	X	X	X	X	X	X	X	X	X	-
	Monetary burden	X	X	X	X	X	X	X	X	X	-
	Energy load	X	X	X	X	X	X	X	X	X	-
	Global warming potential	X	X	X	X	X	X	X	X	X	-
Social aspect	Acceptance of system solution	X	X	X	X	X	X	X	X	X	-
	Microbiological quality	X	X	X	X	X	X	X	X	X	-
	Health	X	X	X	X	X	X	X	X	X	-
Resilience and flexibility	Resilience/flexibility	X	X	X	X	X	X	X	X	X	-
	Accumulated value	-	-	-	-	-	-	-	-	-	-

Fig. 8. Evaluation outline where each water stream is assessed in each area of interest.

other streams of water are largely related to regional, seasonal and cultural aspects, the potential may as well differ and is may therefore be appropriate to perform a similar analysis for the specific region or the building assessed.

The second largest volume originates from greywater; this volume also provides a moderate energy content in the form of sensible heat that could be utilized to pre-heat DHW. There are many heat exchangers commercially available for such purposes and the technology may not be novel and is thus not discussed in this article. Nonetheless, the water itself may as well be of interest as the reuse reduced both the energy demand and the energy demand to produce the water itself. This energy intensity is not included in the figures presented but may as well be of importance depending on the magnitude. As the energy intensity of potable water produced in Stockholm, Sweden is around 0.5 kWh/m^3 (Stockholm Vatten och Avfall, 2023) the importance in relation to other water stream is rather insignificant. However, from a water mitigation point of view, recycling of the water itself may address a water recycling aspect which was a recurrent aspect brought up by the stakeholders throughout the interview. It may also have a much higher significance in regions where the water originates from a source which requires more energy intensive treatment. The utilization of both the water and energy simultaneously have been investigated for use in showers (Knutsson and Knutsson, 2020). It may however lead to challenges regarding acceptance from tenants (Lambert and Lee, 2018). A way to address this could be to separate the sensible energy and the water to enable the resources to be provided for different purposes, and thus balancing the water recycling and facilitate the approval of tenants simultaneously. Similar aspects were brought up during the interview.

The energy within each stream of water that can be recovered in practice will depend on many factors; For water only used for evaporative cooling, its will only be a factor of the efficiency of the system used, i.e. the efficiency of the spray nozzles, and if there is a recirculation system for unevaporated water. In addition, such a system may as well consume energy in terms of pumps and other auxiliaries which will reduce the actual performance of the system. It is also important to note that even though the temperature of the water may as well change the actual energy, this contribution is very small and has a small influence on the total energy content. In terms of the sensible heat, the energy recovery in practice may be a function of the efficiency of the heat exchanger and it is important to design a heat exchanger in such a way that the downtime is reduced due to clogging.

The energy content of blackwater is relatively modest compared to rainwater, condensate, and cold water, and even smaller than the sensible energy of greywater, although, the energy content may vary depending on the conditions (Gao et al., 2019). Both due to the change of characteristics of the blackwater but also due to the treatment method and way of anerobic digestion, thus it is important to make sure achieve a high methane production rate. Here, different method can be employed such as combining food waste with blackwater in the anaerobic digestion, (Wang et al., 2020) or to ensure hydrogenotrophic methanogenesis (Gao et al., 2019).

The interview showed that the main concern regarding blackwater was energy demand for treatment. However, as Gao et al. (2019) stated, this may be an attractive approach for the future decentralized wastewater treatment facilities it is important to make sure that sub optimization is not taking place. A study has shown that although the energy recovery within the building decreases, the energy demand for the wastewater treatment plant increased, indicating that assessment of systems must be comprehensive to catch implication on a societal level (Golzar and Silviera, 2021). The economic benefits depend on the regional price of energy and water (Wallin et al., 2021).

Large scale recovering system may as well have implications. A project in Germany were GW recovery and BW energy recovery in combination with other water management measures employed concluded that a decentralized system had environmental benefits in terms of reduced greenhouse gas emission as well as increased water efficiency and more self-sustainable due to reduced water demand and relinquishment of water transport as well as possibility to utilize the energy in the blackwater. Primary economic viability has also been shown which may indicate the system could be economically feasible (Augustin, 2019). A similar system on Sweden have also been tested with three separate pipes for GW, BW and food waste have also been tested and shown increased biogas, quality of fertilizer production and recovering of greywater energy (NSVA, 2024).

Although, decentralized system could potentially lead to issues regarding operation and maintenance since the vacuum toilets and the food waste pipes are the responsibility of the property owner within the premise. In addition, increased number of pipes can as well increase cross-connection (Tolksdorf and Cornel, 2017).

Looking at the parameters of interest identified from the interview, some are more precise and could in an easier way be translated to a measurable parameter, such as “CO_2-consumption” or “Volume available”, where it’s obvious that GWP in terms of CO_2-equivalent or water in terms of volume should be measured. However, others are vague and require further investigation such as “complexity of installation in relation to volume” or “cost for system solution in relation to potential”. Further interviews ought to be conducted to identify desired quantitative units to make an adequate evaluation of each critical parameter.

In addition, even if each identified critical parameter is sufficient, several views within each parameter could be employed, displaying different insights, with different importance depending on context. Some views, such as time, play a crucial role for how each parameter is considered, and in the end evaluated. Furthermore, even in this category some parameters ought to be defined in the context of how to measure. Such parameters may include “willingness to use function”.

Likewise, the functional unit also possesses a crucial role in how each parameter is displayed, and it ultimately comes down to what is seen as the best way of measuring a certain aspect of interest. It could be determined by the actual objective of the system solution, but also complex issues since some desired functional units may be too difficult to measure. Prevailing building codes and legislation also play a role in determining a functional unit since they in some respects are seen as how well buildings are performing, thus subjected as a requirement for different certification system, such as Primary Energy Rate. This also applies to chosen certification systems. Comparing the framework with prevailing evaluations frameworks such as SRI and sustainability index, this framework may provide a similar structure as the SRI by enabling the weighting factor. For each water stream or aspect, in such a way proving a more flexible tool when dealing with case specific systems. However, the degree of freedom may as well lead to difficulties comparing results for different systems solutions as each aspect and parameter may be assessed differently. Accordingly, this framework should be seen as a general approach rather than a certification tool such as BREAM and LEED. It is also important that to note that regulatory frameworks and standards need to be assessed for each individual system as there may be potential conflict with building codes, industry standards, legislation around public health, but also the lack of regulation and legal framework for managing circular water systems. Regulation is needed to protect and safeguard, for example public health but also public water systems, to avoid suboptimizing.

In conclusion, the actual impact of a certain system solution may extend beyond the envelope of the actual system solution evaluated and it is therefore important to determine the system boundaries in such a way that potential effects are displayed in the evaluation.

6. Conclusion

This paper presents energy and volumetric potential of different water streams from a Swedish context to enable better understanding of possibilities and challenges within recycling and reuse of the water streams within a building. In addition, the interviews conducted were aiming to expand the picture and provide a more thorough view within the field of stakeholders to display possibilities, barriers and parameters of interest when evaluating system designs.

The following conclusions have been drawn:

- Rainwater has potential to work as an energy source for evaporative cooling due to the relatively large volume and quality.
- By separating the sensible energy from the greywater and utilizing both, the potential of bit resources could be used to generate higher acceptance amongst tenants.
- Utilizing recycled water from RW or GW for flushing will have higher acceptance rate than utilizing water for other services such as shower and washing services making the probability for these system designs to succeed higher from a social point of view.
- Rainwater and condensate have a moderate quality which enables utilization for non-potable services using relatively simple treatment methods.
- Several critical parameters for the evaluation of the water supply systems focusing on the building level have been identified as important to evaluate when assessing a new system design.
- The suggested framework divides the performance into three different aspects (Use of Resources, Social Aspects, and Resilience and Flexibility) and 10 Areas of Interest. In addition, identified water streams can be labeled as Natural, Demand-dependent, or released water streams.

Future research should focus on elaborating the framework further by suggesting measurable parameters in order to estimate the performance of each area of interest; thus, providing as versatile an overview as possible. It is important to note that the way of evaluation is not bound by any restriction and thus provides the flexibility to use any methods such as life cycle assessment and varying system boundaries. The classification of the water streams also facilitates future research to understand the potential of the most prominent water streams in terms of energy- and water mitigation.

Funding

This work was supported by the Swedish Energy Agency through the research program E2B2 [project number P51740-1].

Author Statement

We the undersigned declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship than the authors that are listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We understand that the Corresponding Author is the sole contact for the Editorial process. He is responsible for communicating with the other authors about progress, submissions of revisions and final approval of proofs.

CRediT authorship contribution statement

Jesper Knutsson: Writing – review & editing, Data curation. **Viktor La Torre Rapp:** Writing – original draft, Investigation, Formal analysis. **Jörgen Wallin:** Writing – review & editing.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Jesper Knutsson reports a relationship with Graytec AB that includes: board membership. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

The data that has been used is confidential.

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