Potential of Waste Water Heat Recovery in reducing the EU's energy need




PAVEL SEVELA
MSc.
Unit of Energy Efficient Building, University of Innsbruck, Innsbruck, Austria
bauphysik@uibk.ac.at

JOHANNES FRENGER
MSc.
Unit of Energy Efficient Building, University of Innsbruck, Innsbruck, Austria

JÜRGEN SCHNIEDERS
Dr.
Passive House Institute, Darmstadt, Germany

RAINER PFLUGER
Assoz. Prof. Dr.-Ing.
Unit of Energy Efficient Building, University of Innsbruck, Innsbruck, Austria

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Abstract

After extensive research, **Waste-Water Heat-Recovery (WWHR)** technology was identified as the most promising technology to unlock the under-addressed potential in reducing the energy need for water heating.

Particularly interesting application of WWHR is for showering, which accounts for about 70 to 82% of the daily residential hot water tapping profile. Shower-wise installed heat-exchangers offer a cost-effective way of utilizing otherwise wasted heat for preheating cold fresh water, thus reducing the temperature span covered by the water heater. The total energy demand **savings for hot water heating can be up to 40%**. The unique advantage of WWHR, is achieving high thermal energy savings without compromising on user comfort with low material and monetary needs. The cost-effectiveness of WWHR is best in climates with cold ground temperatures and in cases where showers are used extensively.

At European level, the WWHR itself is theoretically capable of surpassing the energy savings targets planned in the "Fit for 55" climate action in the hot water sector, if all buildings are equipped accordingly. If between 2022 and 2030, every second anyways renovated or newly constructed building in Europe were equipped with the WWHR system, **35.7 TWh less energy would have to be generated and 6.6 Megatons of CO_2e emissions less emitted.**

Although WWHR has been a well-proven technology for decades in some countries; it is still unknown in most European regions. Further action, in particular the creation of a European legal framework, the training of professionals and the granting of subsidies, is needed to accelerate the adaptation of this promising, sustainable technology into practice.

Problem statement

Buildings are the single largest energy consumer in Europe. Heating, cooling and domestic hot water account for 80% of the energy that we, citizens, consume [1].

The EU has committed to reduce the greenhouse gas (GHG) emissions by at least 55% by 2030, compared to 1990 levels. This climate act known as the “Fit for 55” package is the EU’s contribution under the “2015 Paris Agreement”, with a target of limiting the increase of global temperature to just 1.5°C compared to pre-industrial levels. For the EU building sector, it means to reduce its energy consumption of heating and cooling by 18%, compared to energy consumption (delivered energy) levels in 2015 [2].

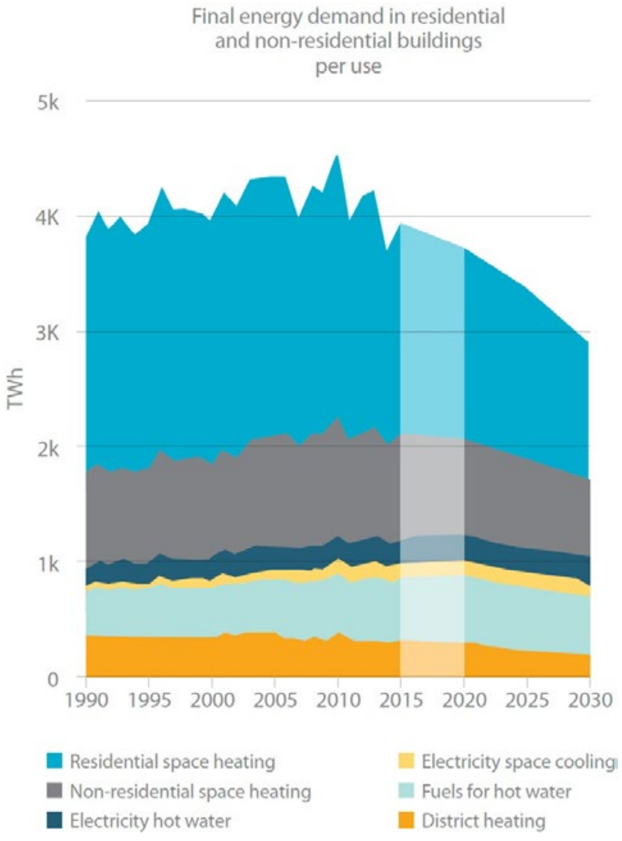


Figure 1. Final energy demand in residential and non-residential buildings by energy use [4].

As illustrated in **Figure 1**, the energy for space heating has decreased significantly in the past decades specially thanks to applied insulation, however this has not been the case for water heating. According to Eurostat, the hot water preparation in the current residential building stock represents 14.8% of the whole energy consumption in buildings [3].

Since the cold water temperature is naturally given by geographic location and the desired hot water draw-off temperature and duration is set by the user, the only way to reduce the energy demand for water heating is to reduce the flow rate or to pre-heat the cold water to reduce the temperature rise by the water heater. The WWHR is the last unaddressed systematical thermal leak in the building thermal envelope, as lightly illustrated on **Figure 2**.

Using **wastewater heat recovery (WWHR)** technology, lowering comfort by reducing hot water flow rates is not necessary while reducing the domestic hot water (DHW) energy demand. WWHR can utilize the waste heat that leaves the building and would otherwise end up in the environment. With this technology, the heat is recovered from the warm wastewater and transferred to the cold fresh water and thus the amount of energy required to reheat the cold water is reduced.

For wasting energy from hot water, showering plays the dominant role, accounting for about 70-82% of the daily hot water tapping profile [5] [6]. Furthermore, the duration of most other hot water draw-offs or its temperature is not great enough to overcome the dynamics at the beginning of the WWHR process. Therefore, **showering is the most effective application of WWHR technology**, as the hot water draw-off at a high temperature level and the fresh cold water supply occur simultaneously and takes on average between 4,5 – 8,5 minutes [7].

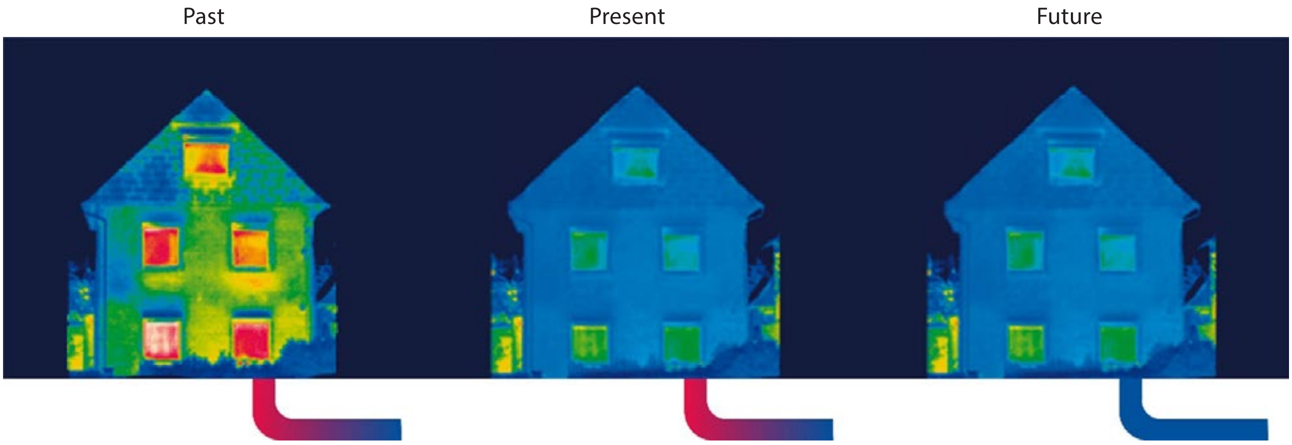


Figure 2. Illustration of the thermal development in building technology as an infrared thermography.

State of the art of WWHR

For decades, heat recovery has been a standard for reducing energy demand in industrial processes by transferring waste heat to another fluid via a heat exchanger that separates the media materially but allows the heat to conduct through. Different techniques to recover energy from warm domestic wastewater are also applied. From municipal applications to centralized (building-wise) installed heat exchangers or de-centralized (shower-wise) devices, the latter shows the most **promising potential and a number of certified products** are already in existence.

Decentralized heat exchangers (**Figure 3**) are placed as close as possible to the source of the warm wastewater (typically 32-36°C). If the heat exchanger is placed further away from greywater source, the warm effluent cools and could be mixed with other colder effluents. Most widespread decentralized devices are screed embedded linear shower drains with horizontal exchanger tubes or vertically installed devices replacing appx. two meters of sewer pipe, which benefit from "no maintenance" at low prices compared to the horizontal ones. However, the space and access required to the floor below can cause difficulties with retrofits. So-called active heat recovery systems pump the shower water into a heat exchanger and are often driven with a vertical heat exchanger but can be installed on the shower level.

Other preinstalled shower units are even equipped with a primary heat source e.g. an electrical water heater. Those benefit from synchronized components without complex plumbing and high circulation losses. As independent hot water modules, they can be evaluated with the existing EU energy label. Beside a smaller hot water storage volume, the WWHR decreases the required power of flow heaters. Almost loss-free DHW production on demand can get a future technology, especially when combined with electric mobility via power-load throw-off.

The energy saving potential of various decentralized WWHR system are mainly influenced as follows:

Efficiency of heat exchanger device

Counterflow driven exchangers with high thermal length and fluid turbulence result in best efficiencies. The robust design for highly polluted wastewater and the double wall construction according to EN1717 limit the efficiency of those heat exchangers. The steady-state efficiency of typical devices range between 37-60% for horizontal systems, 57-78% for vertical systems and 60-82% for active systems [8].

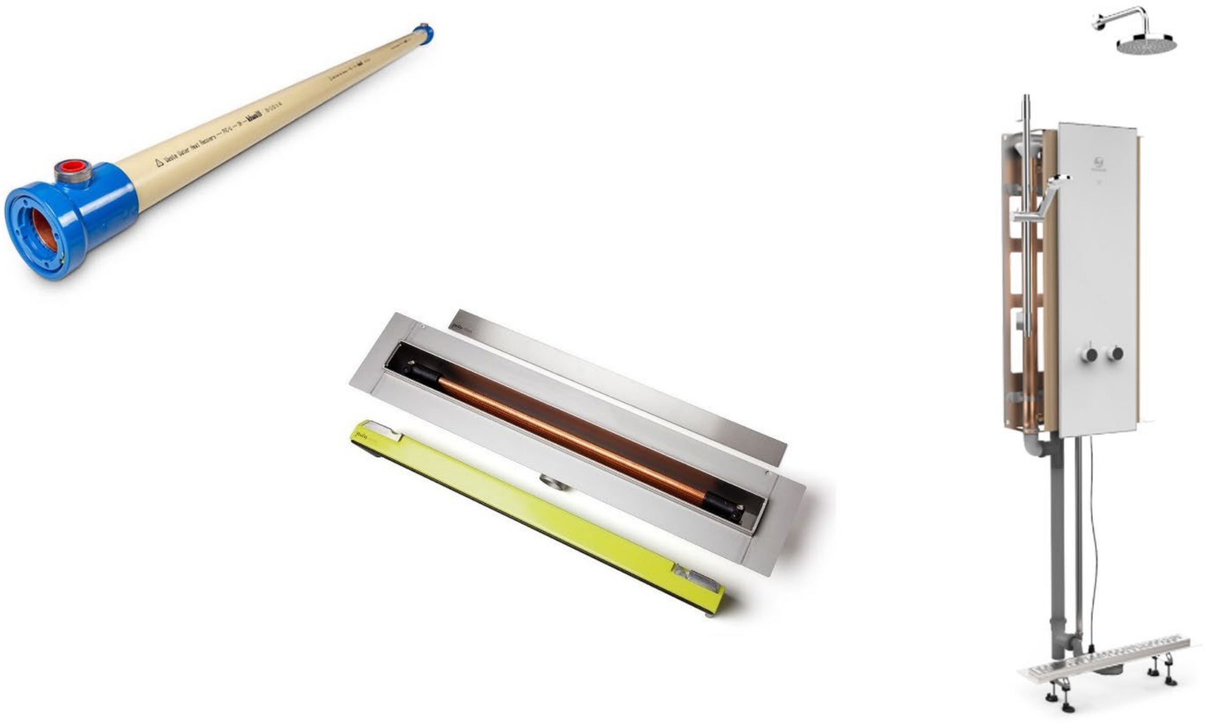


Figure 3. Shower water heat exchanger for vertical (left), horizontal (middle) application; active heat exchanger (right) source: Counter Flow Products B.V., Joulia ltd., Hamwells Nederland B.V.

Hydraulic connection of heat exchanger

Maximum energy transfer in the exchanger also relies on a balanced flow rate of fresh and wastewater side, see **Figure 4**. When applying a decentralised heat exchanger for a shower, wastewater only equals the freshwater flow if the preheated water feeds the shower mixer and the water heater. If the preheated water from the heat exchanger feeds only the shower mixer or the DHW heater, the waste water and fresh water flows in the heat exchanger are unequal, and therefore the efficiency of the heat exchanger could decrease due to the lower possible energy transfer.

Water temperatures and shower duration

Low shower temperatures combined with high freshwater temperatures e.g. in the EU´s southerly member states, have to be considered as less benefitting from WWHR. With increasing shower duration, the dynamic heat exchanger efficiency approaches its steady-state value and obviously supports the absolute energy savings.

Methodology of the energy savings calculation

In order to demonstrate the potential energy saving effect of DHW systems including WWHR, a calculation based comparison study was performed. Saving calculation on household level are based on PHPP [9].

(1) A vertical tube-in-tube heat exchanger with a typical efficiency of 67% was chosen [8], which causes costs of approx. 1000€ for the device itself and additional installation effort.

(2) One WWHR system per dwelling unit is assumed, with an European average occupation of 2.3 persons per dwelling unit [10]. Each person uses the equivalent of 32 l of domestic hot water at 60°C per day, of which 24 litres are shower water.

(3) The calculations were carried out under the assumption that the preheated water outlet is hydraulically connected to the water heater and the shower mixing valve.

(4) The data used for the upscale calculation on EU Level was extracted from each member in the EU´s 2019 statistics [3].

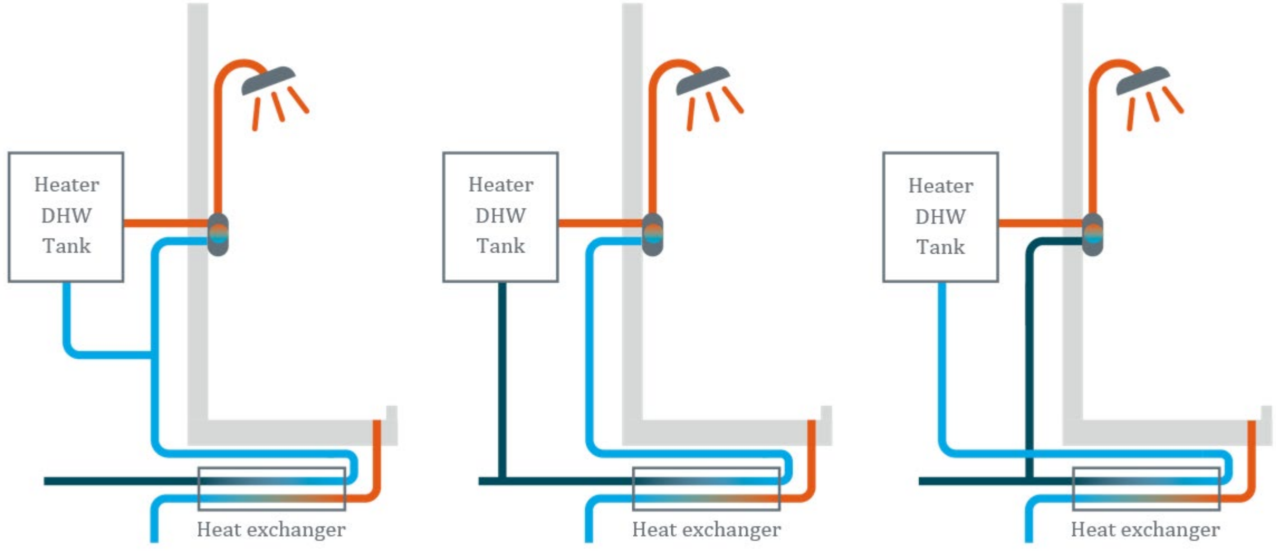
Results and interpretation of energy saving calculations with WWHR

Energy saving potential on household level

It is important to note that WWHR saves the same amount of energy needed for water heating in combination with all three used DHW systems. This means the amount of recovered heat is not depending on the DHW technique.

WWHR **savings in delivered energy (electricity, gas, etc.) vary depending on the water heating technique** due to significant differences in hot water distribution and storage thermal losses, as well as the efficiency of the actual heater, see **Figure 5**.

A clear trend towards higher yields in colder climates can be observed. This can be referred mainly to the colder ground water temperatures in the Nordic climate zone. Possible differences in user behaviour e.g.,



A) **Preheating** for "**cold** and **warm**" water *(balanced volume flow-rate)*

B) **Preheating** for "**cold** water" *(dis-balanced volume flow-rate)*

C) **Preheating** for "**warm** water" *(dis-balanced volume flow-rate)*

Figure 4. Hydraulic connection possibilities of a WWHR device.

tendentially warmer and longer showers in northern regions, which makes the WWHR more effective was neglected in this study to provide a conservative view of the results.

An obvious difference is that WWHR accounts for a larger share of the delivered energy by direct electric water heating; that is close to the actual energy need for DHW; as this system is a decentralized system with zero tank and circulation losses and lower distribution heat losses as by the central DHW system. **These losses account in average for about 1/3 of the delivered energy for DHW in the EU but in some systems can represent more than 50%.** The less efficient energy conversion when burning fossil fuels causes slightly higher possible energy savings.

The savings in energy consumption by WWHR in combination with a heat pump are lower in absolute terms than for the other two systems, since a heat pump requires a lower proportion of delivered energy (electricity) to produce the same amount of heat, thanks to its electricity to heat conversion factor (COP). Nevertheless, cold climate supports the application of WWHR combined with heat pumps because of the colder ambient and hence worse conversion rates of heat pumps. WWHR in heat pump systems can therefore be very cost effective, especially when used with shower-intensive tapping profiles.

Possible contribution of WWHR to the zero-emission building standard

The possible effect of WWHR on an example household is examined, assuming a 104 m² single family house occupied by 2.3 persons in oceanic climate zone. The intention was to evaluate the impact of the application of WWHR in this particular scenario on the reduction of "delivered electrical energy".

The building thermal envelope and HVAC were considered to be state of the art to meet the requirements of the **"zero-emission building" (ZEB) standard, coming into force in 2030.**

Assuming a heat pump-based water and space heating system with a yearly average COP of 2.4, the **annual savings correspond to 13% of the "total delivered**

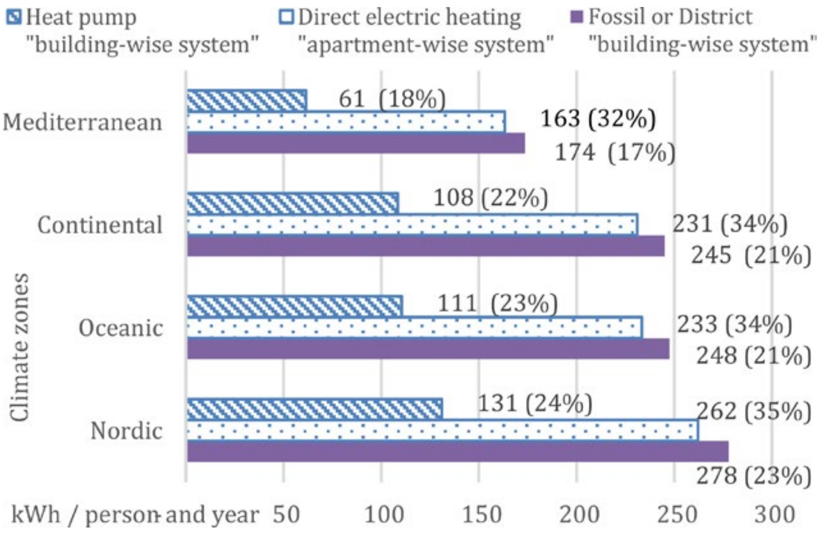


Figure 5. Savings in delivered energy for total DHW with WWHR in combination with various hot water systems per person (in brackets: as percentage of total delivered energy)

energy", as seen in **Figure 6.** In the context of the EPBD, which specifies a maximum primary energy of 60 kWh/m2/a for ZEB in this climate zone, the **WWHR reduce primary energy consumption by ca 7 kWh/m^2/a when a primary energy factor of 2.1 is assumed.** Therefore, in cases of already advanced thermal envelopes or efficient heating technologies, WWHR can play the key role to reach this ambitious standard.

Energy and GHG saving potential depending on country

To evaluate a population independent saving potential, **Figure 7** shows the annual energy and emission savings per installed WWHR device by country. Actual GHG emissions for electrical power consumption were applied. The "steps" in energy savings are due to the use of reference values for mains water temperature and climate data for each climate zone. **Most promising energy savings are seen in northern countries** due to low mains water temperatures. At the same time, GHG emission savings are considerably lower in northern countries due to generally "low-carbon" energy production and high district heating supply rates. **Warm climatic regions with high-emission-power-production can therein still play an important role, despite its relatively lower energy savings.**

Energy saving potential on EU-27 level

To achieve the at least 55% European emissions reduction target for 2030, proposed by the Commission in September 2020, the EU must reduce greenhouse gas emissions in the building sector by 60% and thus the energy consumption of heating and cooling by 18%, compared to delivered energy consumption level in 2015 [11].

The possible energy and emission savings with WWHR were scaled up to EU-27 level to show the role of WWHR in the EU's "renovation wave" in different scenarios. A hypothesis was made by applying the WWHR in four scenarios with a share of 20, 50, 80 and 100% of the **total of 35 million renovated and 15 million newly built buildings between 2022 and 2030.** WWHR technology could be incorporated up to three-times more often as any bathroom or shower renovation is an opportunity for integration of WWHR. The amount of total installed devices and its savings were accumulated linearly during this time.

Figure 8 shows the impact in the hot water sector referring to the 18% energy savings goal compared to the consumption in 2015, although the energy savings by WWHR actually apply to the already higher energy consumption from 2020 onwards. Depending on the scenarios, approx. 4%; 11%; 16% or 25% of the planned energy reduction can be covered by WWHR only. If every renovated or newly built building in Europe were to be equipped with WWHR starting 2022, 25% of the 2030 "Fit for 55" goals in the warm water sector could be expected. If the total current building stock would be equipped with the described WWHR until 2030, **a significant consumption-drop of 100 TWh/a could be observed and the energy conservation goals for hot water would be surpassed by WWHR only.**

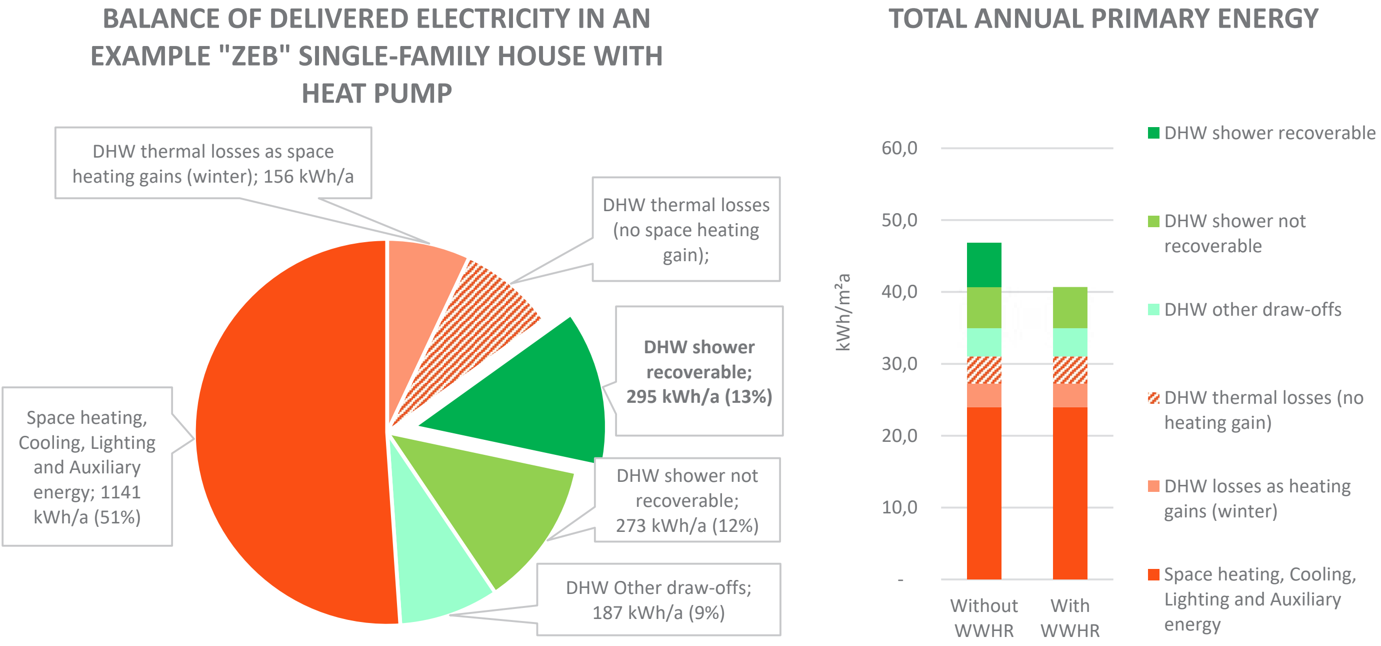


Figure 6. Delivered energy with respect to the recoverable share with WWHR in a single family "ZEB" house.

Conclusion

The main message of this paper is that there is a **14.8% share of the energy consumption in buildings (DHW)** [12] that has been overlooked and unaddressed by the main EU policies in recent decades.

WWHR saves usable energy for water heating from going down the drain, especially for the shower, which is the largest consumer of hot water in the home. **With WWHR, the delivered energy for today´s water heating in Europe could be reduced by 24%**

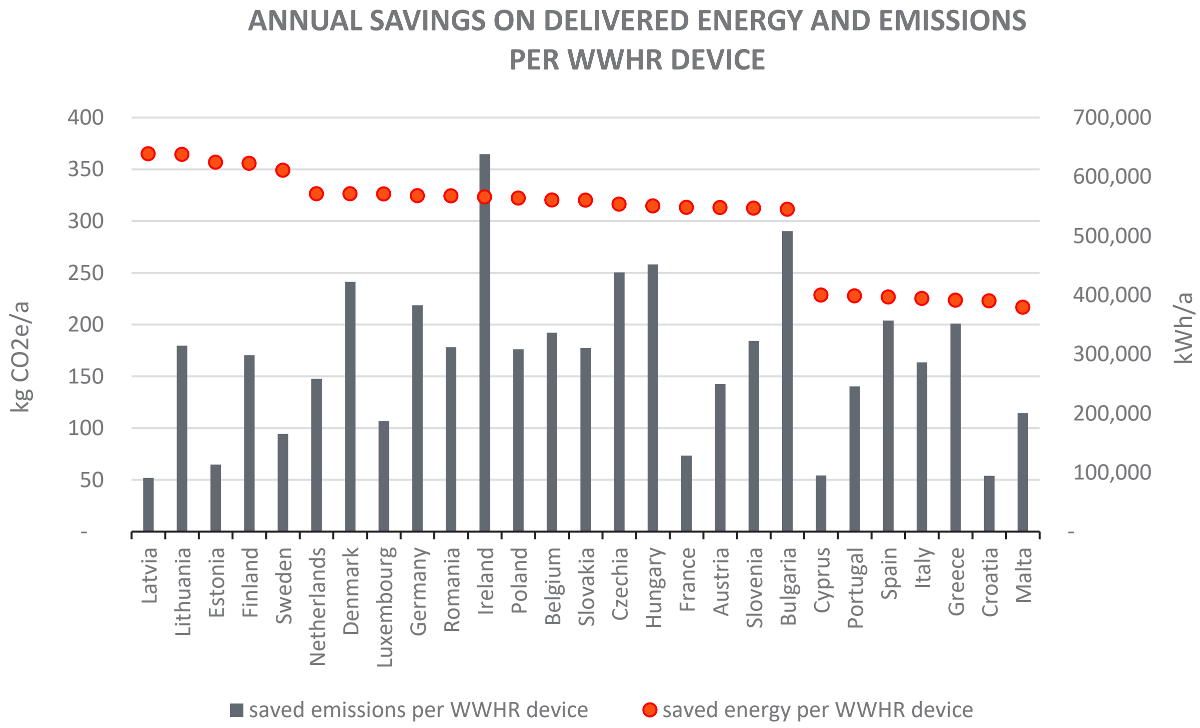


Figure 7. Annual energy and emission savings per WWHR device per country.

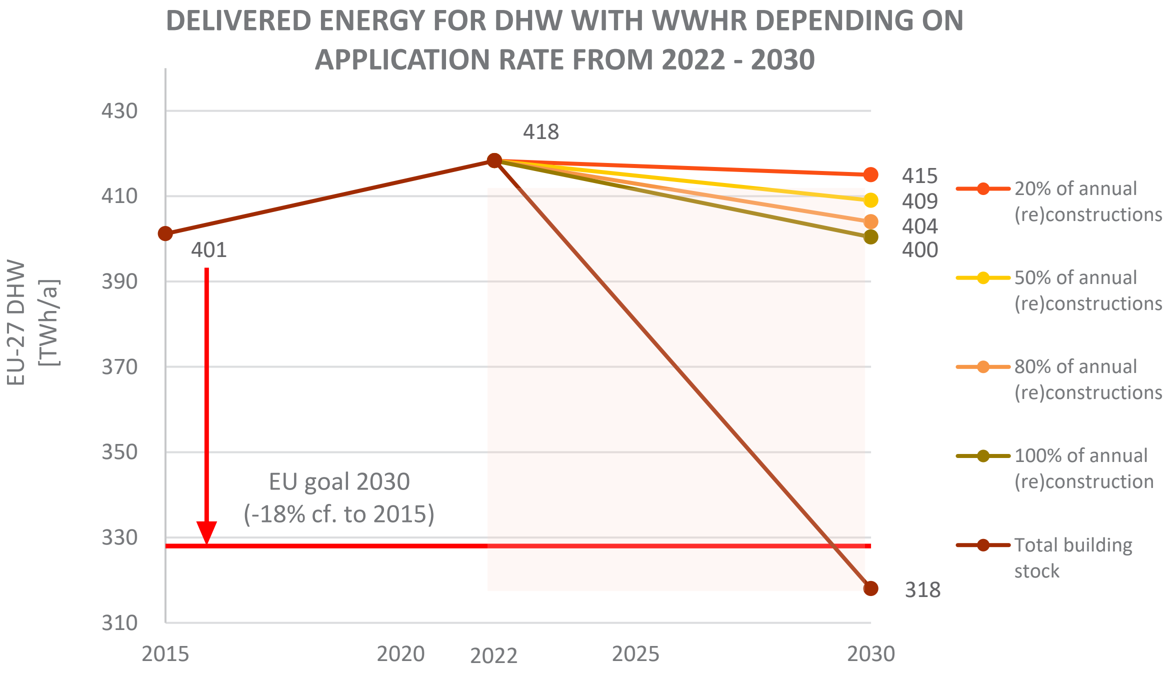


Figure 8. EU-27 (Targeted) Energy demand for DHW in 2030 depending on application rate of WWHR.

(100 TWh/a); see **Figure 6**; if "business as usual" is continued. Further savings potential lies in reducing heat losses from hot water circulation, distribution and storage, since WWHR cannot actively reduce these losses that represent on average about 1/3 and in some cases even more than 50% [7] of the delivered energy for DHW heating. It should be also noted that WWHR does not affect the energy required for not simultaneously tapped hot water, for example in a bathtub. On this background, **suitable devices integrated into a DHW system with optimized distribution, storage and circulation losses can reduce the amount of delivered energy water heating by about 40%.**

WWHR also contributes to minimize DHW technology, especially by systems with high investment costs per kW such as heat pumps with geothermal probes. With the WWHR the DHW systems can become also easier to operate by renewable energies. As the EC states: "**The energy efficiency and the deployment of renewable energy complement each other**" [13].

The economy is particularly good by application with multiple users such as sport facilities, businesses and hotels but also in climates with colder ground water. In all three technological scenarios, the **"price of energy saved", hence a fixed energy price for the next decades when using WWHR, is around or below the average energy price in the first quarter of 2021, rising since then.** One WWHR device can save more than a 100 € per family on the hot water operational costs every year.

Due to its high energy efficiency and level or recyclability, the life-cycle of WWHR devices (>20 years) causes a **minimal ecological footprint that is balanced by CO_2 savings already during the first year of its operation.**

The quick decarbonization of the building stock is limited by the low renovation rate of buildings; currently below 1% [14].   in the EU. **The building stock can be upgraded about three times faster with WWHR than with regular energy-saving measures** such as insulation of the building envelope. This is due to the fact that the renovation rate of HVAC systems is about three times higher, according to the Zentralverband Sanitär Heizung Klima, Germany. This makes WWHR a very effective tool with a rapid uptake in the resident market.

The WWHR is in some EU member countries an established technology, recognized as one of the top 10 most promising energy saving opportunities, scoring in several countries on a first rank, according to the Member State Annex Report done by EC [15]. WWHR is an emerging technology bringing a number of benefits that are in line with the EU climate action plan. These are the identified barriers and measures that need to be taken for the European legal framework to unlock the WWHR´s potential of in the EU and globally:

- The WWHR is currently **not officially recognized in the EPC, EPBD or other building rules** and thus the application of WWHR does not bring constructors any legal improvements in the energy efficiency, despite the obvious energy savings.
- **New European norms** on planning and hygiene criteria of application of WWHR system in the buildings shall be created as well as a common certification procedure for the WWHR units. The adoption of **WWHR in the Eco-design Directive** could convey the benefits of combining WWHR with water heating systems in an easy and understandable way, through established energy labelling.
- The **WWHR may be included in the EU's toolbox** as an effective measure for energy-efficient renovations and new constructions. As WWHR is in some regions a new technology, it needs to be **promoted** and **professionals need to be trained** on its benefits and planning. Together with further incentives this procedure can be an effective way to overcome the well-known psychological effect of "status quo bias", making the professionals more hesitant about new technologies they are not familiar with yet.
- **Scaling-up** the number of applications shall make the WWHR system more affordable due to higher cost-efficiency in production. Although double-wall heat exchanger construction is currently required by law in Europe, **single-wall designs** could increase cost-effectiveness if sufficient drinking water safety is provided. In the NL and UK an exemption has been granted (status by 04.2022) to the active systems where the heat exchanger is located above tile level with an air brake for drainage (overflow).

Removing the barriers and making the energy efficiency measures more attractive and simpler to apply will decide if every well-done renovation and new construction will bring Europe closer to its goals, or if it will become a missed opportunity that could lock-in untapped energy savings and associated emissions in the coming decades. ■

Appendices

Link to the full article:
https://diglib.uibk.ac.at/7640369

Annotation

45,26 m^2 living area / person [16]

Abbreviations

COP	Coefficient of performance
EC	European Commission
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificates
EU	European Union
FSE	Final sewage effluent
GHG	Green House Gas
HE	Heat Exchanger
HVAC	Heating, ventilation, and air conditioning
nZEB	nearly-Zero-Energy Building
PHPP	Passive House Planning Package Tool
WWHR	Waste Water Heat Recovery
DVGW	German society for gas and water installations
ZEB	Zero-Emission Building

Table 1. Current standard.

Country	Efficiency	Hygiene
Germany	PHI (Certified Passive House Components); DIN 94678 (in preparation)	DVGW
Netherland	KIWA NEN 7120	
France	CSTB CAPE/RECADO-PQE	Th-BCE/RT2012
UK	CAPE/RECADO-PQE or KIWA NEN 7120	WRAS
Switzerland	KIWA NEN 7120; Minergie	SVGW
EU	EU No 812/2013 (in preparation)	

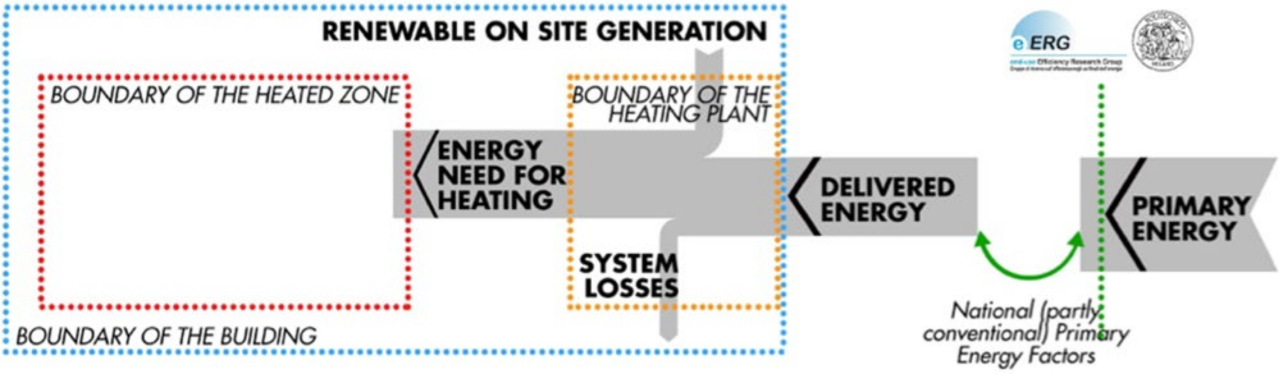


Figure 9. Methodological explanatory to the EPBD. [17]

Data Statement

The team at the University of Innsbruck will be happy to answer further inquiries, share their practical experience and hands on knowledge in WWHR research and development. pavel.sevela@uibk.ac.at

Acknowledgement

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