Drain Water Heat Recovery System

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***Abstract*—The Drain Water Heat Recovery System (DWHRS) is designed to raise the efficiency of a residential building's water heating system. The device captures heat from drain water as it flows through a residential building's drainpipe and into sewer. The system then applies that collected heat to the incoming fresh water before it enters the building's water heating system. With the incoming water preheated to a higher temperature than when it first entered the building, the water heating system will use less energy to further raise the water's temperature. The design of. the DWHRS addresses the drawbacks of currently available heat recovery systems, and it is designed to be compatible with Chicagoland's least energy efficient buildings; prewar multifamily buildings.**

I. Introduction

Heated water that passes through a waste drain is energy waiting to be used. In today's climate, a lot of resources focus on being efficient or environmentally friendly. Whether it's a car being fuel efficient, light bulbs being energy efficient, or even water bottles being biodegradable. Heating water is a resource that should be energy efficient also. The Drain Water Heat Recovery System (DWHRS) will increase water heating efficiency which decrease the energy needed to heat water. The Drain Water Heat Recovery System uses heated wastewater to pre-heat incoming cold water before it enters a building's water heating system. If water enters a water heating system at a higher temperature than when it first entered the building, the water heating system would use less energy to heat the water. This would result in the water heating system having a lower energy output and a lower energy input requirement. Drain water heat recovery devices can add this efficiency to the water heating process. The targeted demographic of this project's heat recovery system is pre-war multi-family housing units located in the city of Chicago.

A "pre-war" building is any building that was constructed before World War II. These old constructions were made to be sturdy, but they were not designed to be energy efficient. This has led to prewar buildings consuming much more energy than later builds, and this problem needs to be addressed. The Chicago metropolitan area has approximately 136,657 prewar multifamily housing buildings that equate to about 500,110 units. everyday day, a single unit in a multi-family building can produce from 10.8 to 39.41 MJ worth of heat in the form of drain water. The entirety of the Chicagoland area's prewar multifamily housing lets about 5.4 to 19.71 MJ of heated water pass through their drainpipes. This amount of heat equates to as much as $859,545 down these buildings' drains on an average day.

II. Design Features

A. Overview

All drain water heat recovery devices collect heat from hot drain water and reapply that heat to incoming fresh water. The main differences between available systems are installation location and the design of the heat recovery device itself. Many systems are installed in the place of a length of drainpipe, so they encounter drain water from all water-using appliances in a building. Others are designed to only encounter greywater, water from showers or sinks. All of them, however, need a building's incoming water to be redirected through the device. Therein lies the main difference between existing products and the topic of this report: The Drain Water Heat Recovery System. Unlike existing heat recovery systems, the DWHRS attached at the drain stack(s) and extends to the incoming water service, so the service does not need to be rerouted. The remainder of this section includes descriptions of the DWHRS' subsystems and explanations of them.

The Drain Water Heat Recovery System consists of a compact plate heat exchanger, a shell and tube heat exchanger of this group's own design, and a heat transfer fluid (HTF) running through both. The heat transfer fluid collects heat from drain water in the Wastewater Heat Exchanger and applies that heat to the incoming water in the Plate Heat Exchanger. The selected plate heat exchanger has an estimated effectiveness of 97.98% and a pressure drop of less than 1 psi (Pa) on the freshwater side, so it works well with the DWHRS [1]. The selected heat transfer fluid is Dynalene HF-LO. It is a low-odor, nontoxic, and noncorrosive heat transfer fluid that was selected based on its performance inside the Wastewater Heat Exchanger and comparisons with other fluids [2].

The prototype DWHRS, depicted in Figure 1, simulates drain water with a pump and tank type configuration. Above the prototype sits a plastic storage bin with a bulkhead fitting installed on one of its faces. The bin is filled with water to start prototype operation. It is released by a valve that is attached to the top of the WWHE. The "drain" water flows through the device, gets forced through the PHE by a small water pump, and is heated by an electric tankless water heater. The hot water is then finally pumped back into the bin. Now that the water is hot, it will give off heat to the HTF as it makes another pass. Afterwards, the water is cooled down to room temperature by an ice filled bin and pushed towards the PHE by the pump once more.

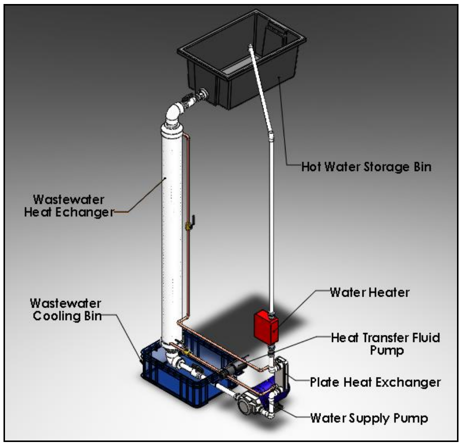

Figure 1. 3D model of Drain Water Heat Recovery System prototype.

B. *Wastewater Heat Exchanger*

The Wastewater Heat Exchanger (WWHE) shown in Figure 2 is a counterflow shell and tube heat exchanger that was designed over the course of this project.


Figure 2. 3D Model of WWHE. Shown with transparent PVC pipe.

The 3/8" Type K copper pipe on the inside is in the shape of a spiral and carries heat transfer fluid (HTF) upward through the WWHE. As the simulated drain water flows downward around and over the coiled pipe, the hot water transfers its heat through the wall of the pipe and to the heat transfer fluid. The HTF then carries that heat toward the plate heat exchanger for the next phase of the process. The Wastewater Heat Exchanger's copper pipe is encased in a 4" PVC pipe to prevent heat loss to the surroundings.

The heat exchanger has been simulated in MATLAB using both steady-state and transient models. The NTU-effectiveness method of analysis was used to first design the WWHE. Steady state results of the full-scale device yielded an expected heat exchanger effectiveness of 68.0% at an average drain water temperature and flow rate in a profiled building of 65 occupants. The prototype sized WWHE performed at 62.08% effectiveness under the same conditions. It should be noted that the difference between the prototype and full size WWHE is a height difference of 1 foot, so transfer area and time is increased with height.

Further analysis with transient methods yielded an average first-pass effectiveness of about 55.7% for the WWHE and 54.5% for the whole system. The transient calculations vary greatly with the drain water related inputs. Specifically, the system is dependent on the drain water's temperature, flow rate, and event length. The data gathered using this method often considers only a single hot water use (shower, sink, etc.) or an average of multiple flow rates and temperatures based on usage trends. Table I depicts how the WWHE and DWHRS compare to existing wastewater heat recovery products.

TABLE I. EFFECTIVENESS OF EXISTING SYSTEMS

Heat Recovery Product	**Effectiveness Rating**
RenewABILITY Powerpipe R2-72	53.8%
Showersave Recoh-vert	62.0%
Heatsnagger VXPipe	57.6%
WWHE (Steady-State and Transient Analysis)	68.0% & 55.7%
DWHRS (Transient Analysis)	54.5%

a. [3-5]

As mentioned earlier, a single unit of a multifamily building lets about 12.13 to 39.41 MJ of heat go down the drain on an average day. Only about 6.56 MJ of heat is recoverable, but 3.575 MJ of that can be recycled with the DWHRS at a rating of 54.5% effectiveness. This equates to a daily savings of 15.6 cents per housing unit. This means that the effect of a DWHRS in all of Chicagoland's prewar multifamily housing would be $77,971.42 of savings on an average day.

III. CONCLUSIONS

Pre-war buildings are the focus of this design project due to their poor performing water heating systems. The energy consumption is extremely high which leads to high cost in power for the water heater. The Drain Water Heat Recovery System can recover an average of 54.5% of available heat and has the potential to save the Chicagoland's prewar multifamily housing 28.5 million dollars on energy each year. Extensive work was put into this design. However, due to the COVID-19 outbreak, an actual prototype was not able to be assembled. Instead, computer aided design software was used to complete this project.

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