# Measurement of Heat Recovered from a Hot Shower using Heat Exchanger

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**Abstract**

Waste heat from a shower was recovered using a heat exchanger. Cold faucet water was pumped into one end of the heat exchanger through a plastic tube. The plastic tube split into ten coiled copper tubes, and hot shower water was sprayed on top of the copper tubing. The copper tubes then recombined to another plastic tube and the cold water, now warmer, exited the heat exchanger. The temperature of the cold water input, the output, and the shower were recorded. The flow rate of the faucet and the shower was also measured. The percentage of heat recovered from the shower was 3.9%-4.9%.

# 1 Introduction

Due to the large amount of energy required to heat up water, and the volume of water used in a shower, recovering waste heat (and potentially recirculating the warm water by combining it with the hot water) could save energy. According to the U.S. Department of Energy, shower water flow has to be less than 2.5 gallons per minute (GPM).[6] Assuming a 2.5 GPM shower flow, a 40°C shower water temperature, and an input shower water temperature of 20°C, then the amount of water used for showers in the U.S. is (2.5 GPM/shower)(300,000,000 people)(1 shower/person) = $7.5 \cdot 10^8$ gallons. Using a basic heat equation (see the next section for a more detailed derivation), this is approximately equivalent to $2.4 \cdot 10^{11}$ Watts. Therefore increasing the efficiency of a hot water shower by any amount, even if very small, will save large amounts of energy in aggregate.

This study focuses on measuring the amount of heat that can be recovered from a hot shower. A heat exchanger solution was characterized. A heat exchanger is a device that facilitates the flow of thermal energy between liquids at different temperatures.[1] Using calculations presented in the next section, based on the temperature and flow rate of the different inputs, it is possible to quantify the heat transferred from the hot shower water to the cool tap water.

The following section gives an explanation of some of the theory behind this experiment and some exposure to information on heat exchangers. The Measurement of Heat section aims to describe specifically the experimental steps taken to use in the calculations. Results are later presented in the next section and the final section provides some reflection and opportunity for future experimentation.

# 2 Theoretical Background

## 2.1 Heat Transfer Theory

Heat is thermal energy stored in the vibration or motion of particles. Heat can be transferred from one substance to another by one of three methods: conduction, convection, and radiation.[2] Conduction is the transfer of thermal energy by exchanging energy on the molecular scale by adjacent molecules or free electrons. Convection is the transfer of heat through different temperature fluids by mixing, and radiation is the transport of heat by electromagnetic waves.[3]

Heat exchangers are the devices that provide for thermal exchange between two fluids of different temperatures. Heat exchangers use a combination of conduction and convection to transfer heat. The heat is first conducted away from the first fluid through the walls of the tube, and then transferred to the second fluid from the walls by convection.

The type of heat exchanger used in this experiment is known as a "recuperator," as it is used to reclaim some of the heat from the hot fluid by transfer to the cold fluid.[1] This type of recuperator utilizes transmural heat transfer, in which the fluids are not in contact but rather transfer heat through another medium - in this case, the copper tubing. Because the amount of thermal heat exchanged is proportional to the contact area between the two liquids, this heat exchanger has an input tube that splits into ten parallel coiled copper tubes. The copper is a good heat conductor, and by having ten tubes the surface area is greatly increased allowing for better heat exchange.

Figures 1 and 2 display the mechanism for a recuperator heat exchanger using transmural heat transfer.


Figure 1: Simple design of a recuperator. Fluid B is at a higher temperature than fluid A, and heat is transferred across the boundary.[1]

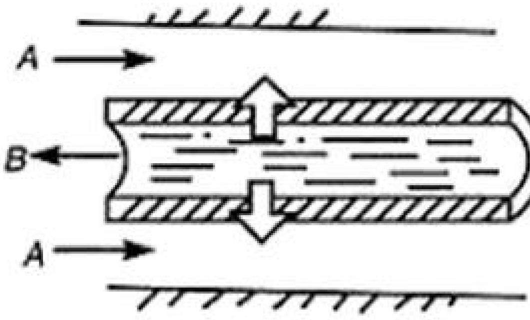



Figure 2: Transmural heat transfer. The heat from fluid B first passes through the walls of the pipe before being transferred to fluid A.[1]

In both Figures 1 and 2, the pictured heat exchangers are counter-flow exchangers, where the two fluids flow in opposite directions. In the experiment, the heat exchanger used was a cross-flow heat exchanger, where the fluids flow at perpendicular directions to each other, as in Figure 3.

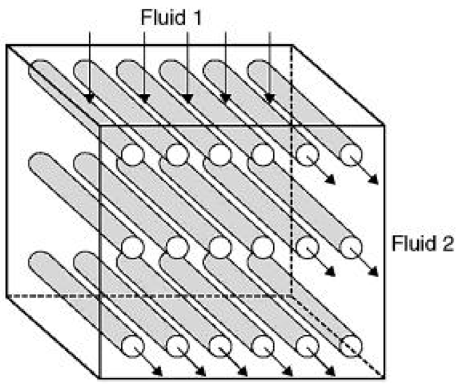



Figure 3: Cross flow heat exchanger. This is a simplified version of the actual heat exchanger used in the experiment, with the difference being that the tubes that fluid 2 flows through are actually spiralled, which gives a larger surface area in contact with fluid 1 and therefore a better heat exchange.[1]

To calculate the transfer of heat from one fluid to the other[2]

$$\dot{Q} = \dot{m}c\Delta T \tag{1}$$

where $\dot{Q}$ is the heat transfer rate, in $[J/s]$, $\dot{m}$ is the mass flow rate in $[kg/s]$, and $\Delta T$ is the change in temperature of the fluid.

Another important equation in the calculation of heat transfer is the overall heat transfer coefficient, $h$.

$$h = \frac{q}{A\Delta T} \tag{2}$$

Or, to rearrange terms:

$$q = hA\Delta T \tag{3}$$

$h$ is measured in units of $[W/m^2K]$. $q$ is the heat flow in $[J/s]$ or $[W]$ and $A$ is the surface area in contact, measured in $[m^2]$.

Because the heat transfer rate is proportional to the exposed surface area, the greater the contact between the two fluids, the greater the amount of heat transferred. The length of time the two liquids are exposed is also a factor to the total amount of heat transferred as

$$Q = \int_0^t \dot{Q}\,\mathrm{d}t = mct\Delta T \tag{4}$$

Therefore, the longer the liquids are in contact, the greater the heat transferred. To take advantage of both these requirements, the heat exchanger in this experiment had a parallel, spiral-coiled water flow.

# 3 Experimental Setup

The heat exchanger was placed in the shower. One of the plastic tubes (the inlet) was connected to a faucet kept at a cold temperature, and the other tube (the outlet) was placed in a bucket. At the connection between the input tube and the faucet a thermocouple was placed. Another thermocouple was placed in the collecting bucket of the heat exchanger, and a third was placed on the shower head.

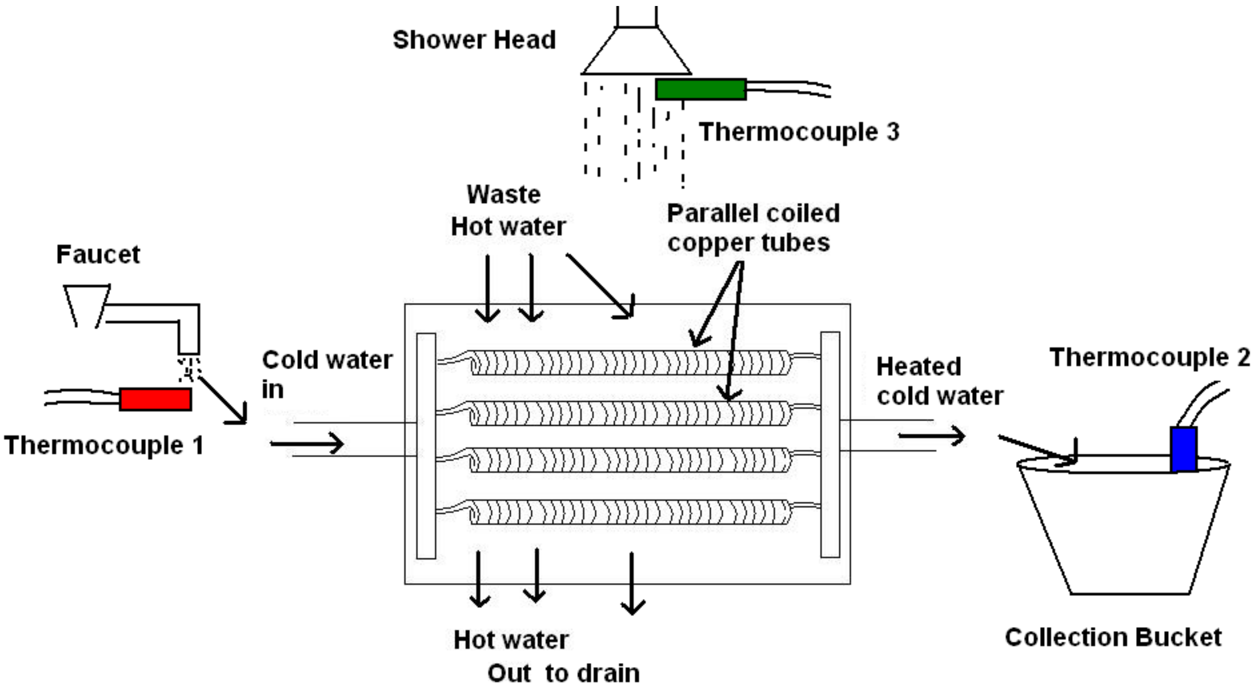



Figure 4: A schematic of the experimental setup used in this experiment. The input tube is connected to a faucet which provides cold water. The cold water is pumped through the coiled copper tubes of the heat exchanger. Hot waste shower water is sprayed over the copper tubes. The heated cold water then is collected in a bucket.

The shower was set to maximum volume (greatest flow rate) for five minutes, in order for the hot water to get from the basement to the shower. The shower was set to a cold setting, and water was pumped through the heat exchanger for approximately one minute in order for the temperatures to reach a steady state. Data was recorded using a LoggerPro device, taking measurements for 30 seconds with 10 measurements/second (for a total of 301 measurements). This process was repeated with the shower on a warm setting and for also a hot setting.

Flow rate of the shower and the heated cold water was also measured. The water was collected in a bucket for 15 seconds. This was weighed and the flow rate (kg/s) was calculated.

# 4 Results and Discussion

The three thermocouple readings for the cold, warm, and hot shower temperatures are shown in Figure 7. The data is summarized in the Table 1.

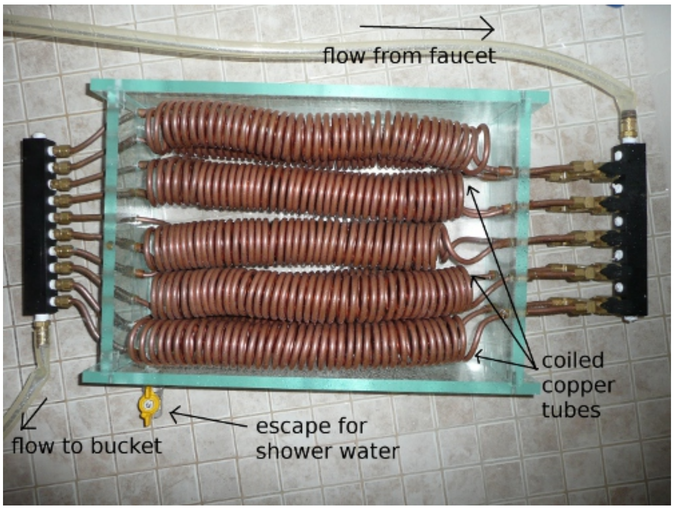



Figure 5: Close up of heat exchanger. The copper tubes are stacked five wide and two deep. The valve pictured bottom left is for the drainage of the hot shower water. It was kept open during the experiment so hot shower water flowed over the copper tubes and out the valve to the drain.

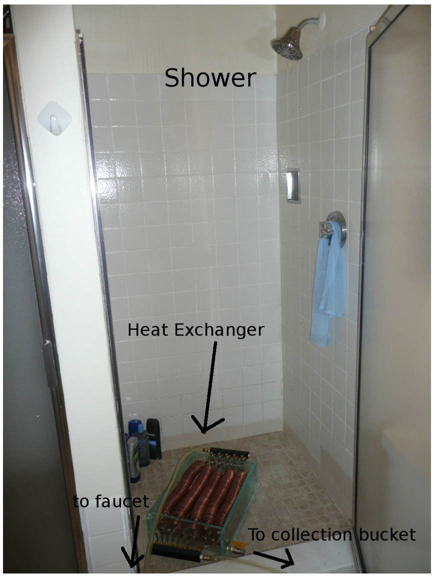
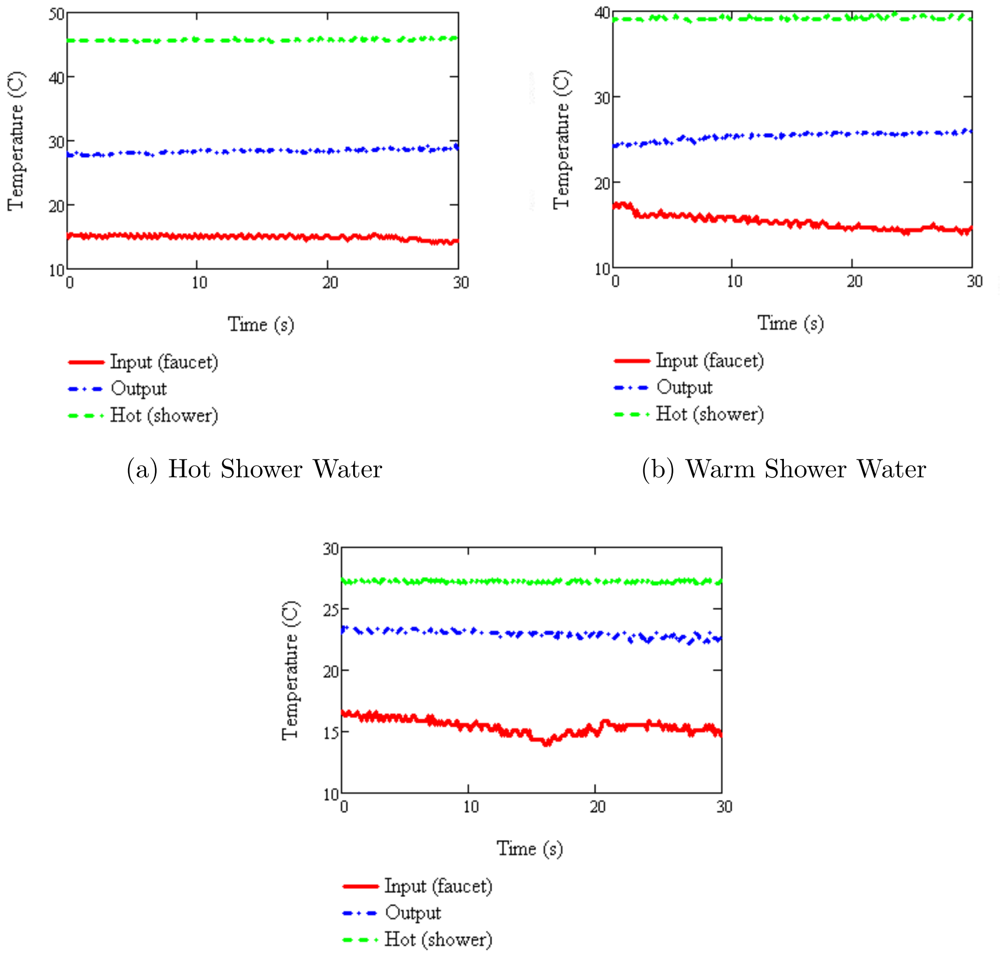



Figure 6: Experimental setup. Heat exchanger has clear tube connected to faucet (not pictured) which splits into ten parallel, coiled copper tubes. Shower water was sprayed on the copper tubes which then recombine. The cold faucet water travels through the copper tubes and is heated up by the shower water. The heated cold faucet water is collected in a bucket.

The difference between the cold water in and the cold water out gives $\Delta T$ from Equation 1. To solve for total power recovered using Equation 1 the flow rate of the




(a) Hot Shower Water

(b) Warm Shower Water

(c) Cold Shower Water

Figure 7: Thermocouple readings with three different temperatures of waste shower water.

Table 1: Thermocouple Measurements

| | Cold(°C) | Warm(°C) | Hot(°C) |
|---|---|---|---|
| Waste Shower Water | $27.20 \pm 0.02$ | $39.23 \pm 0.02$ | $45.67 \pm 0.02$ |
| Cold Water In | $15.41 \pm 0.07$ | $15.28 \pm 0.09$ | $14.89 \pm 0.04$ |
| Cold Water Out | $22.94 \pm 0.04$ | $25.33 \pm 0.06$ | $28.41 \pm 0.04$ |

shower and the heated cold water output was measured.

From Table 2 it was calculated that the flow rate of the shower is $(153 \pm 5) \cdot 10^{-3}$ kg/s and the flow rate of the heat exchanger is $(24 \pm 1) \cdot 10^{-3}$ kg/s.

If it is assumed that the water used in the shower needs to be heated from room

Table 2: Flow Rate Measurements

| Waste Shower Water Flow Rate | Heated Cold Water Flow Rate |
|---|---|
| 0.157 kg/s | 0.0253 kg/s |
| 0.147 kg/s | 0.0233 kg/s |
| 0.153 kg/s | 0.0240 kg/s |
| 0.155 kg/s | 0.0237 kg/s |

temperature at 25°C, then the energy needed to power a shower can be calculated:

$$\dot{Q}_{shower} = \dot{m}_{shower} c \Delta T_{shower} \tag{5}$$

Where $\dot{m}_{shower}$ is the mass flow rate of the shower, $c$ is the specific heat of water at 40°C which is 4.18 kJ/kgC, and $\Delta T_{shower}$ is the difference between the temperature of the shower and 25°C.

Again making use of Equation 1 to solve for the heat transferred per time to the water in the heat exchanger $\dot{Q}_{HE}$:

$$\dot{Q}_{HE} = \dot{m}_{HE} c \Delta T_{HE} \tag{6}$$

Where $\dot{m}_{HE}$ is the mass flow rate of the heated cold water (the output of the heat exchanger), $c$ is the specific heat of water at 30°C which is 4.18 kJ/kgC, and $\Delta T_{HE}$ is the change in temperature between inlet and outlet tubes.

Table 3: Energy Measurements

| | Energy to Power Shower (kW) | Recovered Energy (kW) | Percentage Recovered |
|---|---|---|---|
| Cold | $20.02 \pm 0.02$ | $0.87 \pm 0.04$ | $4.2\% - 4.5\%$ |
| Warm | $28.87 \pm 0.02$ | $1.16 \pm 0.05$ | $3.9\% - 4.2\%$ |
| Hot | $33.61 \pm 0.02$ | $1.57 \pm 0.07$ | $4.5\% - 4.9\%$ |

The amount of recovered power is compared to the difference of the hot waste shower water and the cold faucet input in Figure 8. There is a clear linear relationship between the data and input temperature, and therefore the experimental data confirms the theoretical prediction given by Equation 1 (a linear relationship).

# 5 Conclusion

Through this experiment, it was discovered that this heat exchanger could recover between 3.9% and 4.9% of the energy use of a shower.

A possible installation of a counter-flow heat exchanger in a shower was tested by Wong, etc. in the high-rise buildings of Hong Kong, pictured in Figure 9. Their calculations show that for each building, installing a heat exchanger in the following set up could

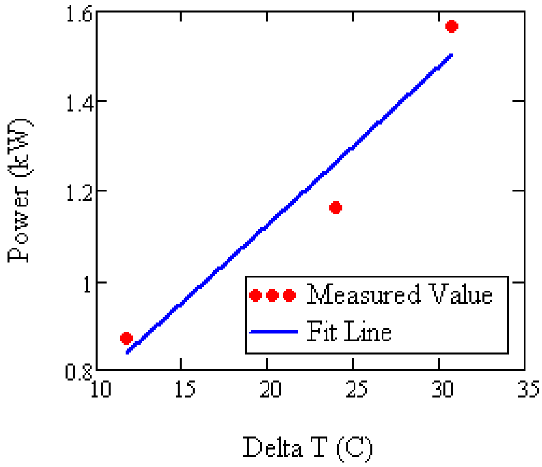



Figure 8: Comparison between the recovered power from the heat exchanger and the difference between the temperature of the hot waste shower water and the cold faucet temperature for the cold, warm, and hot shower tests. A best fit line is also plotted.

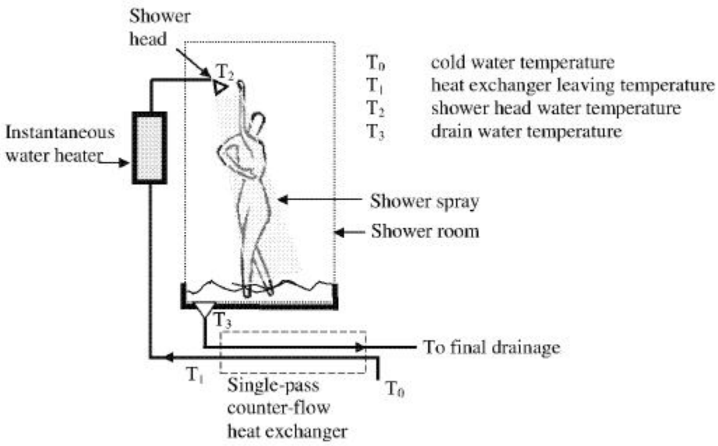



Figure 9: A possible installation for a counter-flow heat exchanger tested by Wong, etc. The hot drain water is used to heat the input water, which is then further heated by the instantaneous water heater. This provides significant energy savings.[5]

save each building from 104 ± 21 MWh/year to 406 ± 84 MWh/year, an energy saving of 4 to 15%.[5] The values measured in this experiment fall within the range predicted by Wong, etc.

There are many opportunities for future experimentation. These include (1) testing the same heat exchanger while a person is showering, (2) installing the heat exchanger in a shower drain and conducting measurements, (3) testing different types of heat exchangers to compare efficiency, and perhaps (4) building, installing, and testing the heat exchanger type that Wong, etc. in a shower and performing more tests.

# 6 Acknowledgements

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