This presentation premiered at WaterSmart Innovations

watersmartinnovations.com

watersmart INNOVATIONS

Automatic Device For Saving Water in Showerheads

(Tests Results)

Fernando Landulfo

fernandolandulfo@terra.com.br

How much time do you have to wait for the warm water at the shower?

It depends on the installation:

- Distance between the water heater and the showerhead
- Water heater type:
  - Accumulative heater (boiler with tank) (Natural gas, LP gas, Electricity):
    - Acquire (40 gal): \$ 480 – \$ 1,200 [1]
    - Operate: (50 gal/day): \$ 238 – \$ 576 (per year)[2]

    Provides hot water <u>immediately</u> for the installation

  - Instantaneous heater (tankless) (Natural gas, LP gas, Electricity):
    - Acquire: \$ 154 – \$ 1,230 [1]
    - Operate: (50 gal/day): \$ 177 – \$ 327 (per year)[2]

    It needs a <u>stabilization time</u> before providing hot water for the installation

It depends on the user:

- Time used to adjust the temperature

---

1 – www.sears.com (7/26/2017)
2- http://www.efficiencymaine.com/docs/Water-Heating-Cost-Comparison-Chart.pdf (7/27/2017)

What happens to the no used cold and hot water while you wait ?

Waste

How much water do you waste during this time?

Let’s try to estimate it

Tankless natural gas water heater performance numerical simulation

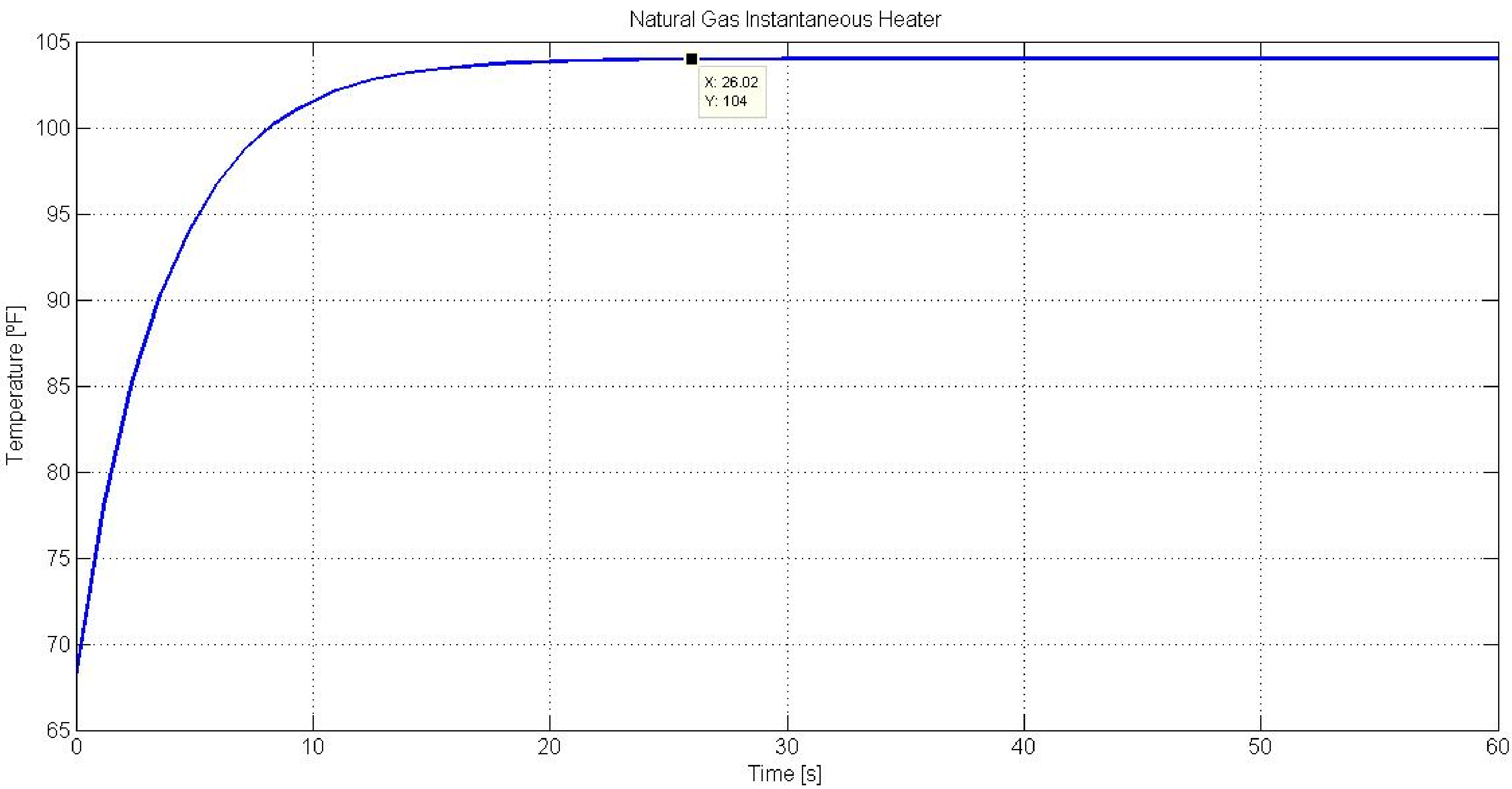
$$\frac{\delta T_s}{\delta t} = \frac{\dot{m}a \cdot C_{p,a} \cdot (T_s - T_e) + \dot{q}_a}{\rho_a \cdot V \cdot C_{p,a}}$$

$$\dot{q}a = \dot{m}a \cdot C_{p,a} \cdot (Ts - Te)$$

Where:

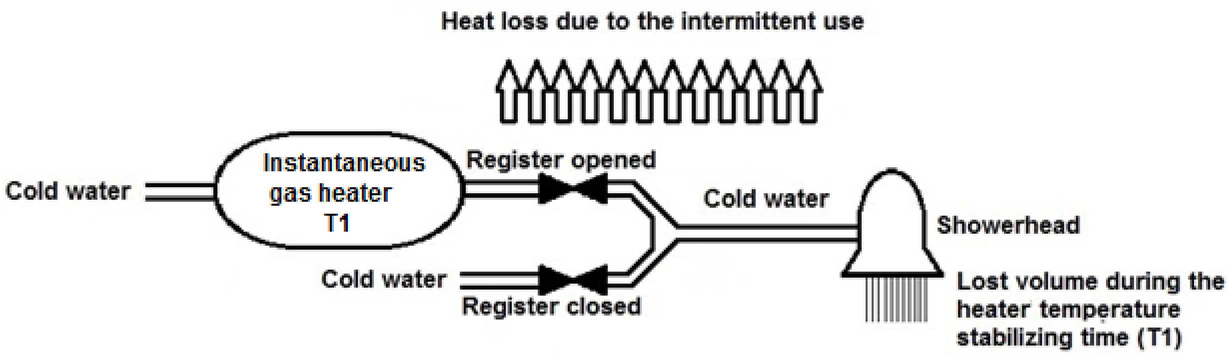
$\dot{m}_a$: Water mass flow rate = 0.0666 kg/s[1] (1.06 GPM)
T_s: Water outlet temperature = 312.15 K (104 °F) (40 °C) (set point)
T_e: Water inlet temperature = 293.15 K (68 °F) (20 °C)
$\dot{q}_a$: Rate of heat input by combustion gases = 5.571 kW (calculated)
V: Heater internal volume = 0.00247 m³ (manufacturer)
ρ_a: Water specific mass = 998.4 kg/m³
$C_{p,a}$: Water specific heat = 4.1825 KJ/kg K

1 – Ilha (1991): comfort shower flow rate = 1.06 GPM (4.00L/min)



Natural Gas Instantaneous Heater
X: 26.02
Y: 104
105
100
95
90
85
80
75
70
65
Temperature [ºF]
0
10
20
30
40
50
60
Time [s]

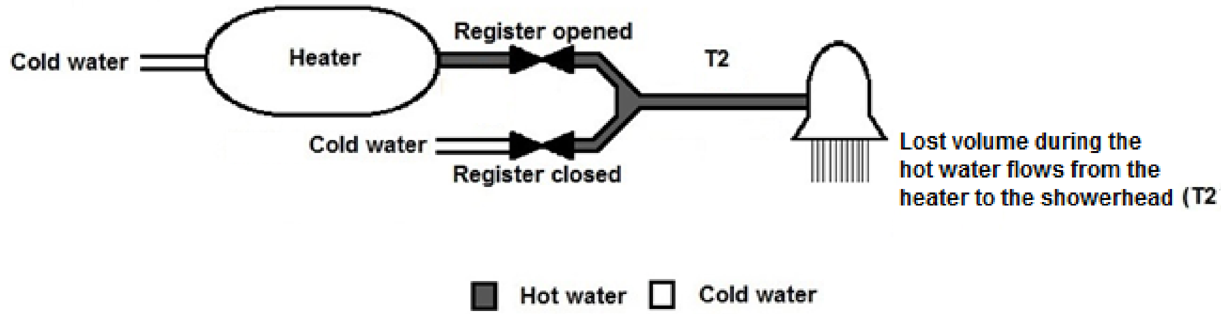
Water loss during the heater stabilization time estimation



Experience	Water Heater Flow Rate (GPM)	Stabilization Time (minutes)	Loss (Gal)
Numerical simulation	1.06[1]	0.44[2]	0.47

1 – Ilha (1991) Confort flow rate)) 4L/min = 1.06 GPM
2 – 26.02 s = 0.44 minutes

Water loss during the hot water flow from the heater to the showerhead estimation



It depends on:

- Heater flow rate
- Hot water pipes cross section
- Hot water pipes length

Assuming:

- A flow of incompressible fluid in steady state
- Hot water pipes inner diameter = ½ inch
- Hot water pipes length = 52.95 ft (prototype)
- Hot water flow rate = 1.06 GPM

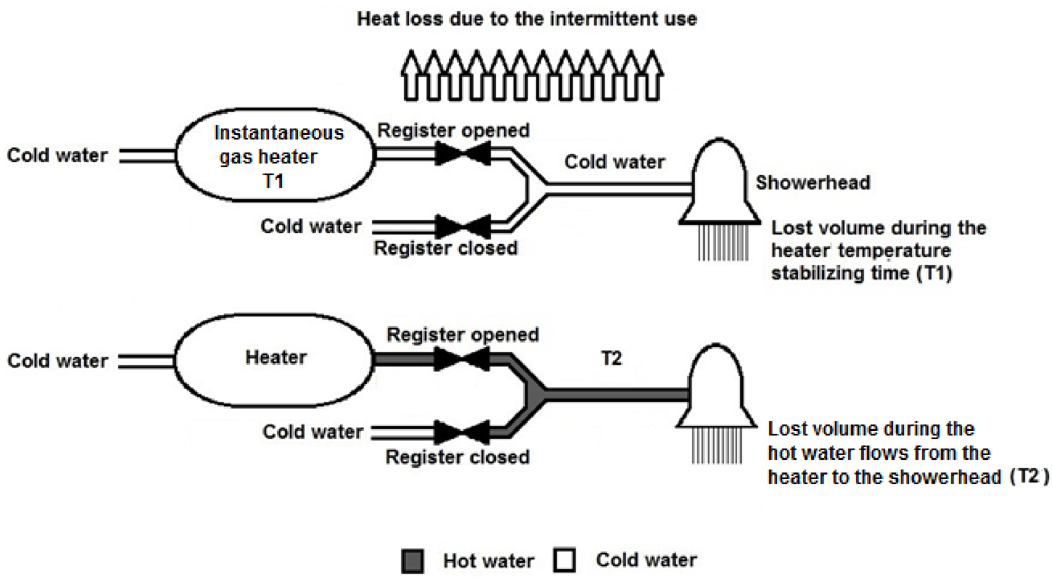
Using:

$V = Q_v . T_t$
$Q_v = v \cdot A$
$v = L / T_t$

V = *Lost Volume*
Q_v = *Hot water flow rate*
T_t = *Hot water flow time*
v = *Flow velocity*
L = *Hot water pipes length*
A = *Hot water pipes cross section*

T_t (min)	V (Gal)
0.52	0.55

Estimated loss during the hot water supply delay



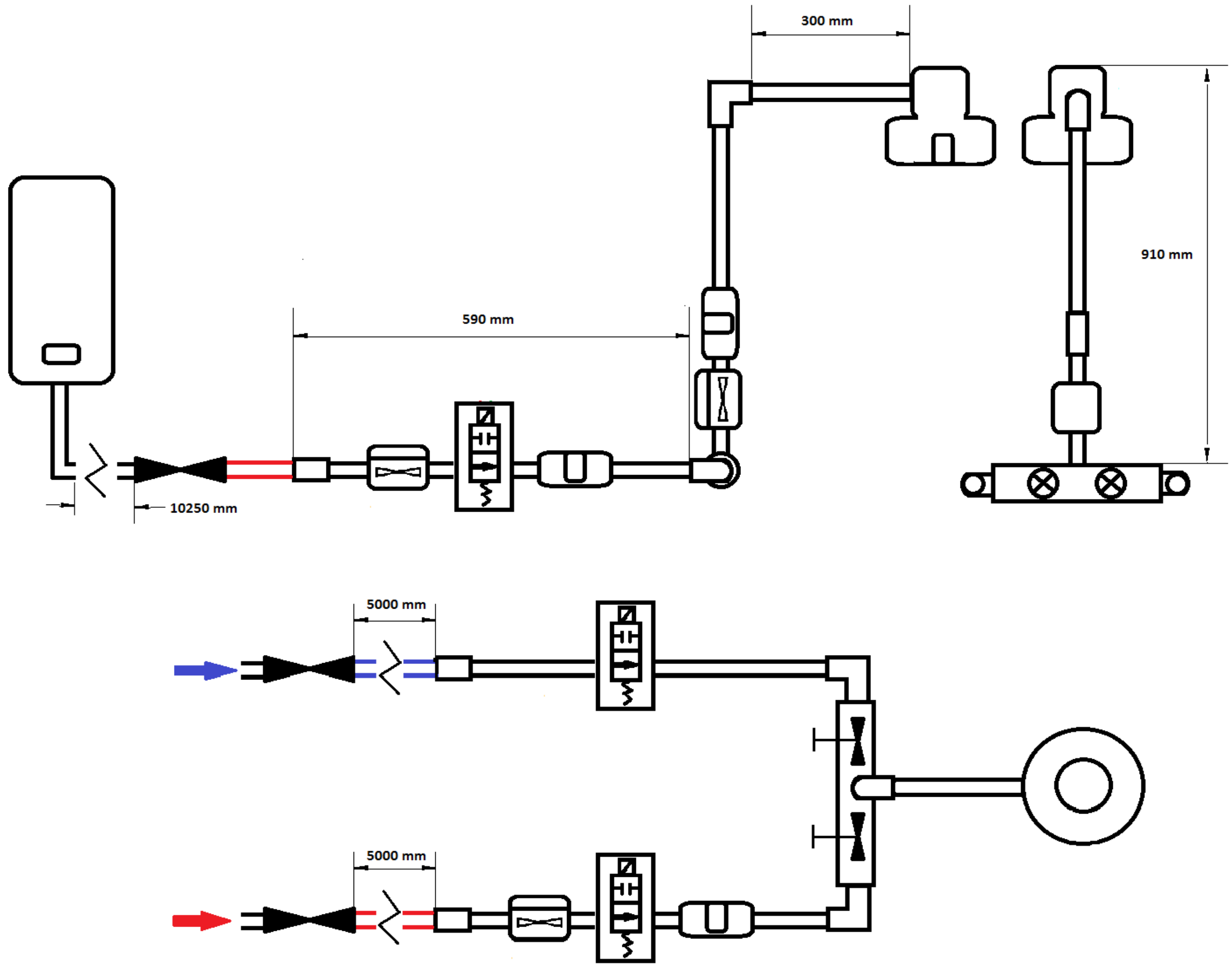
$$T_{LT} = T_1 + T_2$$

$$T_{LT} = 0.44 + 0.52$$

T_{LT} (min)	Q_v (GPM)	V (Gal)
0.96	1.06	1.02

Comparing with the prototype results

Hot water pipes total length = 16,140 mm = 52.95 ft



Comparing with the prototype results

- Test conditions:
  - ✓ Static pressure: 55.46 PSI (39 meters of water colunm)
  - ✓ Heater: Tankless - Natural Gas (10 years old)
  - ✓ Total hot water pipes length: 52.95 ft (16,14 mm)
  - ✓ Setup temperature: 104.00 ºF (40.00 ºC)
  - ✓ Setup flow rate: 1.06 GPM (4.00 L/min)
  - ✓ Number of tests : 5

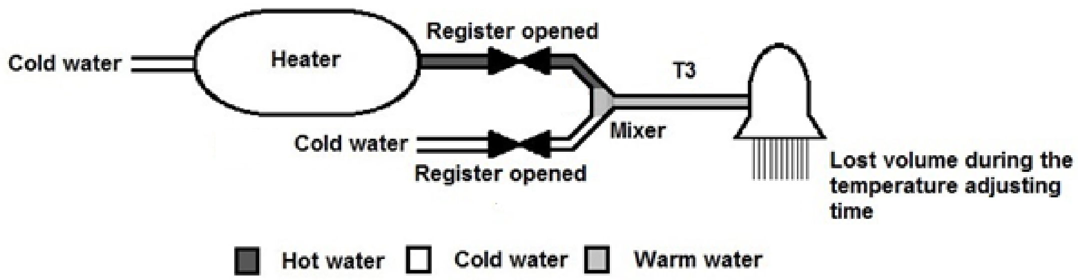
Comparing with the prototype results

Prototype results	Measured Initial Water Temperature (°F)	Measured Flow Rate (GPM)	Measured Final Water Temperature (°F)	Measured Hot water supply delay (min)	Calculated Loss (Gal)
Average (5 tests)	90.50	1.06	104.00	1.44	1.51

Numerical Estimation (all installation)	Assumed Initial Water Temperature (°F)	Assumed Flow Rate (GPM)	Assumed Final Water Temperature (°F)	Estimated Hot Water Supply Delay (min)	Estimated Loss (Gal)
	68.00	1.06	104.00	0.96	1.02

Prototype – Numerical Estimation Difference: 48.00 %

Estimated loss during the temperature adjustment



Subjective: Depends on the user

Assuming:

Warm water temperature: 102.20 °F (39.00°C)
Adjusting time: 10.00 s (0,17 min)
Flow rate: 1.05 GPM

Estimated loss: 0.18 Gal

Comparing with the prototype results

- Test conditions:
  - ✓ Static pressure: 55.46 PSI (39.00 meters of water column)
  - ✓ Heater setup temperature: 107.60 ºF (315.15 K) (42.00 ºC)
  - ✓ Warm water setup temperature: 102.20 ºF (312,15 K) (39.00 ºC)
  - ✓ Setup flow rate: 1.06 GPM (4.00 L/min)
  - ✓ Number of tests : 5

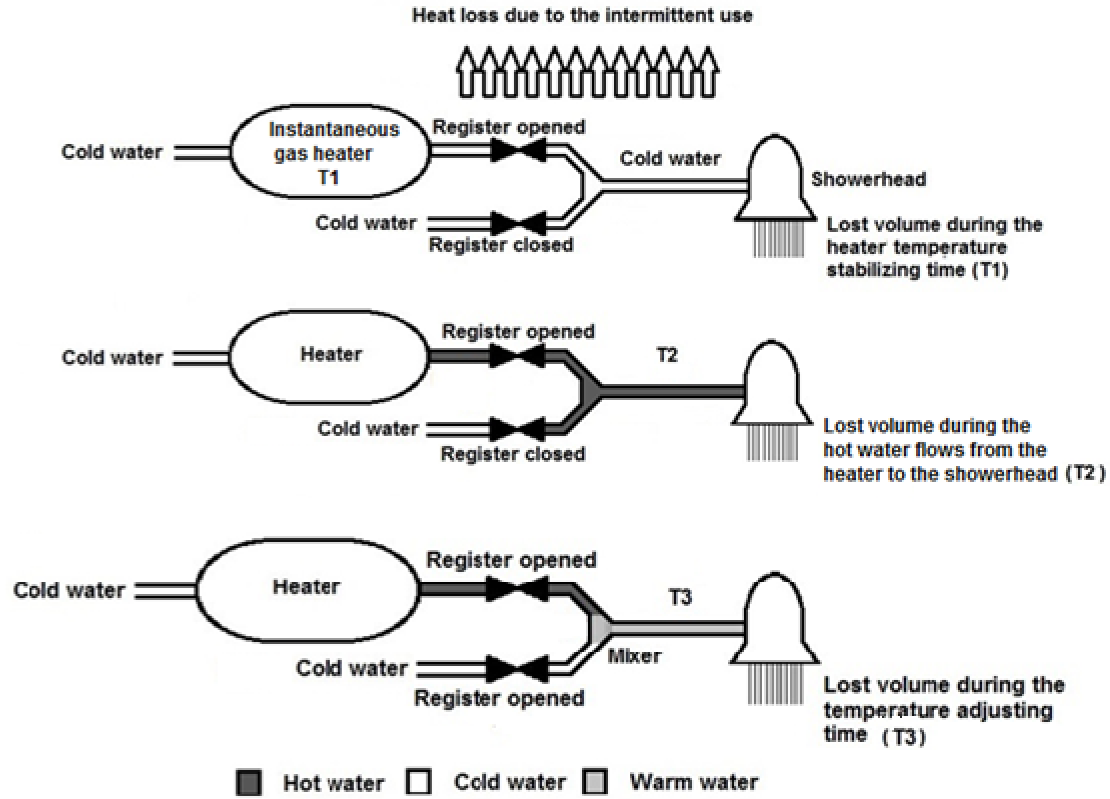
Comparing with the prototype results

Prototype results	Measured Initial Water Temperature (°F)	Measured Flow Rate (GPM)	Measured Final Water Temperature (°F)	Measured Temperature Adjusting Time (min)	Estimated Loss (Gal)
Average (5 tests)	103.60	1.06	102.70	0.24	0.25

Numerical Estimation	Assumed Initial Water Temperature (°F)	Assumed Flow Rate (GPM)	Assumed Final Water Temperature (°F)	Assumed Temperature Adjusting Time (min)	Estimated Loss (Gal)
	-	1.06	102.20	0.17	0.18

Prototype – Numerical Estimation Difference: 38.90 %

Estimated showerhead loss



Estimated showerhead loss

Numerical Estimation	Assumed Water Temperatures Cold / Hot / Warm (°F)	Assumed Flow Rate (GPM)	Estimated Hot Water Supply Delay Loss[1] (A) (Gal)	Estimated Temperature Adjusting Time Loss (B) (Gal)	Estimated Total Loss (A+B) (Gal)
	68.00 / 104.00 / 102.20	1.06	1.02	0.18	1.20

Prototype results	Measured Water Temperatures Cold / Hot / Warm (°F)	Measured Flow Rate (GPM)	Measured Hot water Supply Delay Loss (A) (Gal)	Measured Temperature Adjusting Time Loss (B) (Gal)	Measured Loss (A+B) (Gal)
Average (5 tests)	90.00 / 103.60 / 102.20	1.06	1.51	0.25	1.76

Prototype – Numerical Estimation Difference: 46.70 %

1 – Hot Water Supply Delay = Heater Stabilization Time + Hot Water Flow Time

Idealized Solution:

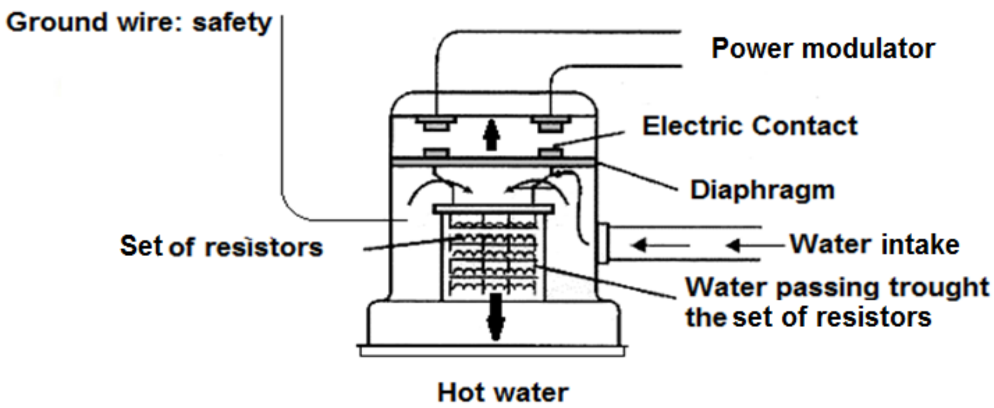
- Reduction of the bath start delay, by heating the water at the consumption place (showerhead)
- Automatically adjust the bath temperature and flow rate

Premises:

- ✓ Use of a secondary heat source: lightweight, compact, proven safe, low stabilization time and lowest possible cost.
- ✓ Use of a control technique that didn't require complex modeling and that allowed control two variables simultaneously.
- ✓ Use of a precise, compact, quiet, reliable, durable and low cost control actuator.

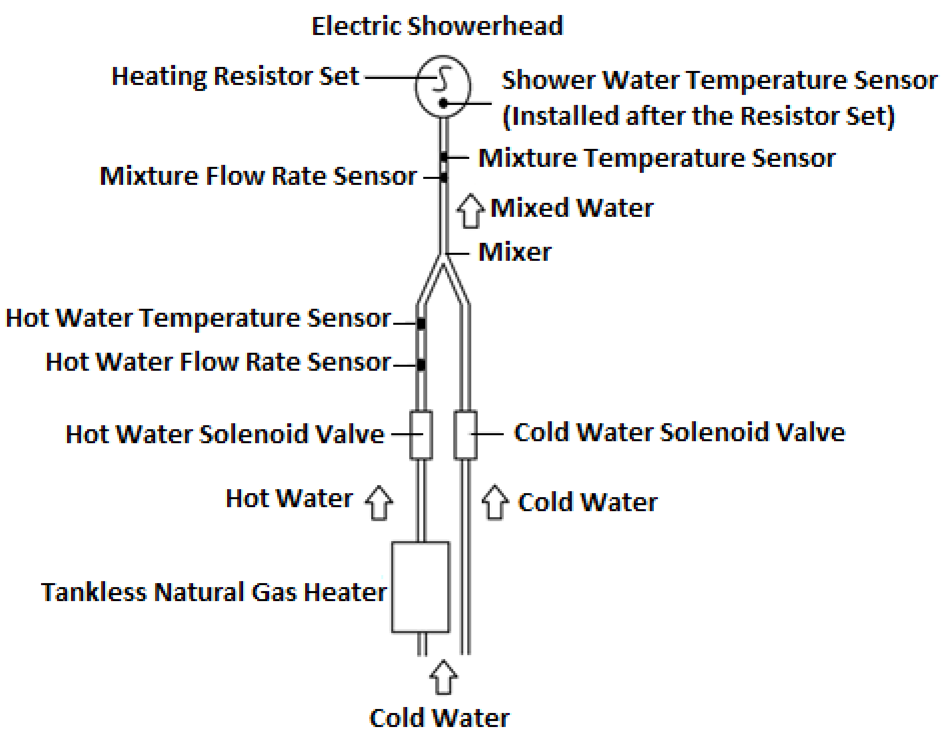
Adopted Solution:

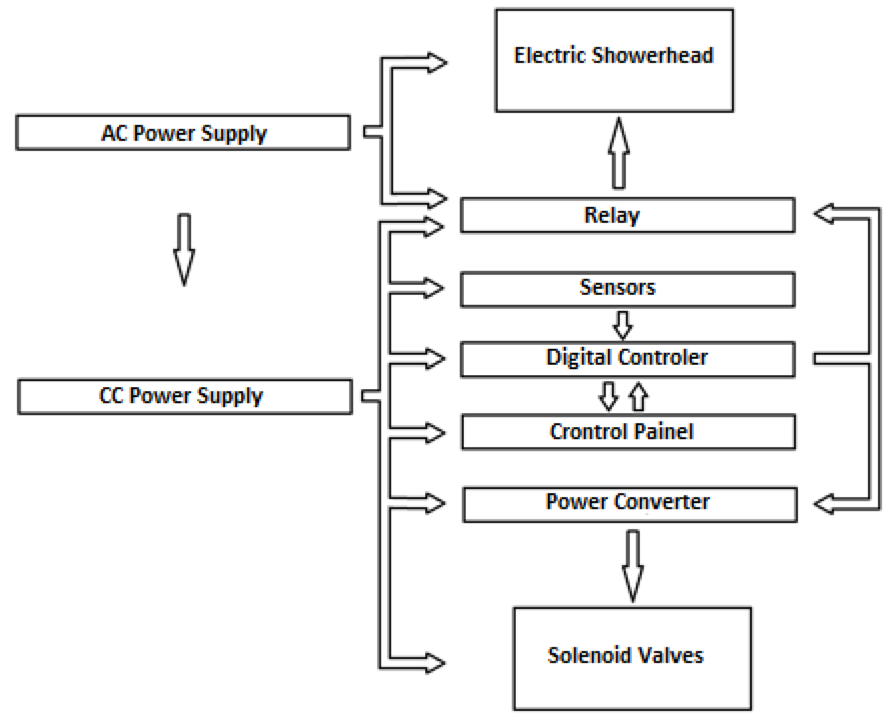
- Use of an electric showerhead as a secondary source of heat (controlled by a microprocessor)



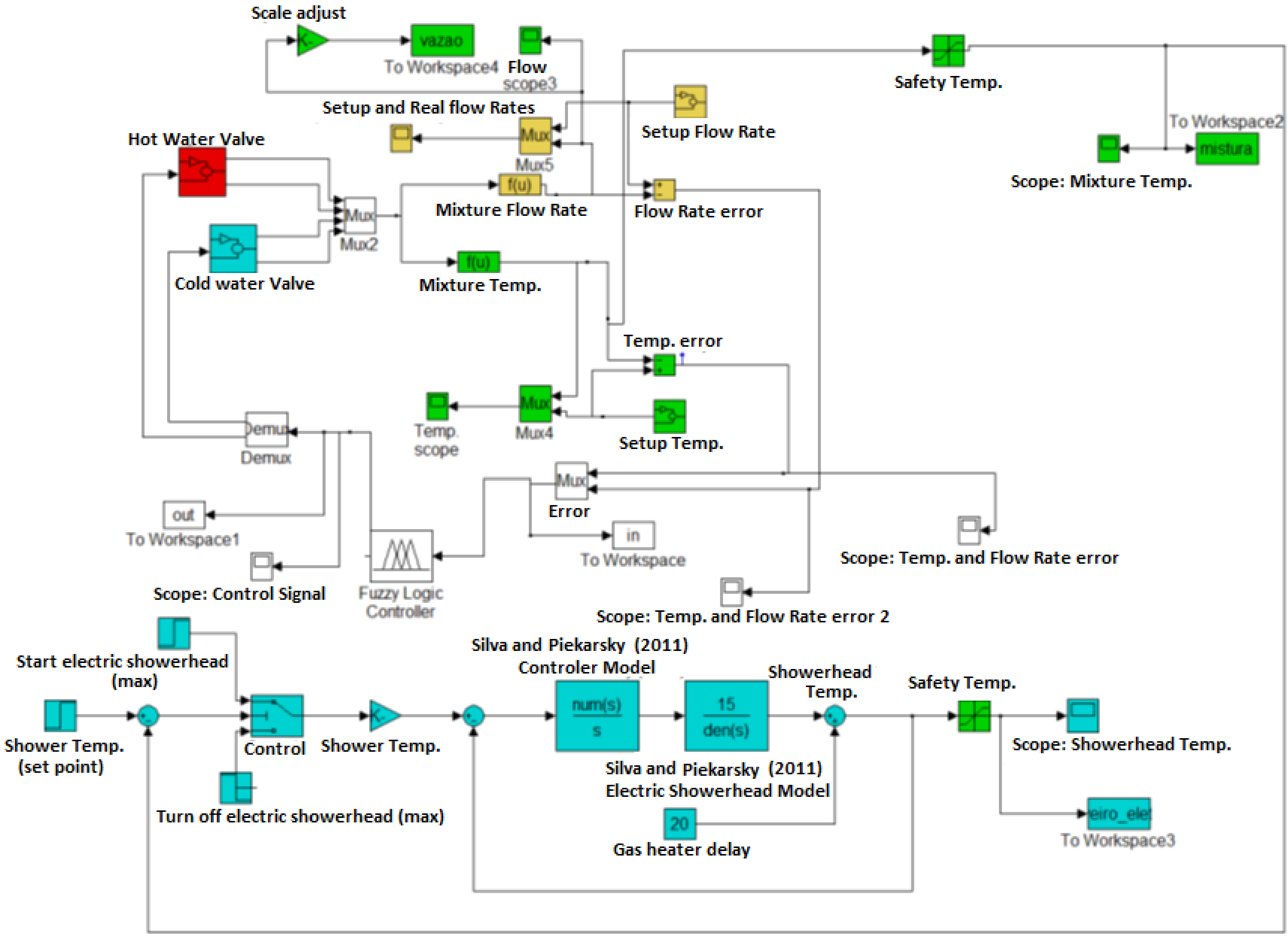
- Use of Fuzzy Logic as a control technique
- Use a Flow 2-way (on-off), normally closed, hydraulic valves, powered by PWM pulses as a control actuator
  - Replace the very expensive hydraulic proportional valves
  - Widely used in the automotive industry to control engine idle speed

Proposed Equipment:





Proposed Equipment Mathematic Model:



8th EFFICIENT Conference

Water Efficiency and Performance Assessment of Water Services

Joint Conference

April 22-24, 2015. Cincinnati (Ohio), USA

CONFERENCE PROCEEDINGS

Editors: Mary Ann Dickinson
Ricardo Cobacho

ISBN: 9781780407722

Prototype

Premises:

- Eclectic functioning:
  - Simulates conventional shower baths with manual temperature and flow control
  - Simulates electric shower baths with manual temperature and flow control
  - Simulates shower baths with water preheating and automatic temperature and flow control
- Compact
- High mobility
- Easy modification or update
- Easy operation
- Low cost

Expected behavior

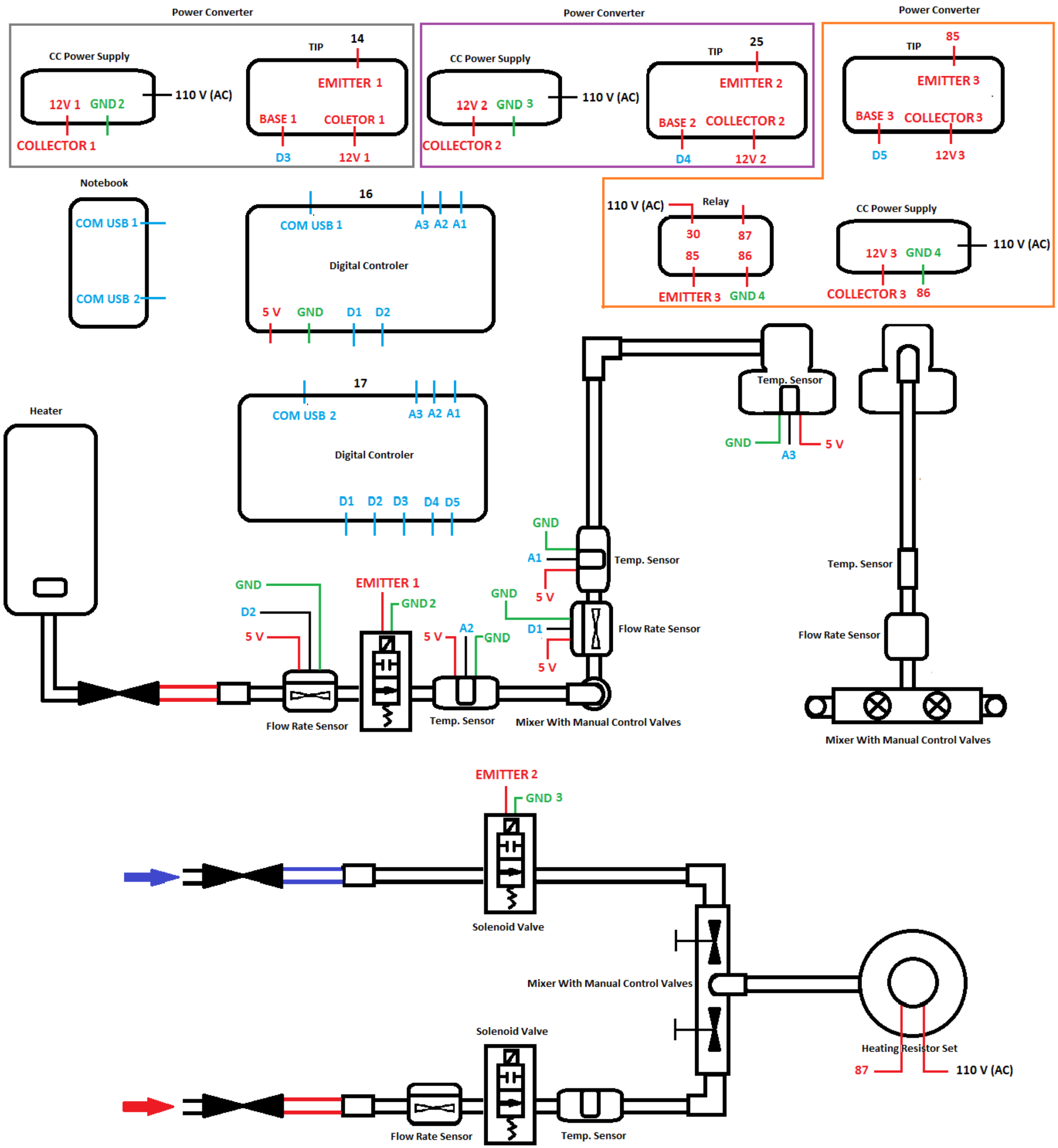
Main target: to reduce water loss during the period between the hot water valve activation and the effective start of the bath.

How?

By preheating the bath water with an electric showerhead, until the gas heater stabilizes, the hot water flows to the mixer and the warm water flows to the showerhead.

Adjusting and maintaining the selected bath temperature and flow rate, by solenoid valves fed by a PWM.

Prototype



Power Converter
CC Power Supply
12V 1
GND 2
COLLECTOR 1
110 V (AC)
TIP
14
EMITTER 1
BASE 1
COLETOR 1
D3
12V 1
Power Converter
CC Power Supply
12V 2
GND 3
COLLECTOR 2
110 V (AC)
TIP
25
EMITTER 2
BASE 2
COLLECTOR 2
D4
12V 2
Power Converter
TIP
85
EMITTER 3
BASE 3
COLLECTOR 3
D5
12V 3
Notebook
COM USB 1
COM USB 2
16
COM USB 1
A3 A2 A1
Digital Controler
5 V
GND
D1
D2
110 V (AC)
Relay
30
87
85
86
EMITTER 3
GND 4
CC Power Supply
12V 3
GND 4
110 V (AC)
COLLECTOR 3
86
17
COM USB 2
A3 A2 A1
Digital Controler
D1 D2 D3 D4 D5
Heater
Temp. Sensor
GND
A3
5 V
GND
A1
5 V
Temp. Sensor
GND
D1
5 V
Flow Rate Sensor
Temp. Sensor
Flow Rate Sensor
GND
D2
5 V
EMITTER 1
GND 2
5 V
A2
GND
Flow Rate Sensor
Temp. Sensor
Mixer With Manual Control Valves
Mixer With Manual Control Valves
EMITTER 2
GND 3
Solenoid Valve
Mixer With Manual Control Valves
Solenoid Valve
Heating Resistor Set
87
110 V (AC)
Flow Rate Sensor
Temp. Sensor

Tests and Results

1) Numerical Simulation (Using the Mathematic Model)

Conditions:

- Bath safety limit temperature: 111.20 °F
- Gas heater stabilization time: 20.00 s
- Gas heater setup temperature: 104.00°F
- Cold water temperature: 77.00 °F
- Bath setup temperature: 96.80 °F
- Flow Rate setup: 2.38 GPM

2) Prototype Test (Full Automatic Mode)

Conditions:

- Gas heater setup temperature: 104.00°F
- Bath setup temperature: 96.80 °F
- Flow Rate setup: 2.38 GPM

Tests and Results

Comparative Results:

Equipment / Parameter	Average Bath Temperature (°F)	Average Bath Flow Rate (GPM)	Bath Start Delay (min)	Loss (Gal)
Setup	96.80	2.38	-	-
Prototype	101.66	2.48	0.28	0.71
Difference from setup (%)	5.02	4.20	-	-
Simulation	95.90	2.38	0.25	0.61
Difference from setup (%)	-0.93	0.00	-	-
Difference Prototype / Simulation (%)	6.00	4.20	12.00	16.39

Tests and Results

Comparative Results:

Equipment / Parameter	Average Bath Temperature (°F)	Average Bath Flow Rate (GPM)	Bath Start Delay (min)	Loss (Gal)
Conventional shower	103.64*	2.38 **	3.78***	3.96***
Prototype	101.66	2.48	0.28	0.71
Difference (%)	-	- 4.20	1,250	457.75

* Setup Temperature: 104.00 °F

** Assumed. Setup Flow Rate: 1.06 GPM

*** Linear projection from a 1.06 GPM Flow Rate

References

Incropera-Frank P. and Witt David P. de (1992). Fundamentos de transferência de calor e de massa. LTC. Appendix A, pp. 437.

Landulfo, Fernando. Dispositivo Automático Micro Controlado para Ajuste de Temperatura e Economia de Água em Chuveiros. 2016. Dissertação de Mestrado. UNICAMP.