Campus Energy 2019: February 26th – March 1st 2019

# Closed-Loop Steam Distribution


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# Maxi-Therm Client Pedigree

University of Colorado Denver

Ohio State

Harvard University

Western Washington University 1893

Towson University

Penn State 1855

Grand Valley State University

The University of Wisconsin Madison

The University of Chicago

University of Connecticut

Penn

Colorado School of Mines 1874

Montclair State University

Yale University

The University of New Mexico

# Agenda

1. Steam Basics
2. Hydronic vs Steam
3. Advantages of Closed-Loop Steam
4. Vertically-Flooded Design
5. Corrosion Prevention
6. Hot Water Applications
7. Example in Practice: Vassar Hospital
8. What is Next? (GenSet)

# Cities With Central Steam

- New-York
- Philadelphia
- Boston
- Baltimore
- Washington DC
- Hartford
- Buffalo
- Rochester
- Minneapolis
- Milwaukee
- Denver
- Montreal
- Vancouver
- Pittsburg
- Saint-Louis
- Tulsa
- Kansas City
- San Francisco
- New Orleans
- Detroit
- Cambridge
- Los Angeles
- Houston
- San Antonio
- Austin
- Richmond
- San Diego
- Grand Rapids

# Hydronic Vs Steam

## Properties of Saturated Steam

Raising 1 lb. of **WATER** 1°F → **1 BTU** of Energy

Raising 1 lb. of **STEAM*** 1°F → **970 BTU** of Energy

*AT ATMOSPHERIC PRESSURE

| Pressure (psig) | Temp. (°F) | Heat (BTU/lb) | | | Volume (ft^3/lb) | |
|---|---|---|---|---|---|---|
| | | Sensible | Latent | Total | Condensate | Steam |
| 0 | 212 | 180 | 970 | 1150 | 0.01672 | 26.80 |
| 1 | 215 | 184 | 968 | 1152 | 0.01674 | 25.21 |
| 2 | 219 | 187 | 966 | 1153 | 0.01676 | 23.79 |
| 3 | 222 | 190 | 964 | 1154 | 0.01679 | 22.53 |
| 4 | 224 | 193 | 962 | 1155 | 0.01681 | 21.40 |
| 5 | 227 | 195 | 961 | 1156 | 0.01683 | 20.38 |
| 6 | 230 | 198 | 959 | 1157 | 0.01685 | 19.46 |
| 7 | 232 | 201 | 957 | 1158 | 0.01687 | 18.62 |
| 8 | 235 | 203 | 956 | 1159 | 0.01689 | 17.85 |
| 9 | 237 | 206 | 954 | 1160 | 0.0169 | 17.14 |
| 10 | 239 | 208 | 953 | 1161 | 0.01692 | 16.49 |
| 12 | 244 | 212 | 950 | 1162 | 0.01696 | 15.33 |
| 14 | 248 | 216 | 947 | 1163 | 0.01699 | 14.33 |
| 16 | 252 | 220 | 944 | 1164 | 0.01702 | 13.45 |
| 100 | 338 | 309 | 881 | 1190 | 0.01785 | 3.8910 |
| 105 | 341 | 312 | 878 | 1190 | 0.01789 | 3.7360 |
| 110 | 344 | 316 | 876 | 1192 | 0.01792 | 3.5940 |
| 115 | 347 | 319 | 873 | 1192 | 0.01796 | 3.4620 |
| 120 | 350 | 322 | 871 | 1193 | 0.01799 | 3.3400 |
| 125 | 353 | 325 | 868 | 1193 | 0.01803 | 3.2260 |

# Hydronic Vs Steam

## Hydronic (212°F)

$$35{,}140{,}000\,{}^{Btu}/_{hr} * \frac{1}{180}\,{}^{lb}/_{Btu} * \frac{1}{8.33}\,{}^{Gal}/_{lb} * \frac{1}{60}\,{}^{hr}/_{min} =$$ ***391 GPM***

## Steam (100psi)

$$35{,}140{,}000\,{}^{Btu}/_{hr} * \frac{1}{1{,}190}\,{}^{lb}/_{Btu} * \frac{1}{8.33}\,{}^{Gal}/_{lb} * \frac{1}{60}\,{}^{hr}/_{min} =$$ ***59 GPM***

***Lower flow rate → Smaller pipes required***

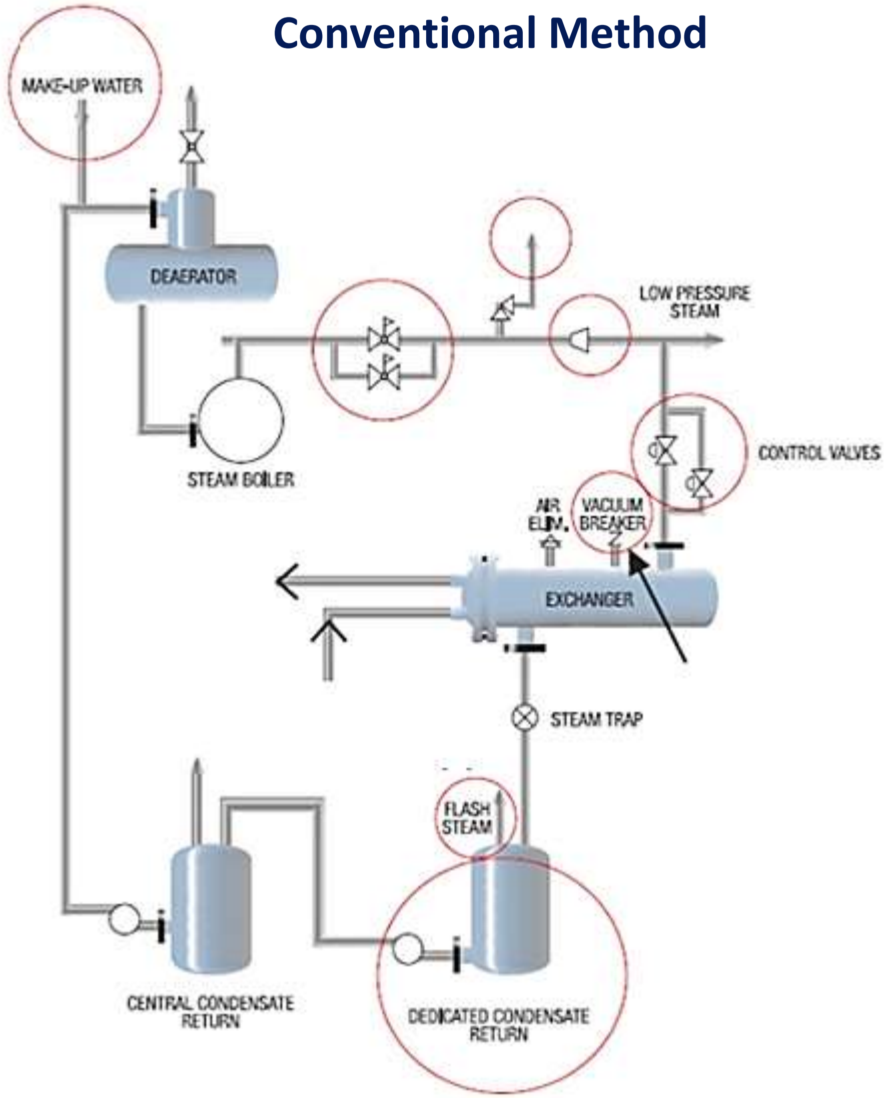
## Reduced Pump Energy

| Steam | Hydronic |
|---|---|
|  |  |
| **15 HP** | **90 HP** |

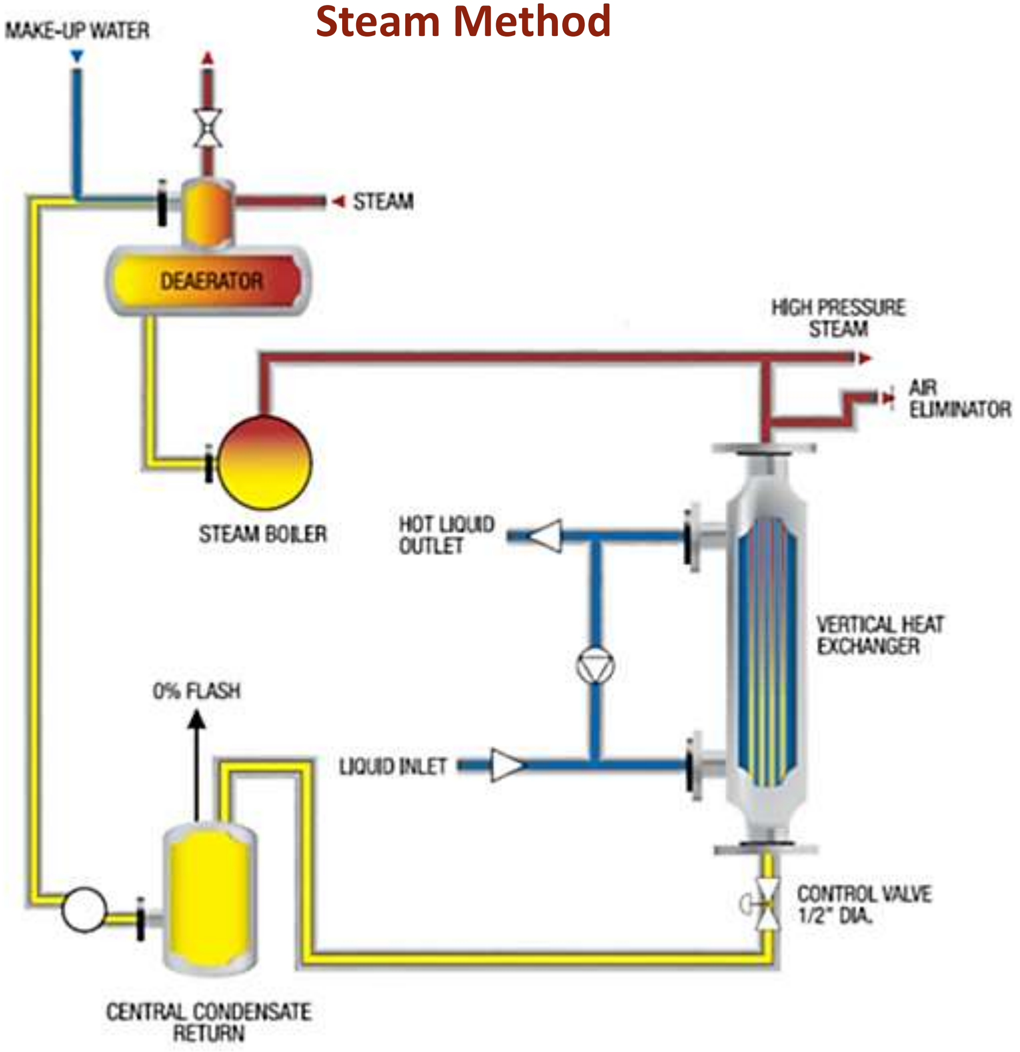
***The pumps represent 3% of the overall energy needed for the hydronic loop***

# Hydronic Vs Steam

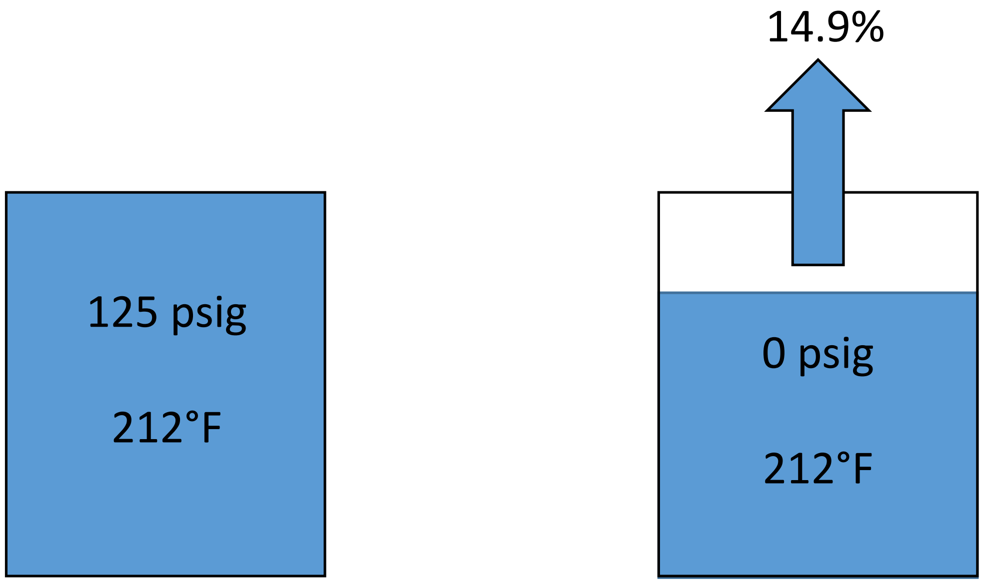
## Conventional Method




## Steam Method



# Advantages of Closed-Loop Steam




$$\dot{m}_{fs} = \frac{\dot{m}_c(h_c - h_{fc})}{h_{fg}} \qquad R_{fs}(\%) = 100\frac{\dot{m}_{fs}}{\dot{m}_c}$$

$\dot{m}_{fs} = mass\ flow\ rate\ of\ flash\ steam$

$\dot{m}_c = mass\ flow\ rate\ of\ condensate$

$h_c = enthalpy\ of\ condensate$

$h_{fc} = enthalpy\ of\ flash\ condensate$

$h_{fg} = latent\ heat\ of\ flash\ steam$

$R_{fs} = flash\ steam\ ratio\ (\%)$

# Advantages of Closed-Loop Steam

- **No flash tank required → No Vent to roof**
- **Energy savings of 5-20%**
- Safety and reliability
  - No steam safety valve needed
- Simplicity
- **No acid contamination**
  - Up to 6 times less corrosive on condensate piping
- Can use **high** or **low pressure steam**


System and Size



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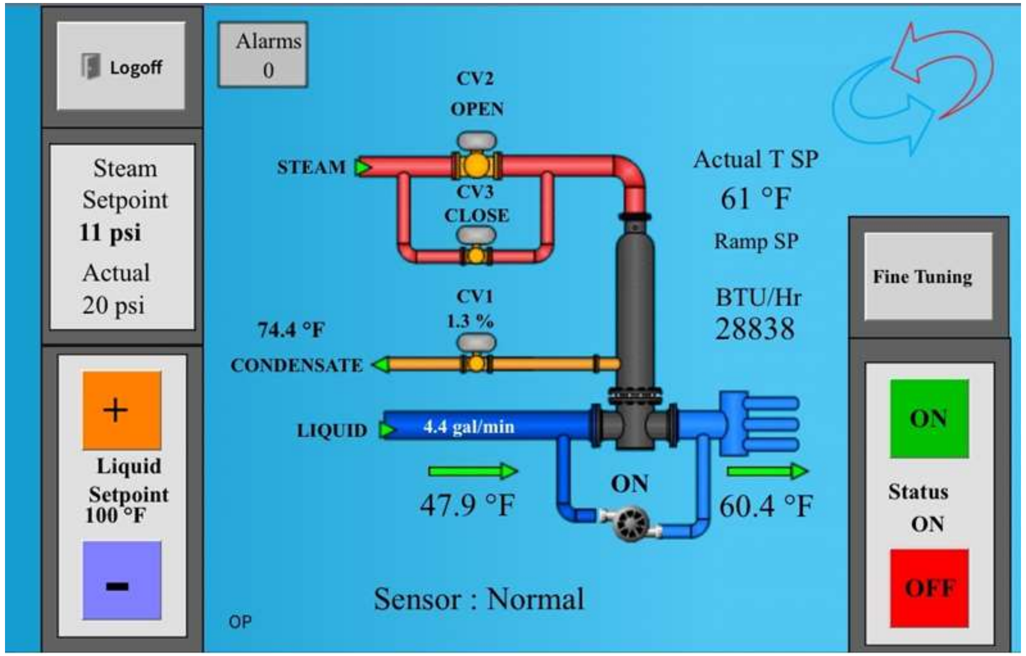
# Advantages of Closed-Loop Steam

- **Less make-up water** required
- **No PRV** required for steam
- **No condensate receiver pump** needed to return steam through loop
- **Smaller pipe size** due to higher energy content
- **Lower maintenance costs**
- **Few chemicals** and **fewer return lines** (with longer lifespan)
- 40%-60% **smaller footprint**
- **Fully automated** control system
- **Digital Energy readouts**
- **No Noise**

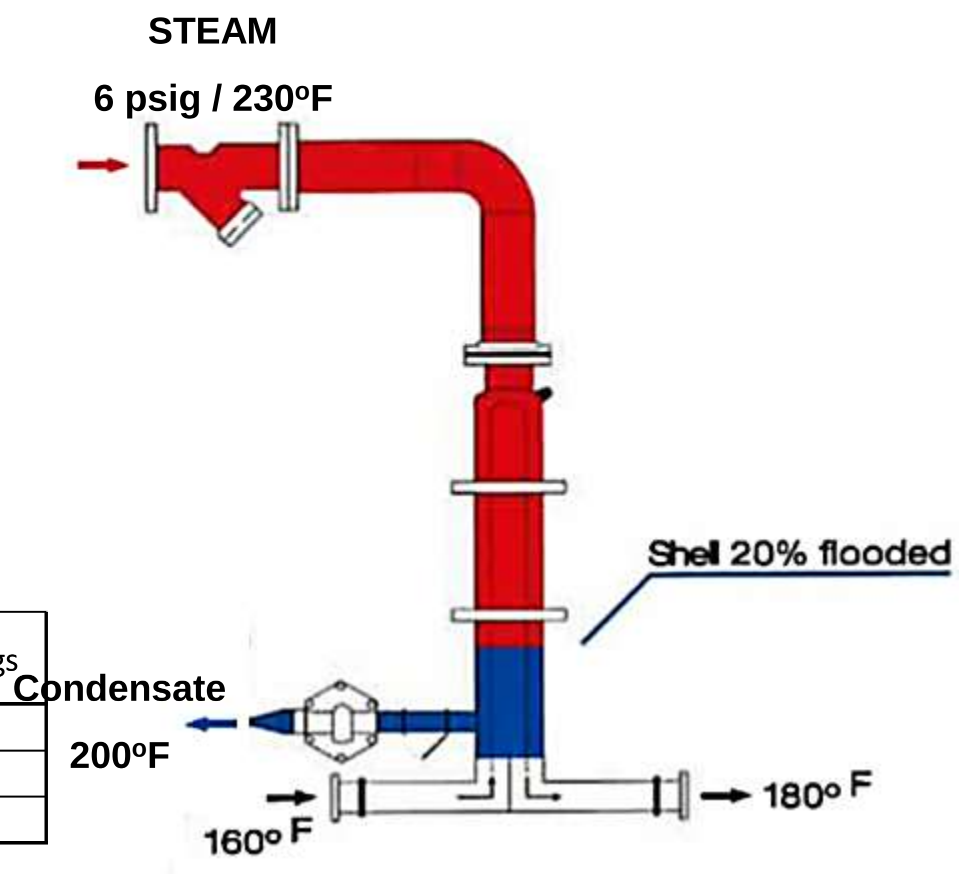


Digital Readout

# Vertically-Flooded Design

- Vary % of shell flooded to avoid flash
- Can use **low**, **medium**, or **high** pressure steam
- **No PRV** downstream of boiler
- Acts as a *Condensing Heat Exchanger*

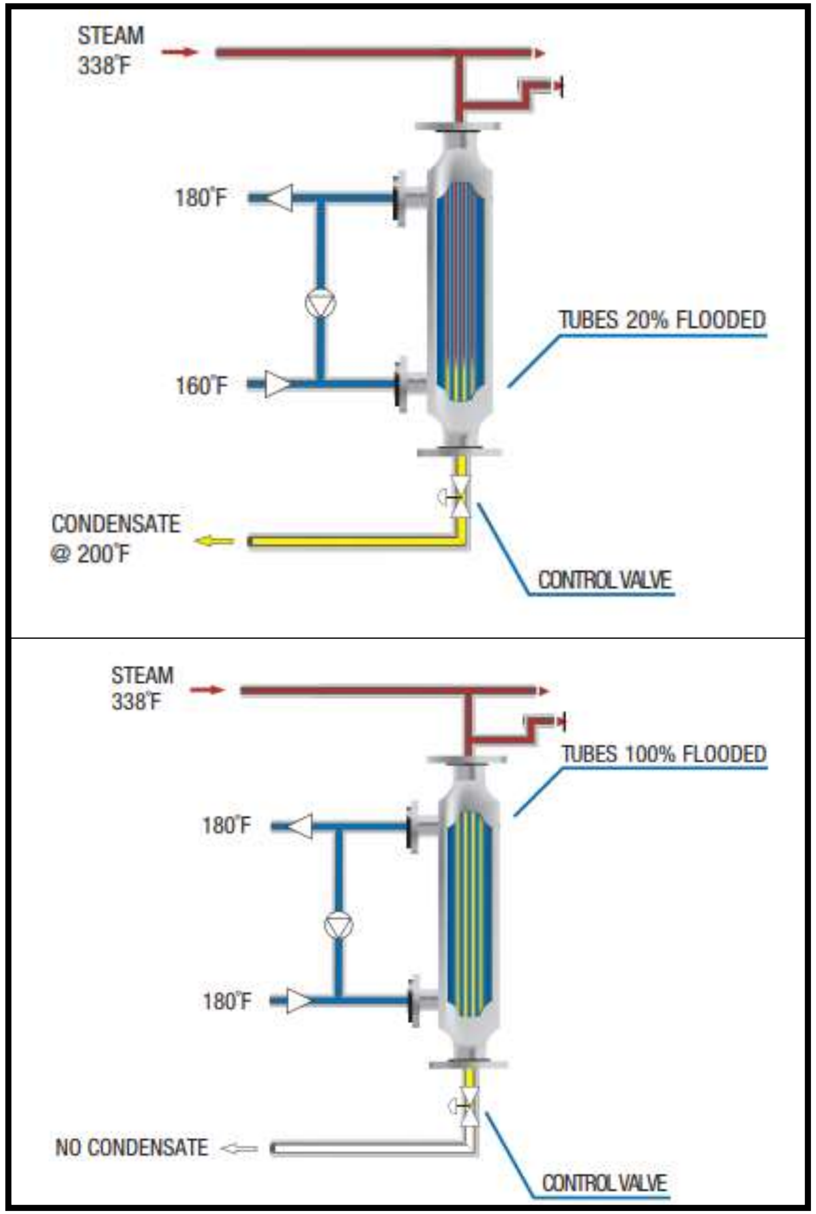
| Process | Pressure (psig) | BTU/h | Sensible (BTU/lb) | Latent (BTU/lb) | Total (BTU/lb) | lbs/h | Savings |
|---|---|---|---|---|---|---|---|
| Conventional | 6 | 4 000 000 | - | 959 | 959 | 4 171 | - |
| Flooded | 6 | 4 000 000 | 50 | 959 | 1 009 | 3 964 | 5,0% |
| Flooded | 100 | 4 000 000 | 158 | 881 | 1 039 | 3 850 | 7,7% |




0% FLASH, 200°F CONDENSATE RETURN

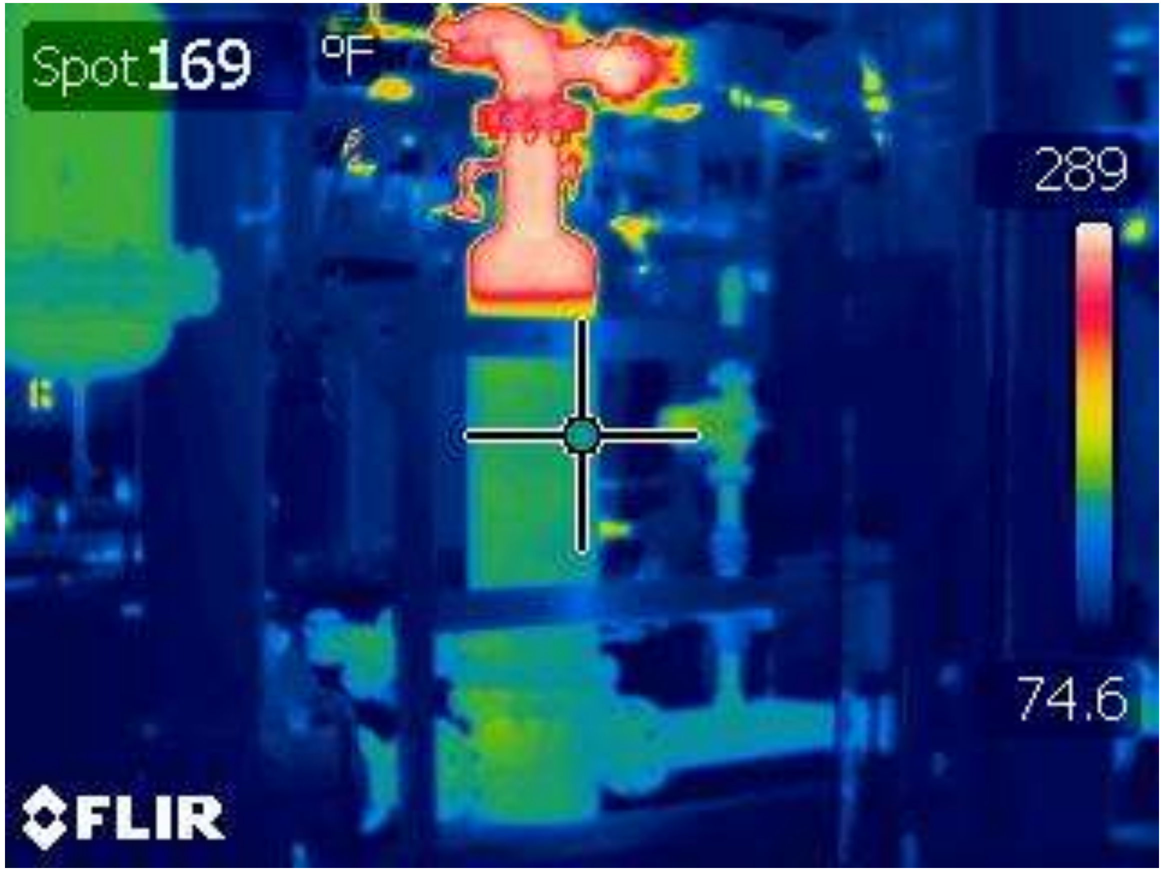
# Vertically-Flooded Design

- <u>Uses **latent** and **sensible** heat of steam to heat liquid</u>
- Oversized vertical shell & tube heat exchanger
- Flooded condensate **subcooled** to **200°F**
- Level of condensate varied by control valve
  - Used to control temperature instead of throttling steam
- Improvements from comparable European models:
  - Steam can be **any pressure**
  - **Control set-point** of heated liquid outlet



# Vertically-Flooded Design


Vertically Flooded Heat Exchangers



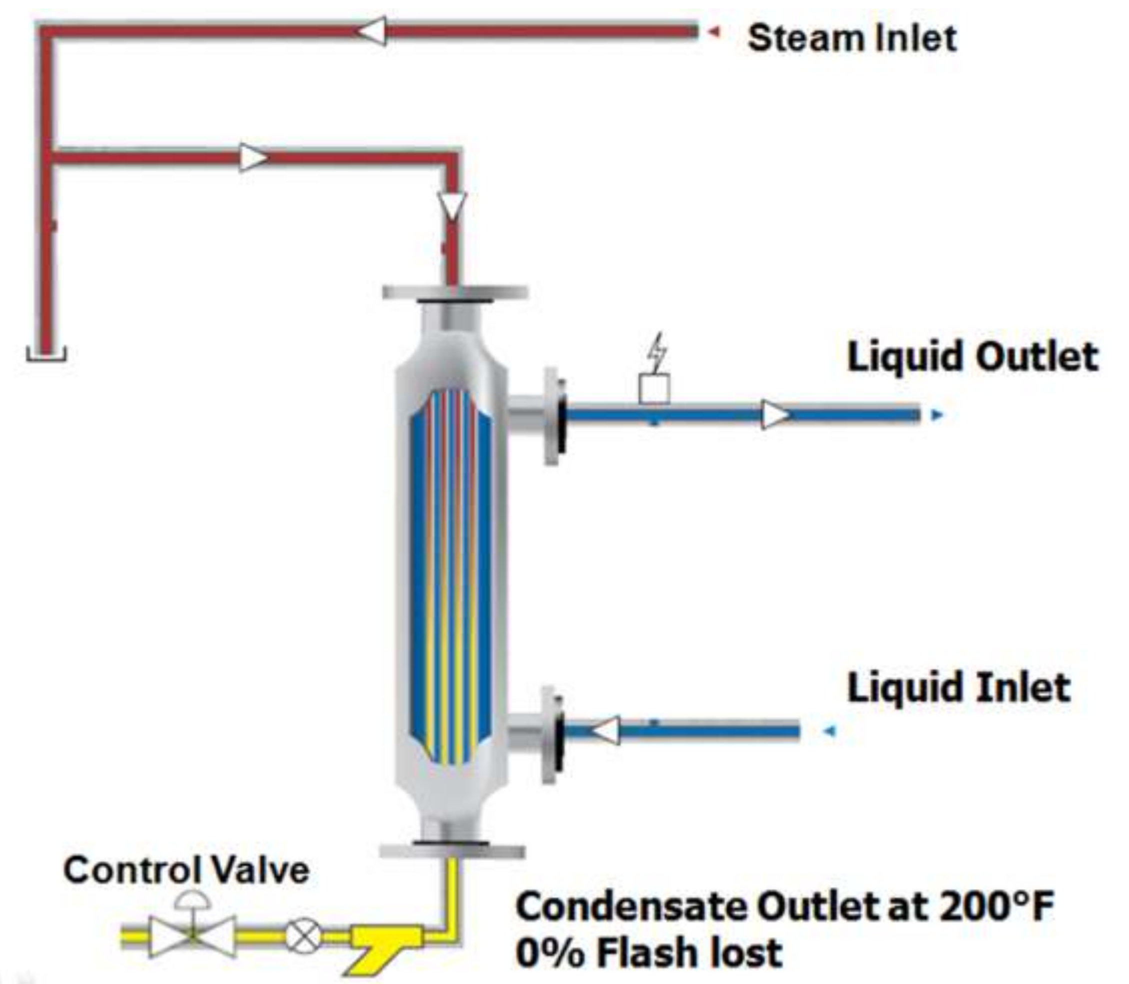

Heat Map Showing Tube Flooding to Avoid Flash

# Vertically-Flooded Design



## Make-Up Water Reduction

- Causes for make-up water to be added traditionally:
  - Boiler blow-down
  - Leaks
  - Flash steam
- Vertical heat exchanger eliminates flash
  - Condensate is subcooled below boiling point
  - Stays as a liquid
  - High pressure condensate eliminates need for condensate pump



## Evaluation- Operating Cost Comparison: Exchanger with Full Load

| | Conventional | Vertically-Flooded |
|---|---|---|
| Pressure (psig) | 10 | 30 |
| Energy Transferred (Mbtu/hr) | 6.01 | 6.01 |
| Steam Flow Rate (lbs/hr) | 6,307 | 5,991 |
| Percentage of Water Lost to Flash | 2.85% | 0% |
| Flash Loss Rate | 180 | - |
| Energy to Heat Condensate (Mbtu/hr) | 0.38 | 0.44 |
| Energy to Heat Make Up (Mbtu/hr) | 0.04 | - |
| Energy to Vaporize (Mbtu/hr) | 5.86 | 5.57 |
| **Total (Mbtu/hr)** | 6.28 | 6.01 |

| Savings | | |
|---|---|---|
| Hours | Dollars | Tons of $CO_2$ per Million BTUs |
| 2,000 | $6,660.99 | **38.92** |
| 3,000 | $9,991.49 | **58.38** |

(0.05843 ton of $CO_2$ per Million BTUs)

# Corrosion Prevention

- **Traditional systems are 6.2 times more corrosive**[1]
- Deaerator uses low pressure steam to **drive out dissolved gases**
- Sensibly heats make-up water from 40°F to 205°F
  - Condensate reclamation reduces need for make-up water
- Cooler condensate **reduces cavitation**
  - Hot condensate cavitates as pump pulls it into the volute
- Lower make-up water requirement → **less chemicals** for treatment → cleaner steam running through pipes
  - Cuts surface blowdown in half
  - Delivers 97% quality steam (3% moisture)

1. Corrosion tests conducted independently at hospital in Montreal over 94 day period. Maxi-Therm has corrosion rate of 2.36 mills per year compared to 14.63 mills per year using conventional methods (both using alloy C1010 black iron)

# Hot Water Applications

## Building Heat Application

- Can control liquid outlet temp to **±2°F for building heat**
- Building heat applications:
  - Heating water/ glycol
  - Hot oil or other heat transfer fluids
  - Wash stations
  - Emergency showers
  - Reactors, pasteurizers, jacketing
  - Booster heaters for kitchens
  - Heat recirculation water at 250°F (no bacteria)
- Can handle liquid flow between 35 and 850 usgpm (and can go above 2,000 usgpm if needed)

Hot Water From Steam Generator

## Domestic Hot Water Application

- Most facilities use **over 50% of steam for hot water** production
  - Service water
  - Domestic water
  - Reheat
  - Clean steam
- Can control liquid outlet temp to **±4°F for domestic hot water**
- Uses Vertically Flooded Heat Exchanger (VFHX)
- **Smaller** than conventional storage tank heaters
  - Can be wheeled through a doorway
- Smaller reservoir and higher temperatures
  - Stops growth of Legionella bacteria

# Example in Practice: Vassar Hospital

# Example in Practice: Vassar Hospital

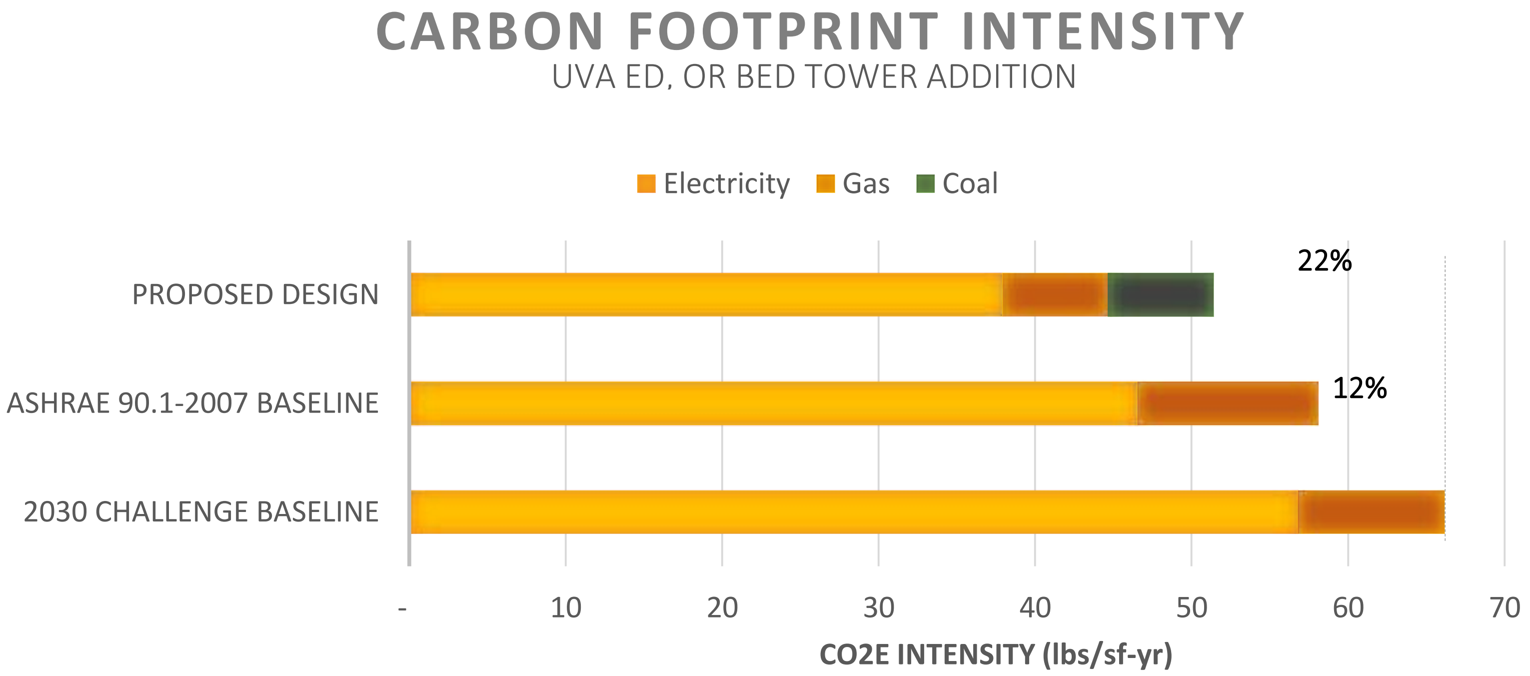
| Flash Steam Loss Calc | | | | | | | |
|---|---|---|---|---|---|---|---|
| Flash Steam (lbs) | Make-Up Water (gal) | Flash Steam Heat Loss (Btu) | Additional Heat Vaporization (Btu) | Additional Gas to Heat Cond. (Btu) | Gas Consumed (Therms) | Cond. Flow Rate (GPM) | Pump Energy (kW) |
| 1,000,406 | 120,097 | 157,063,776 | 1,308,848,422 | 15,362,907 | 17,000 | 50,126 | 1,309 |

| Flash Steam Loss Cost | | |
|---|---|---|
| Gas Savings: | $ | 14,960 |
| Water Savings: | $ | 432 |
| Chemical Savings: | $ | 480 |
| Electrical Savings: | $ | 1,309 |
| Total Savings: | $ | 15,873 |

- **Eliminating flash losses** to the atmosphere **saves energy** and **money**
  - Less gas to reheat make-up water to usable temperature
  - Less make-up water lost to high-pressure water flashing to steam
  - Lower volume of water to chemically treat
  - Less pump energy to pull in make-up water

# Effective designs have positive environmental impacts

- 705,000 SF
- 264 patient beds
- 16 ORs (~800 SF each)
- LEED 2009 Silver rating
- Fuel gas load: 90,000 CFH
- Heating density: 65 Btu/SF



# Example in Practice: Vassar Hospital

| Heat Exchanger (Steam-Water) Schedule | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Water Side (Tube) | | Steam Side (Shell) | |
| Unit | Service | EWT (°F) | LWT (°F) | GPM | PD (ft. H2O) | Min MBH | Operating Pressure | Flow Rate (lbs/h) |
| 1 | Main HVAC Heating | 172 | 220 | 2,275 | 5 | 31,850 | 85 | 31,640 |
| 2 | Domestic Water Heater | 40 | 140 | 40 | 3 | 2,000 | 85 | 1,969 |
| 3 | Non-Potable Hot Water Heater | 40 | 140 | 30 | 2 | 1,500 | 85 | 1,477 |
| 4 | Snow Melt | 105 | 130 | 111 | 10 | 1,388 | 85 | 1,992 |

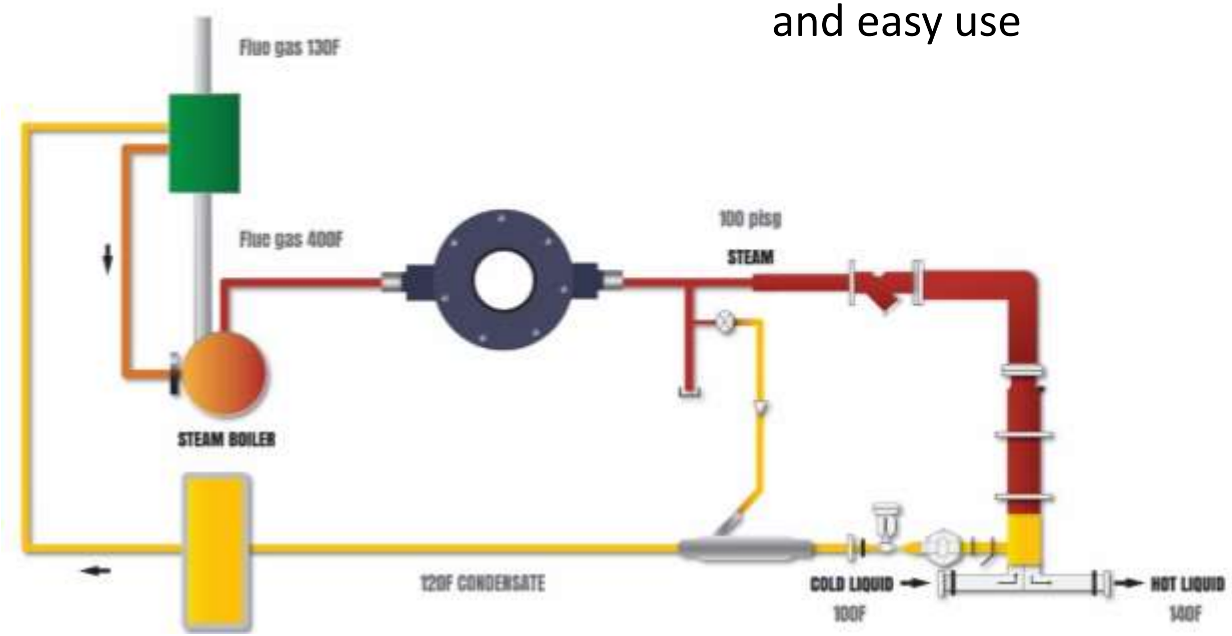
| Steam Boiler | | |
|---|---|---|
| Number | Operating Pressure | Pounds/ Hour |
| BLR-1 | 85 | 24,150 |
| BLR-2 | 85 | 24,150 |
| BLR-3 | 85 | 24,150 |

| Clean Steam Generator Schedule (Steam to Steam) | | | | | | |
|---|---|---|---|---|---|---|
| | | Source Side (HPS) | | Shell Side (Clean Steam) | | |
| Number | Service | PSIG | Pounds/Hour | PSIG | Pounds/Hour | EWT |
| 1 | AHU Humidifiers | 85 | 10832 | 10 | 8500 | 40 |

# What is Next?

## GenSet Replaces PRV

- Potential Energy savings with a closed-loop steam system
- Self-contained, skid mounted
- No external oil lubrication needed
- Generator included
- Small footprint, lightweight
- **5 : 1 turndown**
- **Small Footprint**
- **Easy annual maintenance** (bearing and seals)
- **Monitors electric grid** and generator power for safe and easy use




GenSet Diagram

## Design Specs

**250 PSI to 10 PSI outlet**

| | |
|---|---|
| **50 KW** | (2,500lbs./hr.) Office building |
| **100 KW** | (5,000lbs./hr.) Office building or large hotel |
| **400 KW** | (5,000lbs./hr.) Small campus or a small town |

GenSet Skid

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# What is Next?

## Savings ($0.10/kW)

**100 kW:**

$$100\ kW\ * 8{,}700\ {}^{hrs}/_{yr} * \$0.10/kW - \$12{,}000\ maintenance = \mathbf{\$75,000/yr}$$

**400 kW:**

$$400\ kW\ * 8{,}700\ {}^{hrs}/_{yr} * \$0.10/kW - \$20{,}000\ maintenance = \mathbf{\$328,000/yr}$$

## Return on Investment (ROI)

**100 kW:**

$$\frac{\$260{,}000\ cost + \$104{,}000\ installation + \$72{,}800\ consultants\ - \$43{,}680\ incentives}{\$75{,}000\ savings} = \mathbf{5.24\ years}$$

**400 kW:**

$$\frac{\$450{,}000\ cost + \$180{,}000\ installation + \$126{,}000\ consultants\ - \$75{,}600\ incentives}{\$328{,}000\ savings} = \mathbf{2.1\ years}$$

# Thank you


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