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# Vacuum heating integration with District heating system

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*It is possible that in a few years from now we will be heating .., by steam below atmospheric pressure, of such a low temperature that it gives all of the advantages of hot water without any of its disadvantages.*"

A.G. King "Practical Steam and Hot Water Heating", **1908**

# Vacuum heating versus steam heating

| benefits | disadvantages |
| --- | --- |
| Efficiency | Additional equipement: |
| Wide operating temperatures interval (55 -100$^{o}$C) | vacuum pump<br>condensate pump |
| Comfort | Maintanence |
| Safety | Vulnerability to leaks |
| Smaller pipes, reduced corrosion | Steam traps failures |
| High speed of heat distribution ( > 100 miles/hr) | |

# Steam heating retrofit into vacuum

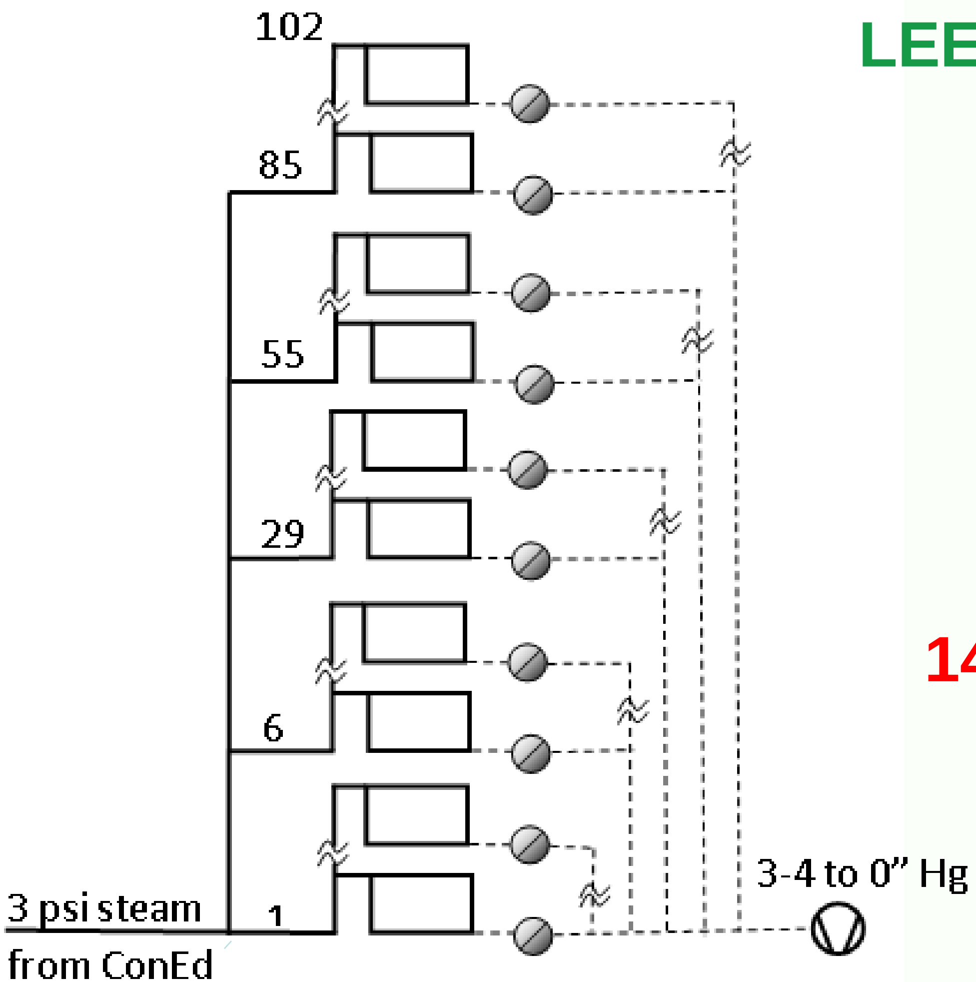
Peter Cooper Village by ITC, since 2006, 110 building NYC apartment complex, over 25,000 residents in 11,000 residential units.

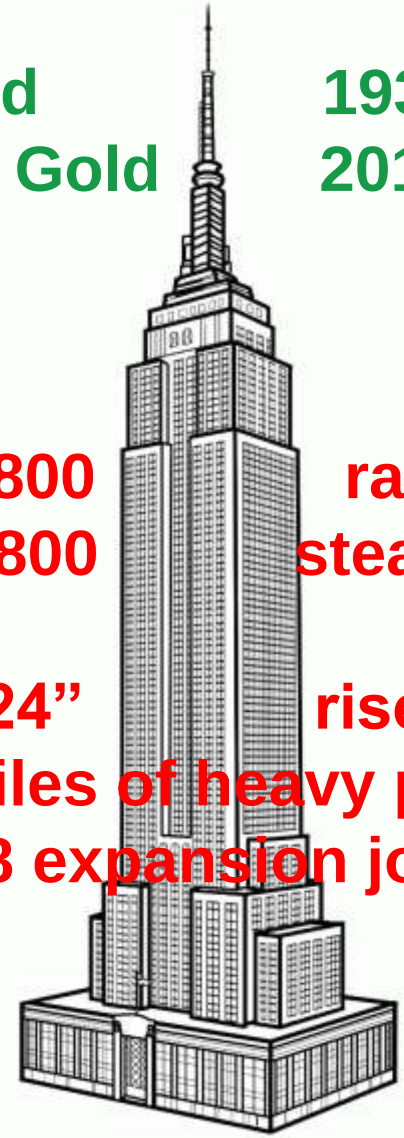

Vacuum up to 20”Hg/ steam temperature al low as 160ºF

Outdoor air temperature sensor installed on the exterior of the building

**28% savings of steam from ConEd**

# Empire State Building heating system



**Installed 1931**

**LEED® Gold 2011**

**6800 radiators**

**6800 steam traps**

**24" riser,**

**14 miles of heavy piping,**

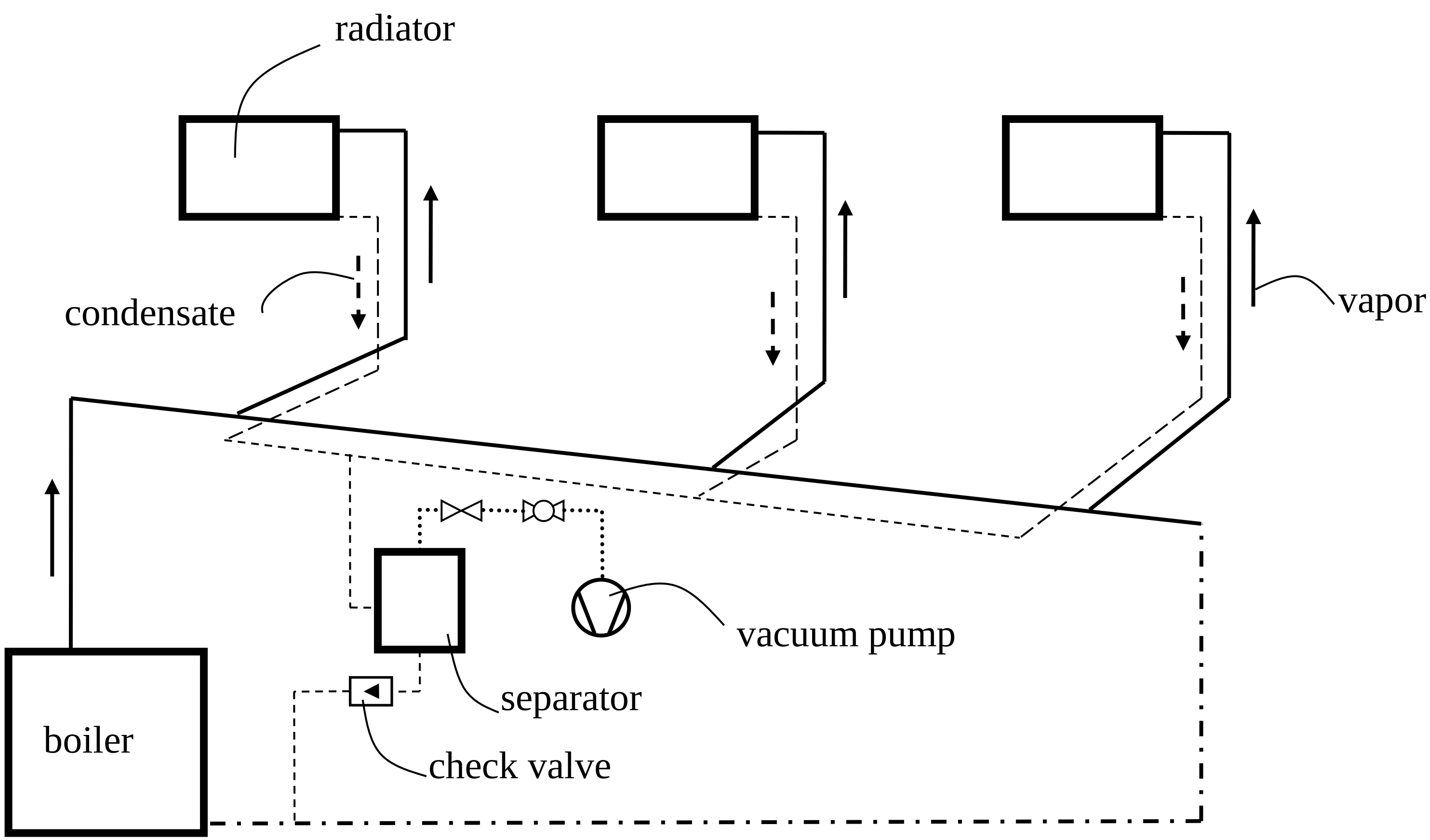
**118 expansion joints**

# Features of novel vacuum heating (NVH):

- deep vacuum – up 25- 28”Hg
- no steam traps and no hot condensate pumps
- lower capacity vacuum pumps employed for a short time
- small diameter copper/plastic tubing – leak tight, less corrosion

# Schematic of NVH pilot

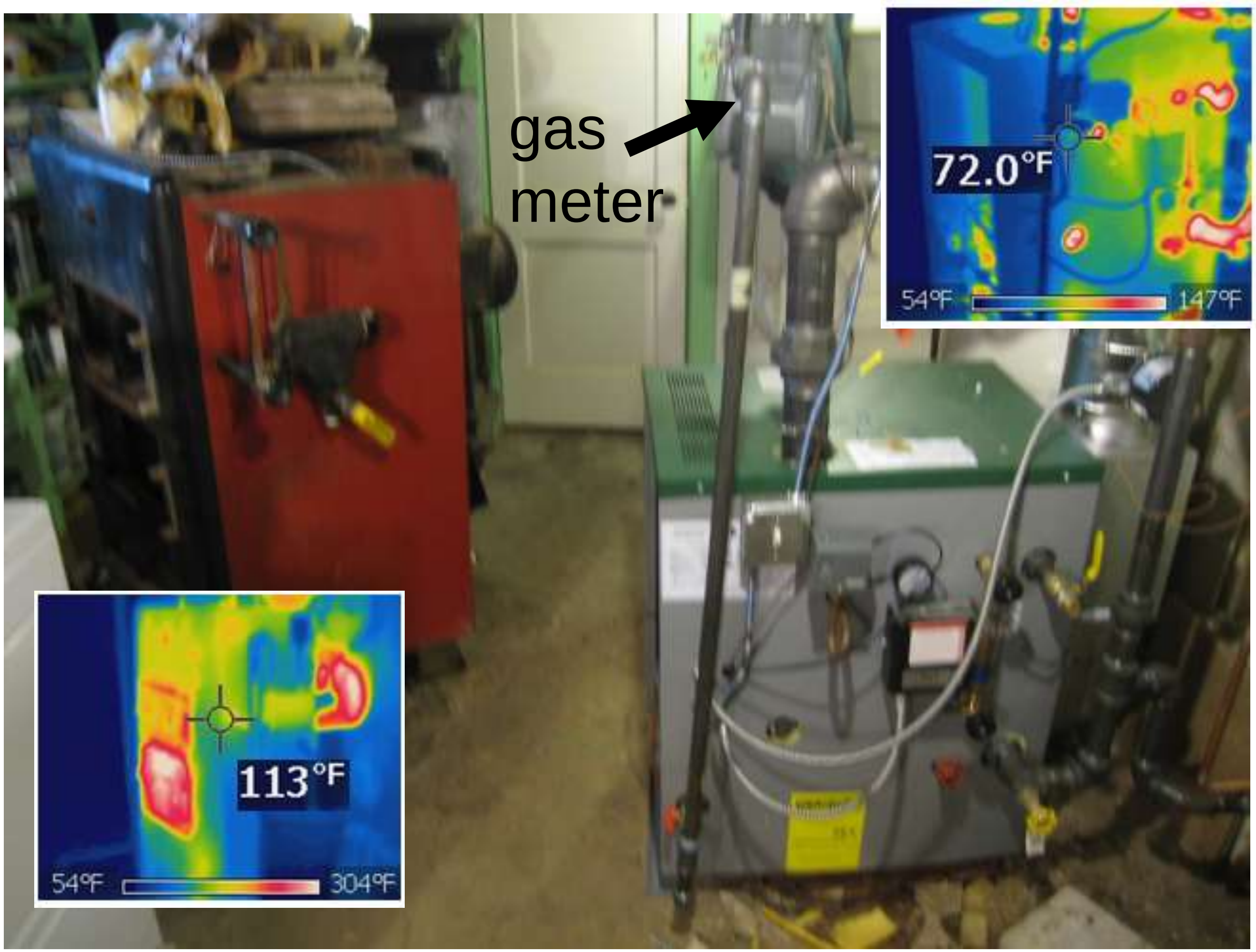
(2nd floor 2 family house, only 3 radiators out of 6 are shown)



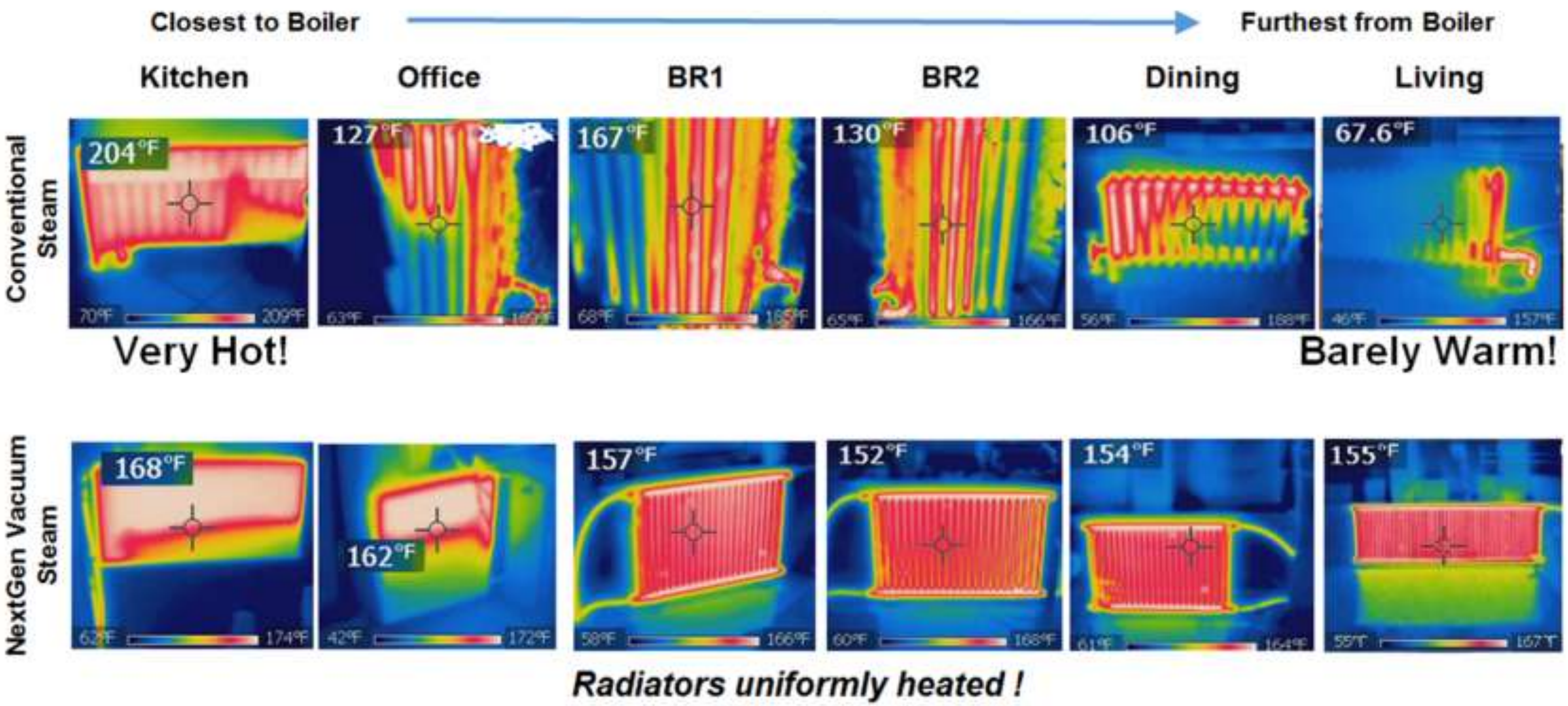
# NVH specific gear




# Obsolete and new boiler were tested with steam and vacuum systems.

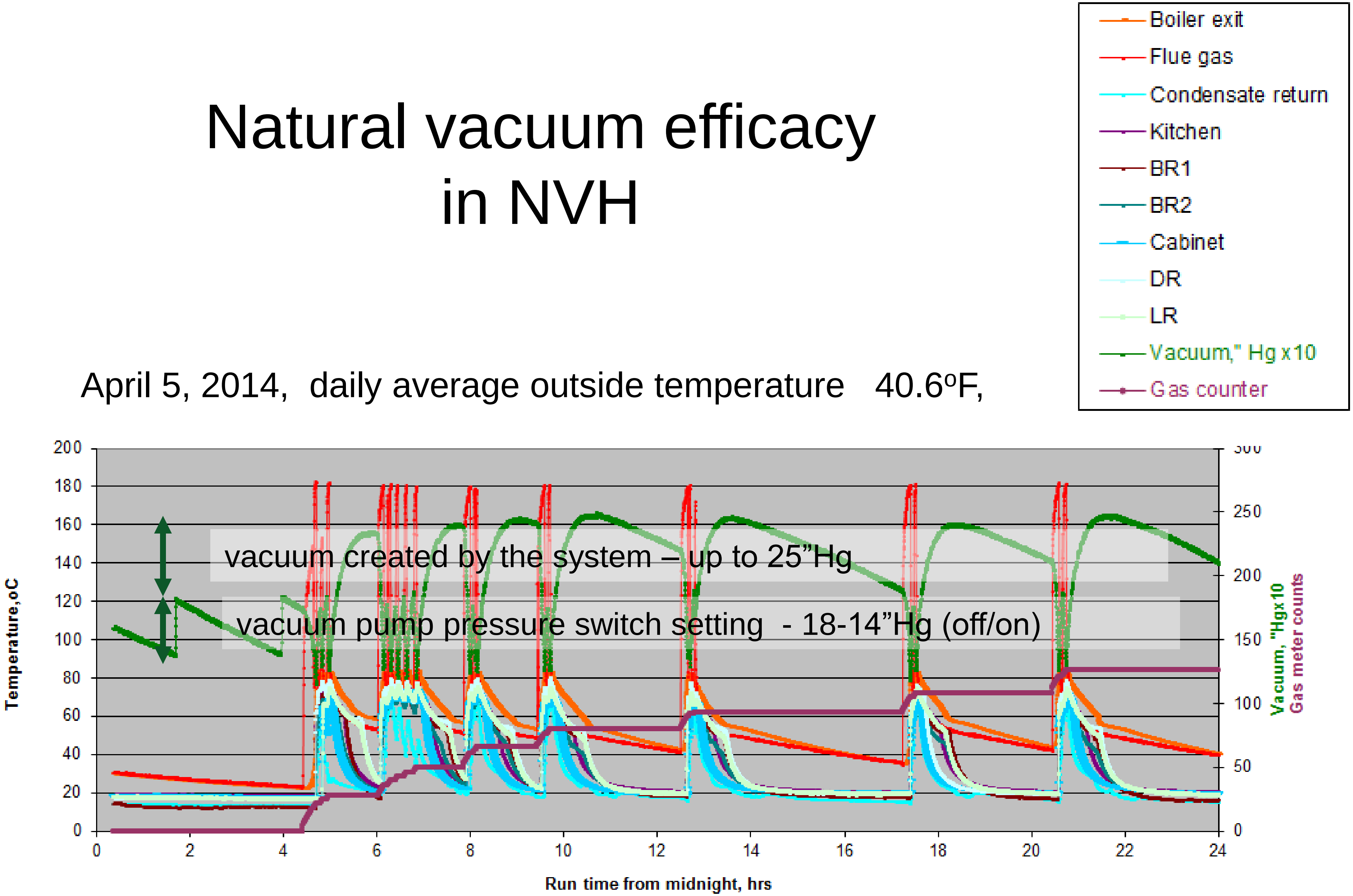


# Radiators heating in ~30 minutes after system cold start

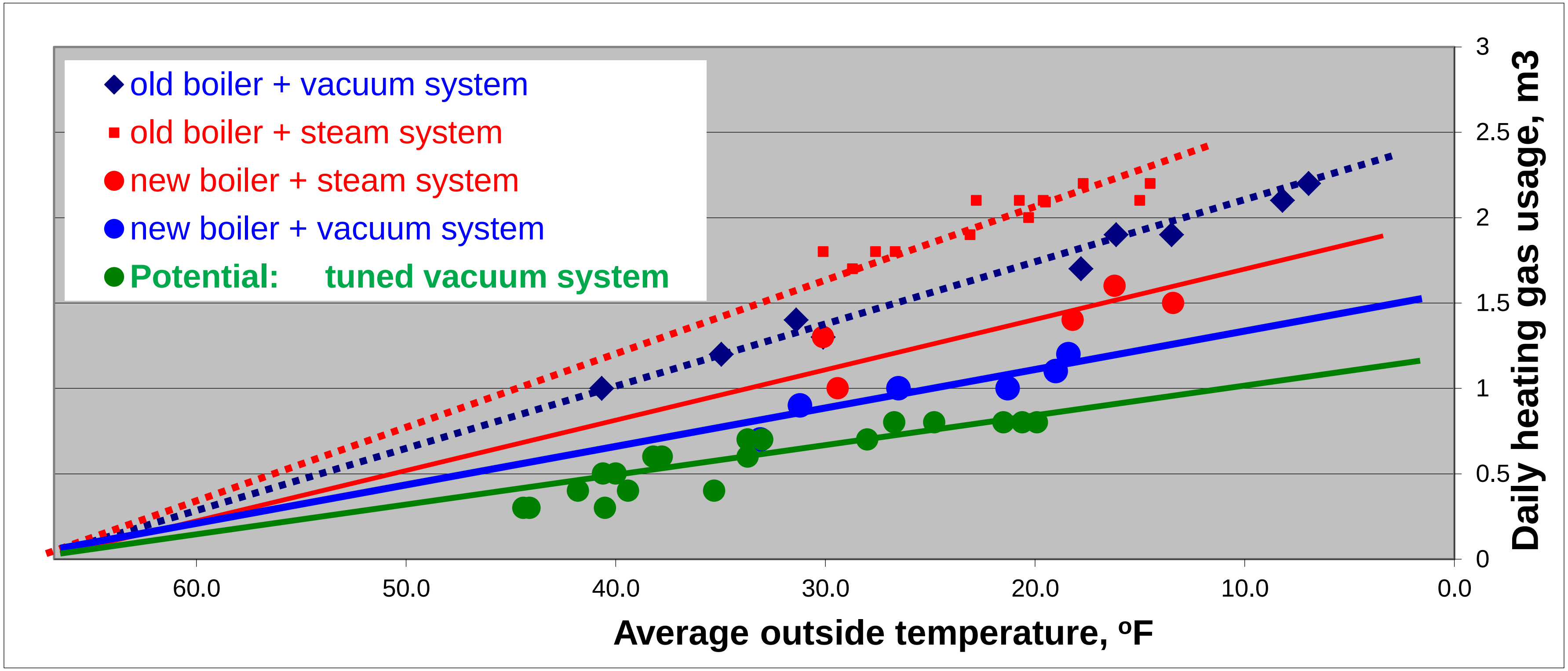


# Natural vacuum efficacy in NVH

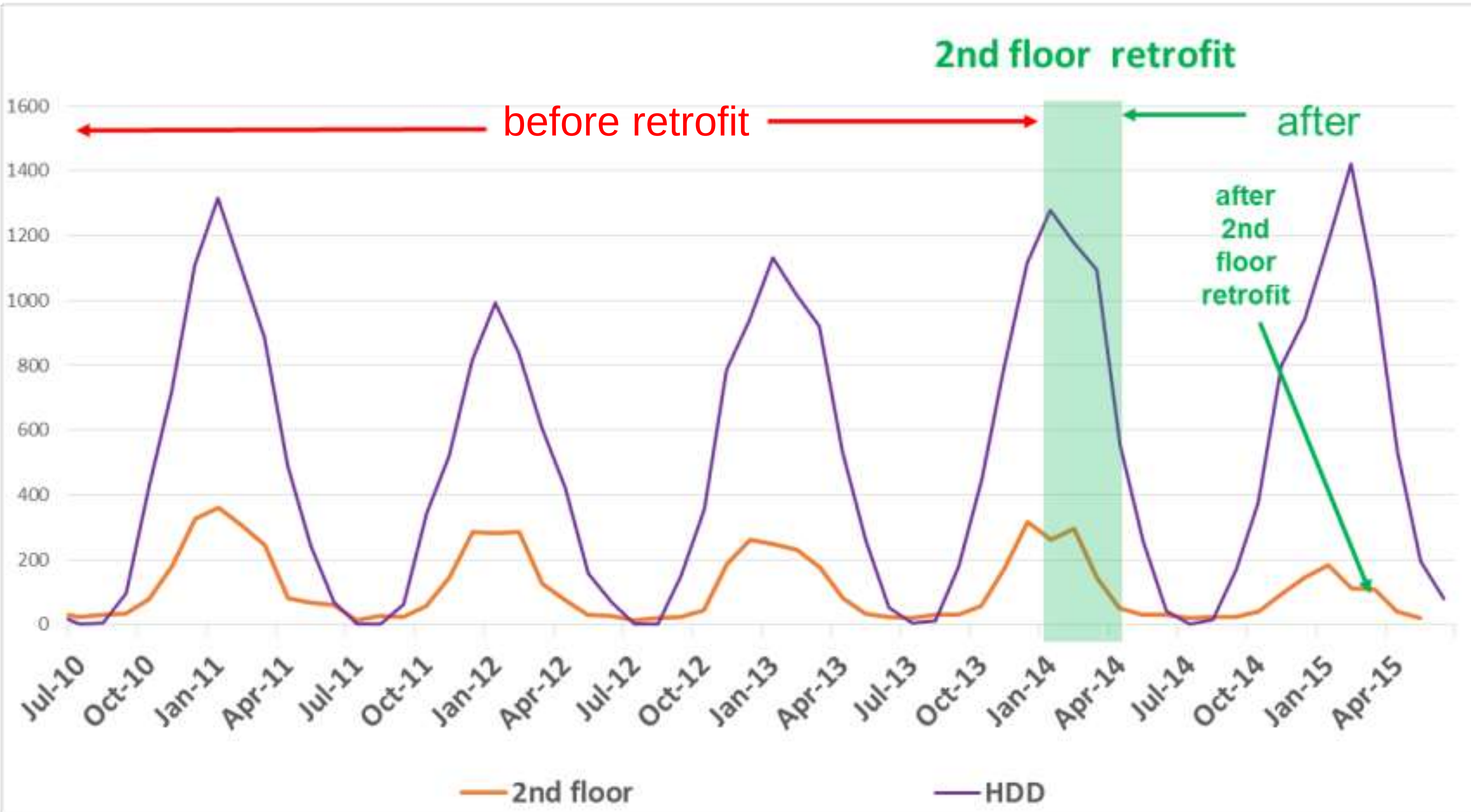
April 5, 2014,  daily average outside temperature   40.6ºF,



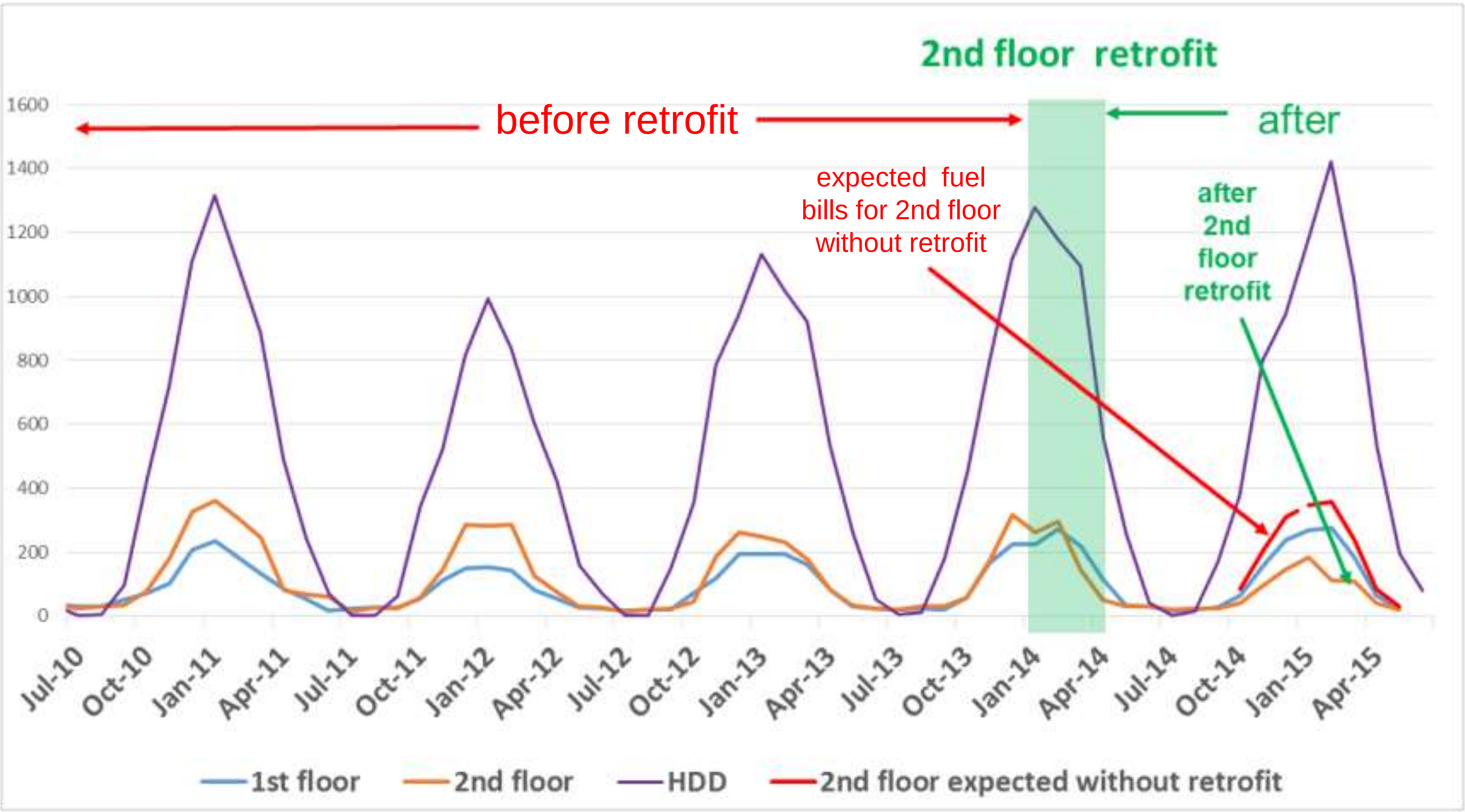
# Daily heating gas usage by the tested system vs outside average temperature



## Heat Degree Days (HDD) , $$ monthly gas bills for 2nd floor apartment before and after retrofit of steam heating system into vacuum heating



## Heat Degree Days (HDD) , $$ monthly gas bills for 1st and 2nd floor apartments before and after retrofit of steam heating system into vacuum heating on 2nd floor, no changes to the first floor (base for comparison)



# Results summary:

NVH pilot was run since 2013 to heat the 2nd floor apartment of a two family house (2x1150 sq. ft):

- plumbing is small diameter copper/plastic tubing
- no steam traps and no condensate pump
- radiators operating temperature - from 65 to 85$^oC$
- the only moving part - vacuum pump - maintains 14-18"Hg vacuum (pump is “on” for 1-1.5hr/day)
- system is able to bring vacuum up to 28"Hg after cooling

Fuel gas savings up to ~60%

- fuel savings ~30% from steam boiler upgrade only
- additional 20-30% from steam to vacuum system retrofit

# What’s in a future …

New plumbing technologies:

- welded plastic tubing – 60 years expectancy, leak tight at 45 psi@200oF
- pressed joints for steel/copper tubing

Liquid crystal polymers for heat distribution grid, - heat deflection  230 - 290$^{o}$C

Cast aluminum radiators at a fraction of cast iron/steel radiators cost

Smart building control systems

# Questions?

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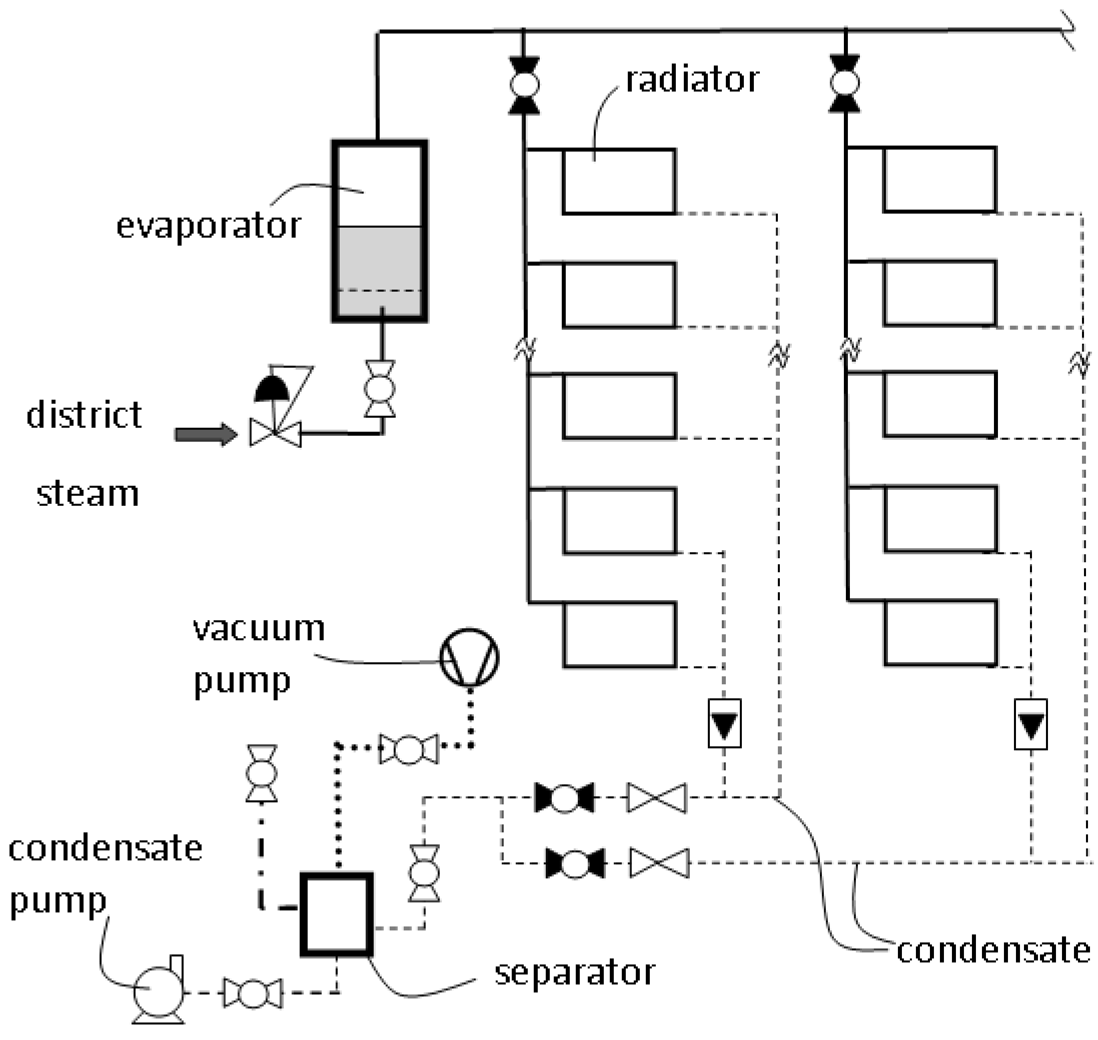
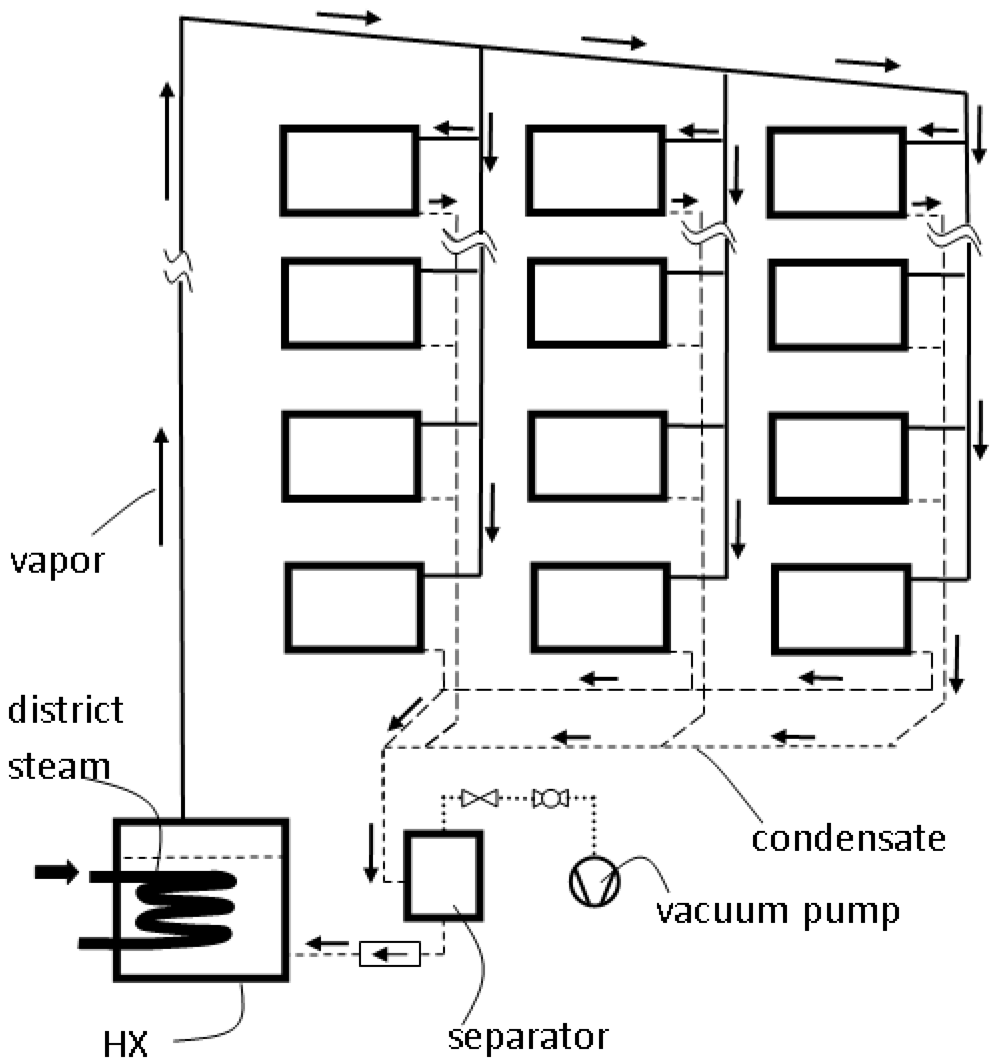
# Q&A
# addendum

# NVH integration with district steam - single loop



# NVH integration with district steam – separate loops



# District heating exergetic efficiency: steam vs hot water

Without return Q/E = 1 – (To/(Ts – To)) x ln (Ts/To)

With return Q/E = 1 – (To/(Ts – Tr)) x ln (Ts/Tr)

To, Ts, Tr – heat sink, supply and return temperature deg. K, resp.

**Göran Wall** “EXERGY FLOWS IN INDUSTRIAL PROCESSES” p.37

http://www.exergy.se/ftp/paper3.pdf

| | To | Ts | Tr | Q/E, % | difference Q/E, % |
|---|---|---|---|---|---|
| Without return | | | | | |
| Hot water | 293 | 353 | | 9.0 | |
| Steam | 293 | 383 | | 12.8 | +42.2 |
| With return | | | | | |
| Hot water | 293 | 353 | 313 | 11.9 | |
| Steam | 293 | 383 | 313 | 15.5 | +30.3 |

# Pumping hot water vs potential energy generation from steam

Exergy (available work): $W = [H - Ho] - To[S - So]$ [1]

where $H$ and $H_o$ – enthalpy of heating media and water at 140ºF

$S$ and $S_o$ – enthrophy of heating media and water at 140ºF

To = 140 ºF– temperature of water return

| Pressure, bars | Temperature, ºF | Available Work using 140ºF Heat Sink Temp. Btu/lb | KWH/lb | Energy for hot water pumping [2] KWH/lb |
|---|---|---|---|---|
| A | B | F | G | |
| Water | | | | |
| 0 | 140 | | | 0 |
| 5.5 | 248 | 8.6 | 0.0004 | 0.000612 |
| 12 | 248 | 8.8 | 0.0005 | 0.000612 |
| Steam | | | | |
| 2.5 bar | 329 | 198.0 | 0.0102 | 0 |
| 10.5 bar | 374 | 273.3 | 0.0140 | 0 |

1 Sussman. M. V. (Tufts University), "Availability (Exergy) Analysis". Mulliken House. P.O. Box 274, Lexington, MA 02155.

2 US Army Corps, ERDC/CERL TR-06-20, July 2006, p.131

# Pumping "low exergy" hot water vs potential energy generation from steam

Exergy (available work): $W = [H – Ho] – To[S – So]$ [1]

where $H$ and $H_o$ – enthalpy of heating media and water at 140ºF

$S$ and $S_o$ – enthropy of heating media and water at 140ºF

To = 140ºF – temperature of water return

| Pressure, bars | Temperature, ºF | Available Work using 140ºF Heat Sink Temp. | | Energy for hot water pumping [2] |
|---|---|---|---|---|
| | | Btu/lb | KWH/lb | KWH/lb |
| A | B | F | G | |
| Water | | | | |
| 0 | 104 | | | 0 |
| 5.5 | 176 | 4.5 | 0.0002 | 0.000612 |
| 12 | 176 | 4.9 | 0.0003 | 0.000612 |
| Steam | | | | |
| 2.5 bar | 329 | 252.9 | 0.0130 | 0 |
| 10.5 bar | 374 | 323.8 | 0.0166 | 0 |

1 Sussman. M. V. (Tufts University), "Availability (Exergy) Analysis". Mulliken House. P.O. Box 274, Lexington, MA 02155.

2 US Army Corps, ERDC/CERL TR-06-20, July 2006, p.131

# Leaks history: steam vs hot water

**US Army Corps,** ERDC/CERL TR-06-20 July 2006 p.27
http://www.dtic.mil/cgibin/GetTRDoc?Location=U2&doc=GetTRDoc.pdf&AD=ADA461391

Table 2. **Leak history in the pipeline systems in Kiel**

| Parameter | Year | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 |
| Steam network | | | | | | | |
| High pressure | 17 | 10 | 8 | 11 | 9 | 13 | 10 |
| Low pressure | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Number of leakages | 17 | 10 | 8 | 11 | 9 | 13 | 10 |
| Hot water | | | | | | | |
| Mettenhof | 2 | 0 | 6 | 1 | 7 | 3 | 5 |
| North/South | 26 | 8 | 17 | 22 | 16 | 20 | 21 |
| East | 10 | 6 | 0 | 4 | 3 | 1 | 2 |
| Island network | 1 | 0 | 0 | 0 | 0 | 1 | 1 |
| Number of leakages | 39 | 14 | 23 | 27 | 26 | 25 | 29 |
| Total | 56 | 24 | 31 | 38 | 35 | 38 | 39 |

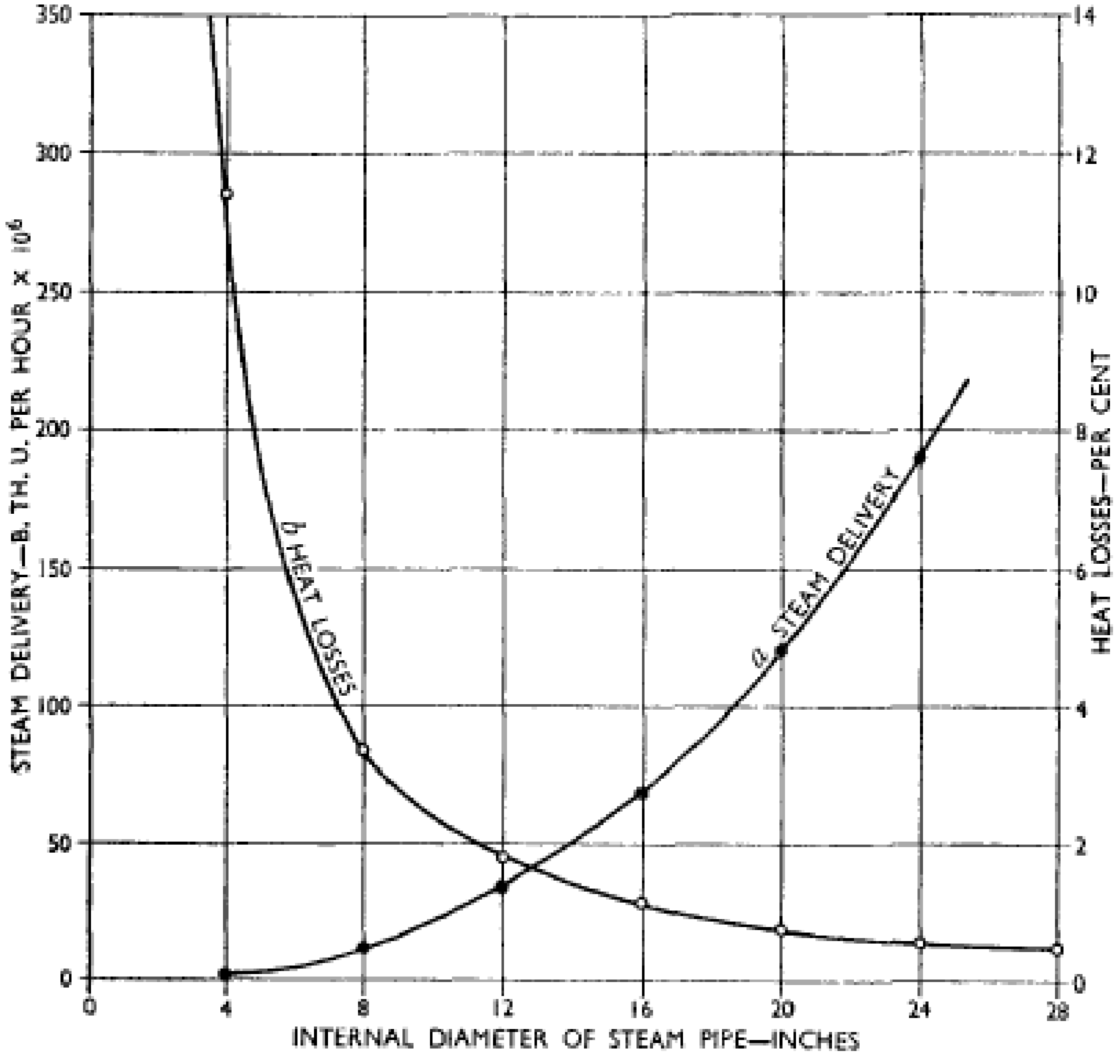



Fig. 16. Relative Economies for Various Sizes of Steam Mains

Length of main, 1 mile; average pressure, 20 lb. per sq. in. gauge; pressure drop, 0·5 lb. per sq. in. per 100 feet; air temperature in conduit, 95 deg. F.; conductivity coefficient 0·365 B.Th.U. per sq. ft. per inch thickness per deg. F. temperature difference per hour; thickness of insulation, 2 inches.

The curves illustrate the relation of the rate of heat delivery and the rate of heat losses.

Through a 4-inch pipe, heat delivery is $2{\cdot}2 \times 10^6$ B.Th.U. per hour.

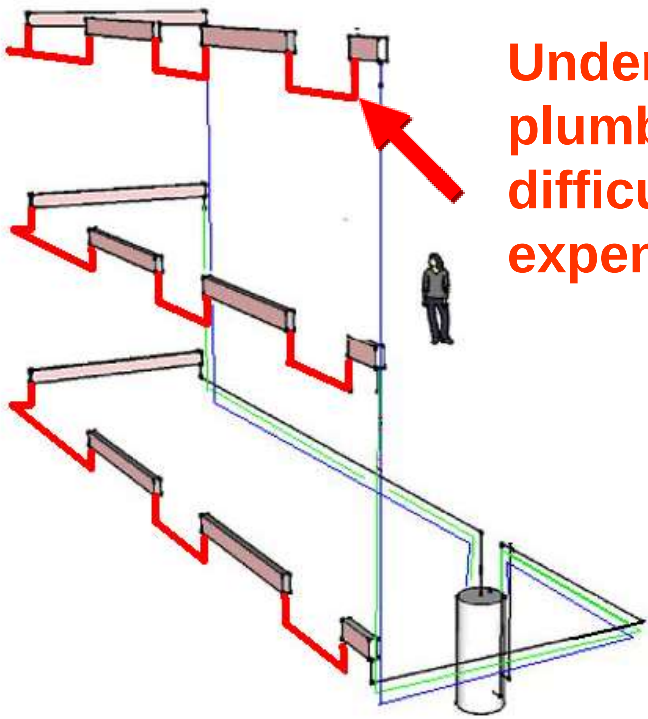
# Heat loss from steam pipe vs diameter

0.59% per mile
24” pipe @ 20 psig

**Margolis**, A.
“**Heat Distribution**”
Proceedings of the Institution of Mechanical Engineers
June 1937 135: 359-382

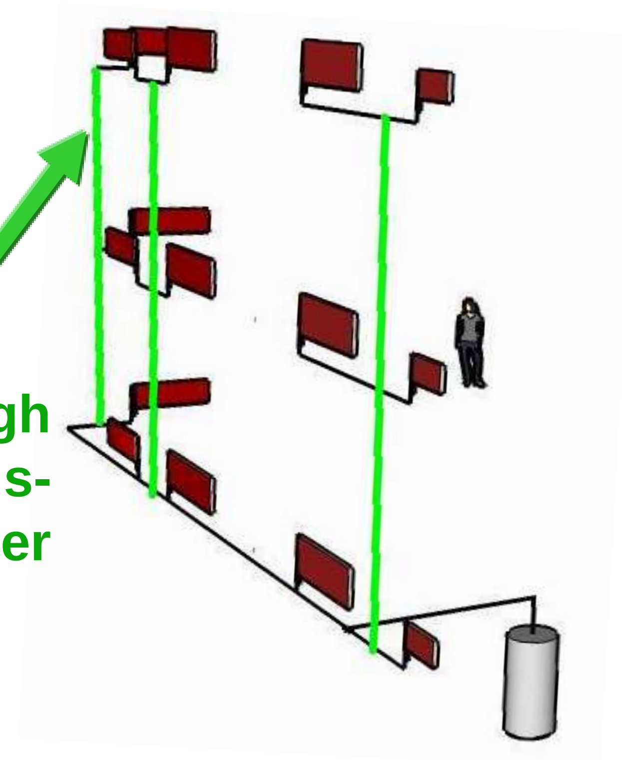
# Today's steam heating systems retrofit options

## into hot water



Under floor plumbing - difficult and expensive

## into VASH



Plumbing through external walls- much easier