“Vacuum Boost” for steam heating system.

Millions of people living in older buildings have to concede to noise, uneven heat distribution, and low energy efficiency of typical steam heating systems. Many of these systems have served decades from construction and slowly deteriorated with time. Modern hot water and forced air heating systems look appealing but conversion is too expensive and often not feasible for an aged dwelling. Rationales are against investing into an old structure. Another approach – deep energy retrofit by insulation, – is supported heavily by government incentives, but return of investment can exceed 100 years [1]. Furthermore, it’s not unusual that homes are damaged as a result of improperly installed insulation and windows - doing the right thing the wrong way may be worse than doing nothing at all [2].
Conversion of steam heating into vacuum heating may be a more reasonable solution. It may not be as trendy as solar or heat pump, but it is more practical. The approach is analogous to the fine tuning of the motor in a car instead of trashing it and buying Hybrid or Tesla. Back in the 1900s the conversion of single-pipe steam heating into vacuum heating on average saved 35% on fuel bills [3]; LEED Gold Empire State Building is still heated by original vacuum heating system of 1931. How many modern systems will still be around in 2200?

Conversion from steam heating into next generation vacuum heating system can provide the same benefits but it is simpler, easier and cheaper. In the winter of 2013-14, a pilot retrofit of a single-pipe steam heating system confirmed fuel gas savings for different systems used to heat the same apartment – Table 1[1]. Energy efficiency of the original single pipe steam system (~100 years old boiler, piping and radiators) was compared to the same boiler connected to new flat panel radiators by copper/plastic lines; the same comparison was carried later on new regular steam boiler. Up to 50% in savings was demonstrated by the retrofit into a vacuum heating system and in a winter of 2014 -15 results were confirmed [4-7].

Table 1

Effect of	System Comparison	Predicted Consumption (Therms)	Percent Savings
Vacuum distribution	**Old Boiler - Single Pipe Steam**	**1,004**	
	Old Boiler - Vacuum System	**741**	**26.2%**
	New Boiler - Single Pipe Steam	840	
	New Boiler - Balanced Vacuum	500	40.5%
Boiler upgrade	**Old Boiler - Single Pipe Steam**	**1,004**	
	New Boiler - Single Pipe Steam	**840**	**16.3%**
	Old Boiler - Vacuum System	741	
	New Boiler - Balanced Vacuum	500	32.5%
Total	**Old Boiler - Single Pipe Steam**	**1,004**	
	New Boiler - Balanced Vacuum	**500**	**50.2%**

Although potential savings are quite attractive, replacing radiators and plumbing still looks risky for owners of steam heating buildings. Therefore**,** a study was carried out on converting a single-pipe steam heating system into a vacuum system, using the existing boiler and with minimal retrofit cost and changes to the existing piping/radiators. This may allow your “old clunker” to surprise you for a long time ahead with energy efficiency and the forgotten comfort of radiant heating.

Study details. Retrofit was carried out on the same single-pipe steam heating system on the second floor of a two-family house used in 2013-14 study. Conversion into vacuum system included the following steps:

- air vent removal from each radiator

- connecting air vent opening on each radiator to a vacuum pump in the basement by ½” polypropylene tube
- additional piping, new vacuum pump and vacuum pump separator.

The schematic of the retrofitted system is shown on Fig. 1, - only 3 out of 7 radiators are shown for simplicity, original piping and radiators are shown in solid black lines.

Pressure test indicated a drop from 22 to 10 psig in 30 minutes: fixing leaks in the existing hundred year old piping buried within the walls is not feasible. Therefore, the system control concept was modified - instead of maintaining a vacuum 24/7, the “vacuum boost” approach was applied. When the thermostat calls the boiler to start, the vacuum pump is also switched on to evacuate air from the system to preset vacuum level (18.5”Hg in this particular test). The boiler starts in a vacuum and continues to fill the system with steam until the pressuretrol cut-in setting is achieved (2 psig). It oscillates further at a positive pressure between pressuretrol cut-in and cut-out settings. When the thermostat switches the boiler off, the vacuum pump maintains a vacuum in the system for another 1.5 hours to pull more heat from the boiler; it is likely that corrosion is reduced as well, due to reduced air content in the hot, moist system.

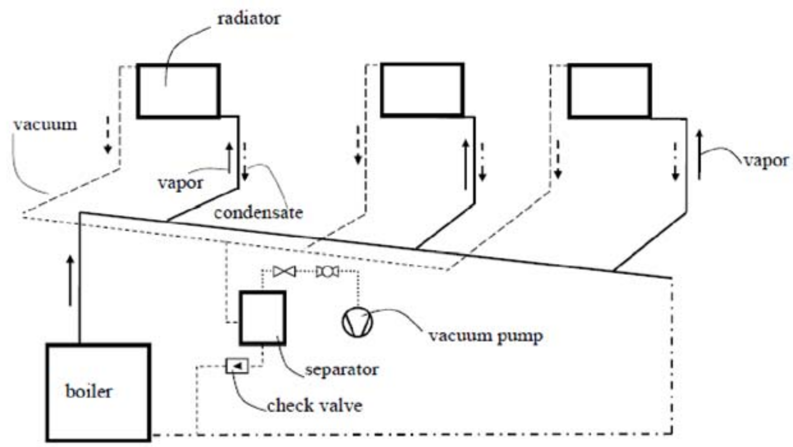

Figure 1

A typical heating day of operation is shown in Figure 2A, compared to a day of operation in the 2013-14 winter – Figure 2B (vacuum heating system with new boiler connected to new radiators by new copper/plastic lines, vacuum 24/7); vacuum is shown by green line. Because there is a vacuum in the system when the boiler is switched on, the heat is distributed evenly throughout all radiators; following this, the vapor pressure increases to 2 psi which prevents air leakage into the system during the heating cycle. The system has no steam traps; a vacuum is created by a 4scf/min vacuum pump (run 1-1.5 hour/day in 3-7 minutes intervals), and condensate is returned by gravity. Although this new approach does not

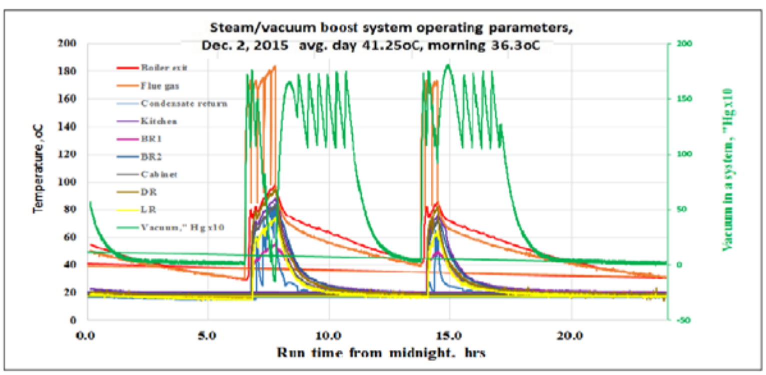

Figure 2A

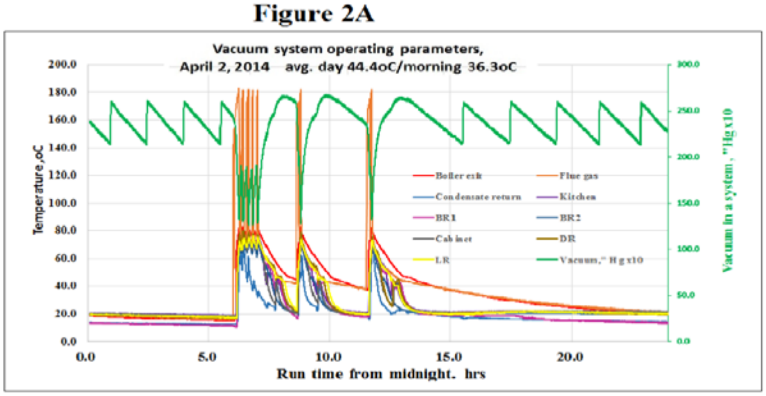

Figure 2B

completely eliminate the requirements for an air-tight system, it makes it possible to convert a regular steam system into a vacuum system with minimal changes to the plumbing buried in the walls.

Because no changes were made to the original single-pipe heating system on first floor, it is

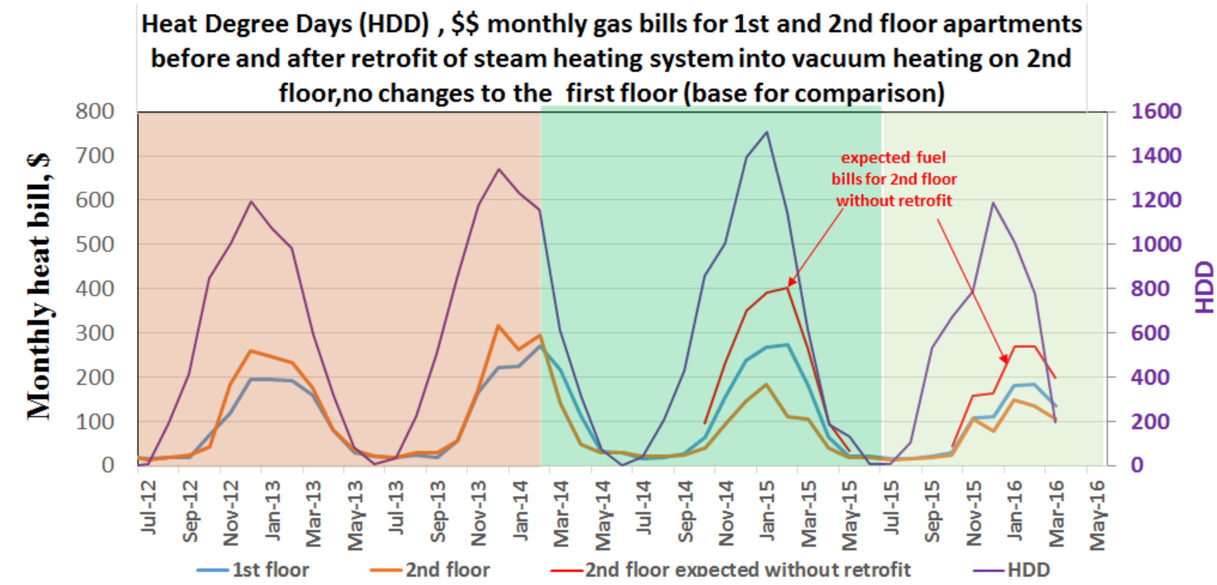

Figure 3

used as a base line to compare results. In Figure 3, the annual HDD and heating cost data are presented for both floors, starting from the winter of 2012-13. The heating cost for the first floor is used as a base level to estimate the effects of the heating system retrofit on the second floor. The heating cost data, presented in Table 2, are used to estimate potential savings from "vacuum boost" of steam heating. When both apartments were heated by steam, the heating cost ratio was 1:1.19. system was retrofitted into a two-pipe vacuum heating pipe system, the ratio dropped to 1:0.64, which correspond to an energy efficiency increase of 46.4% ((1.19-0.64)/1.19). These results were achieved with a new boiler/radiators/piping. During the 2015-16 winter, the retrofitting of a single-pipe steam system on the second floor apartment into a steam system with a "vacuum boost dropped the ratio to 1:0.81, which corresponds to an energy efficiency increase of 32.0% ((1.19-0.0.81)/1.19). Assuming that the effect of upgrading the boiler is 16% (please, see Table 1), the effect of the "vacuum boost" is in the range of another 16%. Please note that the calculated ratios were not affected by changing fuel gas prices.

Table 2

1st floor system	Single pipe steam system				
2nd floor system	Single pipe steam system		two-pipe vacuum heating system, new boiler/radiators/piping		Single pipe steam system, new boiler "vacuum boost"
Time period	**8/2012 - 7/2013**	**8/2013 - 1/2014**	**2/2014 - 7/2014**	**8/2014 - 7/2015**	**8/20015 - 3/2016**
Gas bills, $					
1st floor	**1129**	**987**	**411**	**1360**	**791**
2nd floor	**1350**	**1163**	**273**	**827**	**638**
Ratio 1st/2nd floor, $/$	**1.20**	**1.18**	**0.66**	**0.61**	
average	**1.19**		**0.64**		**0.81**
2nd floor savings from retrofit, %			**46.44%**		**32.03%**

Sections of the old cast iron radiator were connected by pipe only at the bottom. Differently, sections are connected at the top and at the bottom in new cast aluminum SIRA radiator. Cast aluminum radiators are flat panel type, modular (five sections were added to a standard size of twelve sections), space saving economical alternative to cast iron and warranted for up to 20 years. Pictures and IR images (40 minutes after the boiler cold started in the morning) of an old cast iron and new cast aluminum radiators are shown in Figure 4, - top and bottom, correspondingly. The difference in IR images is quite transparent in favor of SIRA radiators

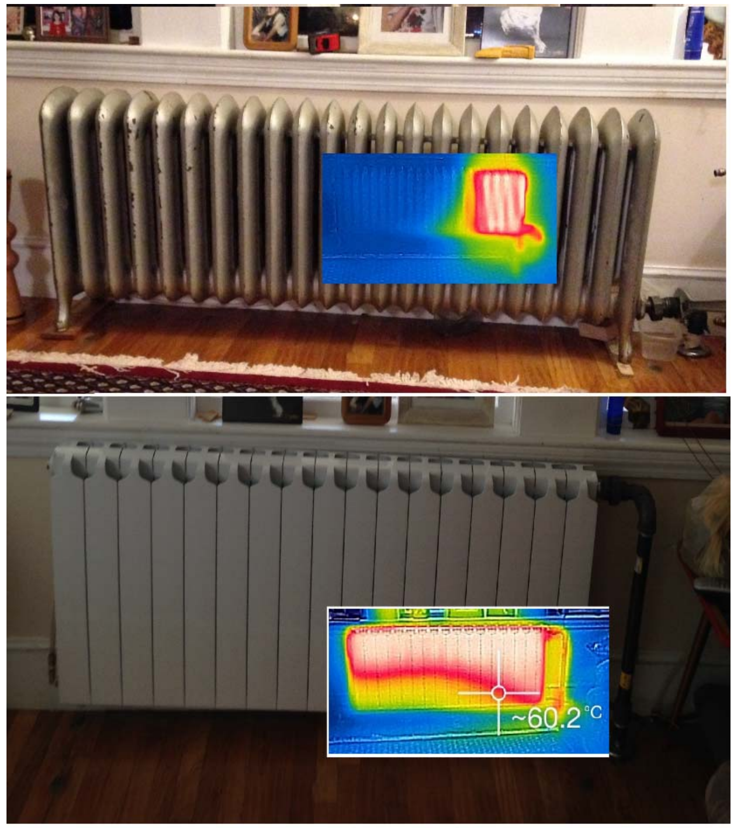

Figure 4

In a single-pipe steam system with a known history of water hammering, it would be more reasonable to add a small diameter vapor supply line to the top of each radiator and use original piping for condensate return and air evacuation via a vacuum pump – Fig. 5. Such a schematic will speed up the heating cycle by eliminating the necessity to preheat heavy steel piping before any heat is delivered into the radiators (35-50% load factor for regular steam system). Steam/vacuum heating systems are highly scalable, as proven many times in small and large scale projects. The schematic of “vacuum boost” for a project of Empire State Building scale would be similar to Figure 5, - multiple risers and radiators to be added, no steam traps, gravity return.

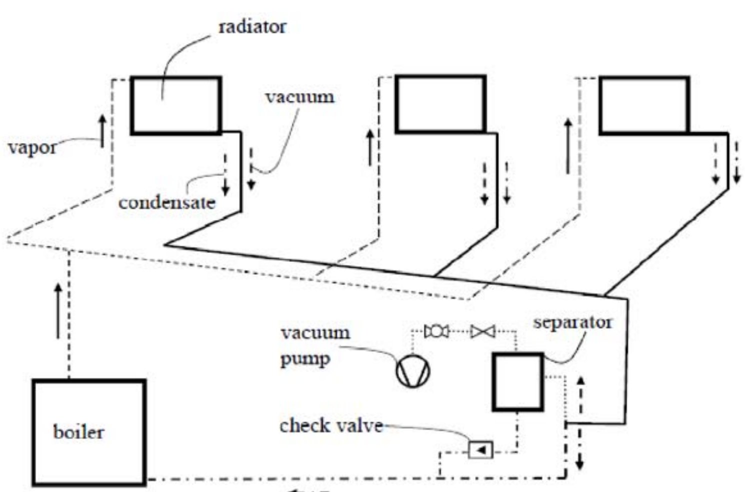

Figure 5

Likely, the vacuum pump separator can be eliminated as well, because vapor and condensate are naturally separated in the original heavy steel piping. Another attractive option is to put control valves on the supply lines and enable system zoning.

Results discussion

Some thoughts about heat distribution in a vacuum system. Local vacuum spots are created (by steam condensation) and moved from the boiler to the radiators at a total pressure of 1-2 psig within a regular steam system. From one side of this local vacuum spot, steam is supplied by the boiler- from the other side, air from the air vent. Thanks to this, the pressure throughout the system is uniform, but in some places there are vacuum spots. The concept of the vacuum system is quite different: the vapor from the boiler is moving along the tubes, condensing and creating local vacuum spots. Unlike in a steam system, no air is sucked in through the air vents, so the radiators are still under a vacuum. When vapor gets into and heats some radiators, the temperature/vapor pressure in these radiators increases, so less vapor is sucked in. Correspondingly, more vapor is sucked into other colder radiators so the heat distribution is naturally balanced by the system.

Water lost from the new vacuum system was negligible – 1-2 gallons in winters of 2013-14 and 2014-15 (water in vapor form was evacuated by vacuum pump along with air). It turned out that water lost from the "vacuum boost" steam heating system was even less, - the same water level was kept in a boiler throughout the 2015-16 winter. pH = 8 was found in routine water analysis. The less time the vacuum pump is on, the less water loss there is. Ideally, no water will be lost from a leak tight system.

Heat transfer under vacuum shifts from conduction to boiling regime where heat transfer coefficients are order of magnitude higher [9, 10]. That's a reason of higher efficiency of a regular steam boiler under vacuum, additional bonuses are reduced water loss/chemical treatment and less corrosion (longer life expectancy). Steam boiler upgrade has not always improved system, and in some anecdotal cases, the energy efficiency of the retrofitted system actually dropped [11]. Differently, retrofitting a steam heating system into either vacuum heating or adding a "vacuum boost" would enable savings from both boiler and distribution system upgrades.

Retrofit complexity. Notorious vacuum system problem of steam traps malfunctions and painstaking maintenance can be eliminated by "vacuum boost" concept. Actually, steam traps removal is not necessary - neither properly working nor failed steam traps would effect the operation of upgraded system. Retrofit of an existing vacuum system would be the easiest with minor changes to piping and controls. Applying a "vacuum boost" for **a** two-pipe system would still require adding a vacuum pump and some changes to plumbing. Prospective saving are between 32 and 46%, because of supply lines reduced diameter, heat loss and quicker heating. More savings would be expected for a bigger project where uneven heat distribution has more of an effect.

Market. A 2009 NYSERDA survey of 63 arbitrarily-selected existing multifamily buildings found 46 (73%) to be heated with steam boilers, and six additional buildings (9.5%) heated with purchased steam, for a total of 82.5% of the buildings heated with steam. Of these 52 steam-heated buildings, 32 have 2-pipe distribution (62% of steam-heated buildings) and 10 have 1-pipe distribution (19% of steam-heated buildings). Most of these buildings are 20 years older or more, but the tradition of steam heat is so strong, that even relatively new buildings, as recent as five years old, have been found to be designed and built with steam boilers [12]. 2013 report on multifamily houses in Chicago region indicate portion of steam heat ~50% [13].

Northeast Energy Efficiency Partnerships 2014 report on multifamily properties indicated that "… in the Northeast and Mid-Atlantic region, the small multifamily housing sector accounts for approximately 2.1 million occupied housing units out of a total of 26 million total housing units"[14]. 69% and 39% of these buildings were built before 1980 and 1960 correspondingly, so similar statistic of ~50% or higher can be expected for steam heating throughout Northeast and Mid-Atlantic of US.

Further projects.

I'm looking for steam heated multifamily house to be retrofitted into a "vacuum boost" heating system. The least difficult/expensive project would be carried out on an existing vacuum heating system followed by two-pipe heating system, and a single-pipe heating system with easily accessible piping. Project audit, management, financing (with no upfront cost to owner), design and execution is available through US and Canada. Contact izhadano@gmail.com with any questions or interest.

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