Hydronic radiator heating with thermostatic valves: Improves thermal comfort or upgrades efficiency?

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ABSTRACT

Energy performance standardisation evaluates all measures at the building and building services level that improve energy efficiency. Thermostatic valves are one of the choices, which are considered. To demonstrate their effect, a detached house, a terraced house and an apartment with three different levels of thermal insulation and hydronic heating were evaluated. Variants considered were (1) the fuel, (2) the boiler and (4) thermostatic valves or not. The TRNSYS and BOILSIM tools were used to simulate an Ukkel TRY-year. That way, comfort, system efficiencies, annual energy consumption, annual CO_2 release and net present value were evaluated. The results learned that thermostatic valves not always decrease consumption. In fact, in the moderately insulated detached and terraced house the valves improved comfort, not energy efficiency. In the well-insulated detached and terraced house and in the apartment instead, a net decrease in heating was noticed, together with a better comfort.

KEYWORDS

Central heating, radiators, thermostatic valves, simulation

INTRODUCTION

As the thermal resistance of the building enclosure increases, extra insulation gradually looses its efficiency in further energy reduction. Substantial additional economy may only be realised by an energy performance evaluation (EP). EP considers all measures which improve energy efficiency: not only thermal insulation but also ventilation, heat recovery, passive and active solar and all services for hot water, lighting, heating and cooling.

One of the unknowns in EP is heating efficiency. In a previous paper, Hens, 2001, presented a study aimed at better understanding the efficiencies of a hydronic heating system and the effect of the type of building, the insulation level, the boiler and the water temperature. The water temperature had a marginal impact. Present study discusses the use of thermostatic valves. Do they improve energy efficiency? In an analogous study, Eisenmann, 1997, considered an well-insulated apartment, subjected to a very cold and a mild day. Present study takes the TRY year for Ukkel and a range of dwellings as a basis for conclusions (F. Ali Mohamed et al, 2001).

DEFINITIONS

The term efficiency is used to indicate the ratio between the heat demand and the energy used to cover that demand during a given time window. With the heating season as time window:

$$\eta = 100 \frac{Q_{\text{net,demand,heat}}}{E_{\text{heating}}} \quad (\%) \tag{1}$$

with $Q_{net,demand,heat}$ the net heating demand in kWh/a and $E_{heating}$ the end energy consumed in kWh/a. Electricity for pumps, boiler functioning and controls may or may not be included in $E_{heating}$. To characterise a heating system, efficiency is split in two parts: one related to the heat production, the production efficiency (η_{prod}) and one related to all other system components, the system efficiency (η_{syst}):

$$\eta = \frac{\eta_{prod}\eta_{sys}}{100} \qquad (\%) \tag{2}$$

If electricity is kept apart, production efficiency equals boiler efficiency. If not, electricity consumed by the boiler and its controls are part of the denominator. System efficiency η_{sys} evaluates the distribution ($Q_{loss,distr}$), emission ($Q_{loss,em}$) and control losses ($Q_{loss,control}$). Electricity consumption by the pump may or may not be included:

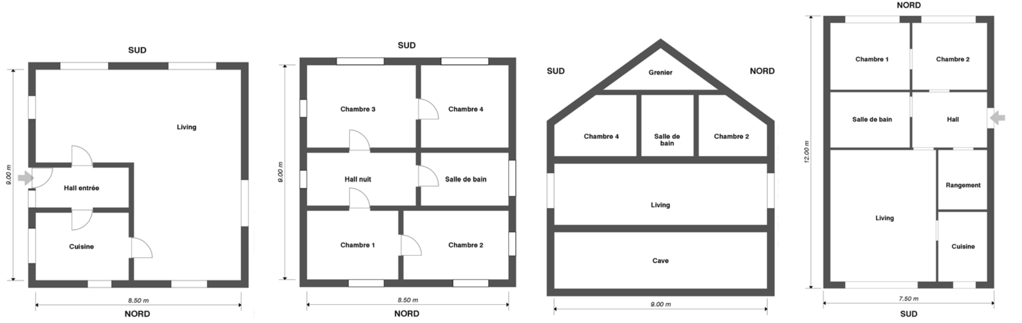
$$\eta_{sys} = \frac{Q_{net,demand,heat}}{Q_{gross,demand,heat}} = \frac{Q_{net,demand,heat}}{Q_{net,demand,heat} + Q_{loss,distr} + Q_{loss,control} + Q_{loss,em} + (E_{pump})} \tag{3}$$

with $Q_{gross,demand,heat}$ the gross heating demand in kWh/a. Quite important when discussing efficiencies is a clear definition of what is the reference system and what the environment. If the heating system acts as reference than all heat flowing to the interior environment which is not needed to balance the demand is a loss. If instead the building acts as reference, only unused heat dissipated to the exterior is a loss. As a consequence, the building related efficiencies are always higher than the heating system related efficiencies.

CASES

The three dwellings considered are shown in Figure 1 (Verbeeck et al., 1999). Table 1 summarises their characteristics. The level of thermal insulation in that table is a performance indicator, introduced by the Belgian standard B62-301 (Anon, 1989) and given by Eqn. 4. C is the compactness of the building, i.e. the ratio between the heated volume (V, m^3) and its enclosure (A_T, m^2) and U_m the average thermal transmissivity of that enclosure (W/(m_.K)). Basic heat demand was calculated according to the standard B62-002 (Anon, 1987), supposing 21°C in the living room, 20°C in the kitchen, 23°C in the bathroom and 19° in the sleeping rooms. Outside temperature -8°C, ventilation rate 1 h^{-1}. B62-002 does not consider temperature set back. This may result in a lack of capacity. Therefore, the heating capacity of all radiators except for the kitchen was increased with 30%.

The net energy demand for heating was calculated using TRNSYS^R and assuming as temperature set point (θ_{set}) the values of figure 2. A key problem! An on/off control in the living room cannot master different on/off schemes in other rooms. When a higher temperature is demanded there for short periods of time, three situations are possible: (1) the radiator valves stay closed, (2) the radiators follows the same on/off scheme as the living room, (3) the user opens and closes the radiator valves according to the set point imposed. The third, a non-realistic but ideal action, has been taken as the basis for the net energy demand. Energy consumption instead was calculated with TRNSYS^R and BOILSIM for the second situation. Another key parameter concerns the set point itself. While for the net energy demand the θ_{set}-values of figure 2 were used, energy consumption situated the comfort temperature at θ_{set}-$\Delta\theta_{diff}$, $\Delta\theta_{diff}$ being the control difference in °C.



Detached Apartment

Terraced

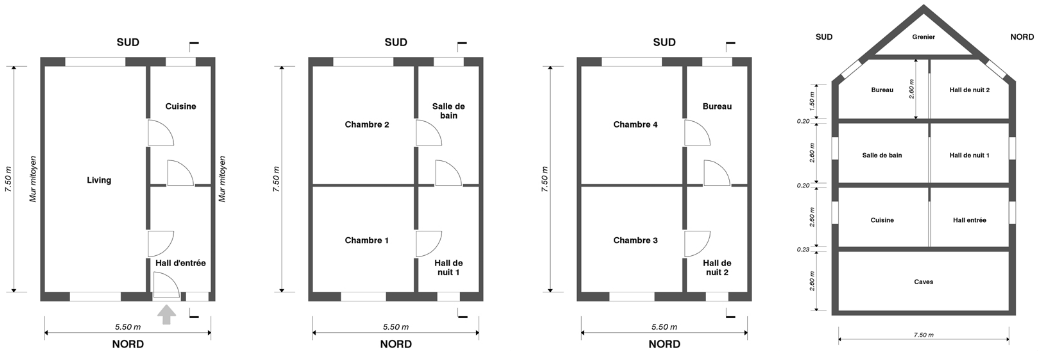


Figure 1-The reference dwellings

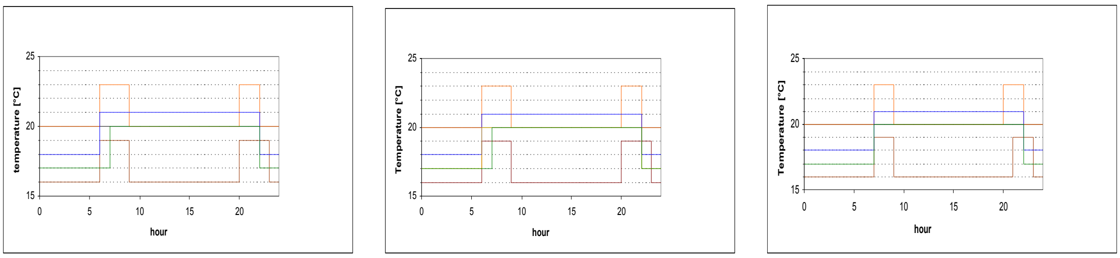
TABLE 1
The three dwellings

Dwelling	Compactness Enclosure m, m_	% glass (related to the enclosure)	U_m-value W/(m_.K)	Level of thermal insulation K	Heat loss W	Net energy demand kWh/a
Detached						
	1.42 410	6.3	1.14	100	13000	28200
			0.63	55	9000	15500
			0.46	40	7700	13600
Terraced						
	1.92 177	9.7	1.31	100	9500	16100
			0.72	55	6300	8900
			0.52	40	5500	8100
Apartment						
	6 41.5	22.9	2.67	100	4000	7400
			1.47	55	3100	4500
			1.07	40	2800	4300

Level of thermal insulation

$$C \le 1, K = 100U_m \qquad 1 < C < 4, K = \frac{100U_m}{C/3 + 2/3} \qquad C \ge 4, K = 50U_m \tag{4}$$

Three boilers were used. See table 2 for their characteristics. Control strategies: (1) on/off control with a room thermostat, fixed boiler temperature and 80/60°C radiators, (2) boiler temperature commanded by an outdoor sensor, control curve $\theta_{boiler}=\mathrm{Min}(\theta_{boiler,max}, a\theta_e+b)$, night set back thermostat in the living room and thermostatic valve at each radiator. Emission efficiency: 96% at 60/80°, 98% at lower temperatures, emission losses being caused by radiation and convection between the radiator's backside and the wall surface behind and by temperature stratification in the room.



Detached Terraced Apartment

Figure 2 -Ideal temperature set point lines assumed

Green: kitchen, blue: living room, orange: bathroom, red: sleeping rooms, yellow: office room

TABLE 2

Boiler characteristics

	1 high eff.	2 high eff.	3 modul.
Fuel	Oil	Gas	Gas
Net power	16700	16700	20940
Modulation	None	None	10-100
Efficiency	89	89	93
Built in fan	no	no	yes

RESULTS

Energy consumption

Table 3 gives the calculated consumption with inclusion of the pump electricity (some 1-% of the total). Apparently, the type of dwelling has a large impact. Passing from detached to terraced practically is as effective as insulating the detached house. Also the first upgrade in thermal insulation, from K100 down to K55, is really efficient. From K55 to K40, however, does not give an important relieve anymore. As far as the effectiveness of thermostatic valves is concerned, the result depends on the specific transmission losses, as is illustrated by Figure 3. The turn from more to less consumption is situated at about 150 W/K. For the detached and terraced house, this means a very good insulation, $U_{m=}$0.37 W/(m_.K) respectively 0.86 W/(m_.K). The high specific transmission losses demanding additional heating at night to track the set point explains most of the increase.

Heating efficiencies

At the system level, production efficiency is highest for modulating gas boilers, from 93 to 98%. The value for high efficiency boilers ranges between 84 and 90%. Thermostatic valves tend to lower that number with a few percent. System efficiency does not depend on the boiler. For on/off, 80-60°C its value is quite constant, 71 to 77%. As Figure 4 shows, thermostatic valves induce a large scatter, with values ranging between 59 and 95%. Lower values are noted at higher and higher values at lower specific transmission losses. Going from the system to the building as the reference adds some 4 to 6% to the total efficiency in on/off, 80-60°C mode. That surplus drops to 2% with thermostatic valves.

Thermal comfort

As an exemple, Table 4 shows the average temperatures in the separate rooms of the detached house. With thermostatic valves, inside temperatures stay closer to the set point and are better stabilised (cfr. the lower standard deviation). The last also helps in explaining why the system's efficiency does not necessarily profit from the lower averages.

TABLE 3
Energy consumption

	Met demand kWh/a	Energy consumption (kWh/a)					
		Boiler 1	Boiler 2	Boiler 3	Boiler 1	Boiler 2	Boiler 3
Detached		Room thermostat, on/off, 80-60°			Thermostatic valves		
K100	28200	40900	40800	38700	44000	43900	41200
K55	15500	22800	22800	21100	22600	23000	20500
K40	13600	20600	20600	18800	18900	19100	16800
Terraced		Room thermostat, on/off, 80-60°			Thermostatic valves		
K100	16100	24400	24600	22800	30700	30900	28400
K55	8900	13900	13800	12600	15100	15400	13300
K40	8100	12600	12700	11300	12600	12800	11000
Apartment		Room thermostat, on/off, 80-60°			Thermostatic valves		
K100	7400	11500	11600	10400	9200	9400	8300
K55	4500	7100	7100	6800	5600	5600	5200
K40	4300	6400	6400	6100	5500	5500	5100

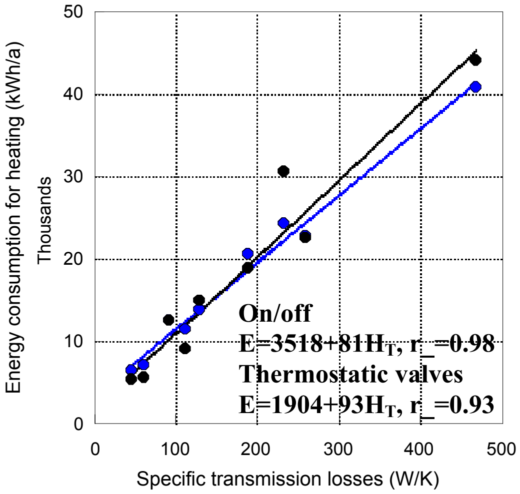


Figure 3 High efficiency oil boiler, energy comsumption. On/off in blue:, thermostatic valves in black.

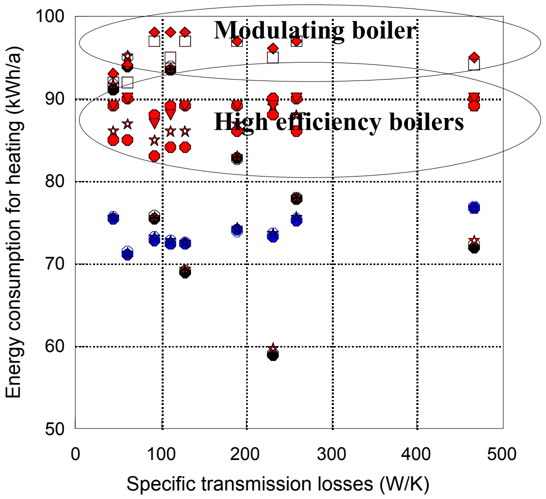


Figure 4 System's level. System efficiency, on off in blue, thermostatic valves in black. Production efficiency in red

TABLE 4
Inside temperatures in the detached house

Thermal insulation	Inside temperature (°C)/*Standard deviation (°C)*						
	Living	Kitchen	Bath-room	Sleeping room 1	Sleeping room 2	Sleeping room 3	Sleeping room 4
Set point	21	19.9	21.6	17.8	17.8	17.8	17.8
Room thermostat, on/off, 80-60°							
K100	21.2/*1.4*	21.7/*1.4*	23.8/*2.3*	20.3/*1.9*	20.4/*1.6*	20.8/*1.8*	21.0/*1.6*
K55	21.3/*1.1*	22.9/*1.1*	23.6/*2.3*	20.5/*1.6*	20.6/*1.4*	20.2/*1.5*	20.3/*1.2*
K40	21.4/*1.0*	23.4/*1.1*	23.4/*2.0*	20.8/*1.4*	20.8/*1.2*	20.2/*1.3*	20.5/*1.1*
Thermostatic valves							
K100	20.2/*1.1*	21.0/*1.0*	21.3/0.8	20.4/*1.2*	20.2/*1.1*	20.5/*1.3*	20.5/*1.1*
K55	20.5/*1.2*	20.8/*0.8*	20.2/*0.6*	19.0/*1.1*	19.0/*1.0*	19.0/*1.2*	19.0/0.9
K40	20.5/*1.0*	23.6*1.2*	23.6/*1.7*	19.3/*0.7*	19.3/*0.7*	19.0/*1.0*	19.2/*0.7*

CO_2 release

Best choice is a K40 insulation level, linked to a gas fired modulating boiler with variable water temperature and thermostatic valves at each radiator. Compared to the worst case (K100, oil fired high efficiency boiler), avoided CO_2 numbers 8.3 T/a for the detached dwelling, 5.9 T/a for the terraced dwelling and 2 T/a for the apartment.

Net present value (NPV)

On the average the optimum choice for all three dwellings in terms of NPV fitness is a level of thermal insulation K40, a high efficiency boiler on constant temperature and an on/off control with thermostat in the living room. The differences between the separate choices however are so small that even restricted changes in prices shift the optimum to modulating boilers.

CONCLUSIONS

The paper discussed energy consumption, CO_2 release, thermal comfort and NPV of hydronic radiator heating with variable water temperature and thermostatic valves and compared with a traditional on/off hydronic radiator heating with constant water temperature. Main conclusions:

- Thermostatic valves decrease energy consumption in well-insulated dwellings. In dwellings with worse thermal insulation, energy consumption increases somewhat;
- In all cases, thermostatic valves guarantee that the inside temperatures stay closer to the set points and are more stable;
- Avoided CO_2 between the worst (K100, oil fired high efficiency boiler) and the best case (K40, gas fired high efficiency boiler with thermostatic valves) is quite impressive;
- Optimum choice in terms of NPV is a high efficiency boiler on constant 80°C water temperature with on/off room thermostat.

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