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# COMPARISON OF HEATING SYSTEMS IN A RESIDENTIAL BUILDING

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## ABSTRACT

This paper presents the results of a case study in which Low Temperature radiators, High Temperature radiators and floor heating systems are compared using a TRNSYS16-model of a typical terraced house. The influence of radiant heating on temperature control is investigated as is the introduction of an outside temperature sensor, insulation around piping, different boiler types and temperature profiles, such as night set back.

## INTRODUCTION

As the thermal resistance of a building enclosure increases, the impact of any additional thermal insulation on energy economy decreases. This physical law forces countries with tough insulation requirements to turn to Energy Performance Regulation (EPR). EPR not only evaluates thermal insulation, but also takes into account the energy efficiency of ventilation, lighting, hot water production and heating systems and the benefits of passive and active solar energy. (Hens et al., 2001) A great unknown in such a vast corpus of possibilities is the heating system's efficiency.

Floor heating is renowned for its high level of radiant heat and its low supply water temperature, which leads respectively to a lower air set point temperature and a possible coupling to high efficiency systems such as heat pumps, condensing boilers or other systems that supply low temperature heat. Furthermore, thermal mass integrated with a floor heating system is often cited as a solution to reduce peak heating loads, decrease temperature swings and increase the use of solar gains. (Arneodo et al., 1988) On the other hand, scant attention is paid to the control difficulties resulting from the inherent large thermal lag of these systems. When intermittent heating is applied, the control efficiency can be so low that all benefits are neutralized. In other words, the total efficiency at the building level, defined as the ratio of net heat demand and total heat consumption, is not higher.

To assess overall efficiency between heating systems, four main types are compared. These include High Temperature radiators, Low Temperature radiators and two systems with floor heating in the day zone and Low Temperature radiators in the night zone. The latter two systems differ in their floor capacity. The influence of controlling the operative or air bulb temperature is investigated, as is the introduction of a condensing boiler possibly combined with a variable boiler exhaust temperature. The simulations are con-ducted with TRNSYS16 on a typical terraced house.

Results show that floor heating systems do not outperform radiators. On the contrary, only when coupled to condensing boilers, they consume less energy than the HT-radiator system, and LT-radiators perform best in all cases. This difference in efficiency is reduced when constant set point temperatures are applied or when the operative temperature is controlled instead of the air temperature. Finally, increasing the thermal lag of the floor heating systems has the undesirable effect of increasing rather than reducing heat consumption.

## SIMULATION

In this paper, the Dynamic Building Energy Simulation Program TRNSYS16v1.036 is used to simulate the building and its heating installations.

**Building**

The terraced house is quite compact with an outer volume of 446 m³ and an exterior surface of 226 m². Together with an average U-value of 0.8 W/m²K, this leads to the exact compliance with the Flemish insulation decree (BS, 1992) and a net energy demand of 10181 kWh.

The day zone, which comprises the kitchen and the living room and has a floor surface of 48 m², can be equipped by radiators or a floor heating system, while the night zone of 83.5 m² only contains radiators. This is due to the highly intermittent set point temperature in the latter area. (See figure 1)

The ventilation is modeled as non-forced natural ventilation with the minimal flows of the standard NBN D50-001 (BIN, 1992). The internal gains show a peak in the morning and the evening due to the activity of people in the room and the normal use of home appliances.

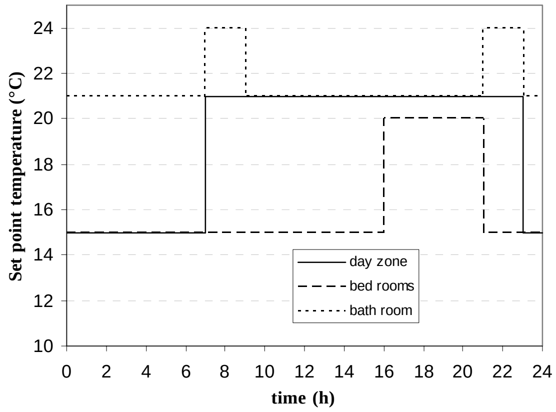


*Figure 1 Set point temperatures in the building*

## Heating systems

The heat demand of the zones was calculated using the prEN 12831 and the national NBN B62-002. We did not take the indoor temperatures from the standard, but the highest level from the temperature profile. Otherwise the desired temperatures could not be reached in an intermittent regime.

The radiators and floor heating are then dimensioned following the technical reports of the Belgian Building Research Institute (De Meulenaer et al., 2004).

The floor heating is simulated using "active elements" available in TRNBuild (SEL, 2004) and extra floor insulation is applied to compensate for the extra losses due to a higher floor temperature. In one case the insulation is put in between two concrete layers, namely the thin layer around the heating tubes to ensure an equal distribution of heat in the floor and the structural floor slab. In the other case, the first layer is made thicker and the insulation is put under the structural floor slab. Thus, a high-capacitive floor is created. The floor heating system is controlled by a four-way valve and a proportional controller.

The radiators used are based on Type 72 from IEA annex 17 and numerically optimized (Kummert, 2001). Each radiator is accompanied by a proportional controller that determines the incoming flow. These controllers can be regarded as "perfect" thermostatic valves. That is to say, they measure the exact air or operative temperature in the middle of the zone, they cause a perfect proportional relation between room temperature and water flow and they are not system pressure dependent.

In reality, the thermostatic valve measures a temperature that is the weighted average of the temperatures of air, walls, the water in the pipe and the emission system itself. Furthermore, the flow also depends on the pressure drop of the flowing water over the valve and the history of the valve itself, i.e. hysteresis (Ast, 1988). To focus on the behavior of the emission system itself, it is assumed that the valves are adjusted for these deviations.

The water flow through the distribution system is then determined by adding the flows to and from the radiators.

## Boilers

The boiler is modeled in TRNSYS as a combination of an ideal heater and two water pipes (see Figure 2).

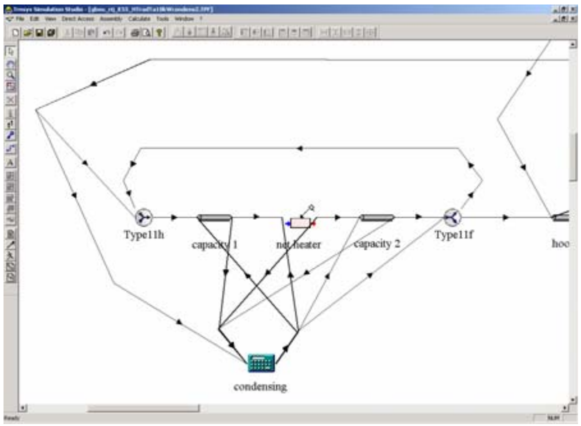


*Figure 2 Boiler model in TRNSYS*

The pipes represent the water that flows through the boiler. The capacity of the water in the pipes is set equal to that of a real boiler. If the heat demand of the system reaches the power that the (modulating) boiler can produce, the boiler is turned on and the water from the distribution system flowing through is heated by the ideal heater until the set temperature is reached. At the same time the pipes loose energy and with the correct loss factor they can represent the boiler losses to the environment. If the water temperature of the boiler reaches the minimum and the heat demand is too low, water is sent around the boiler and the boiler heats up. When the boiler water temperature is high enough and the necessary load still too low, the heater is turned off and heat can be added to the small distributed flow through the boiler or be lost to the environment; i.e. the boiler is cycling. (see hour 0 till hour 7 in figure 3)

When the energy to the boiler flow is divided by the burner efficiency, the total consumption is calculated. A condensing and a non-condensing boiler are modeled in EES by Professor Lebrun from the University of Liège (ULG). Parameter analysis of these models gives us a function for the heat losses of the boiler through the chimney. These heat losses

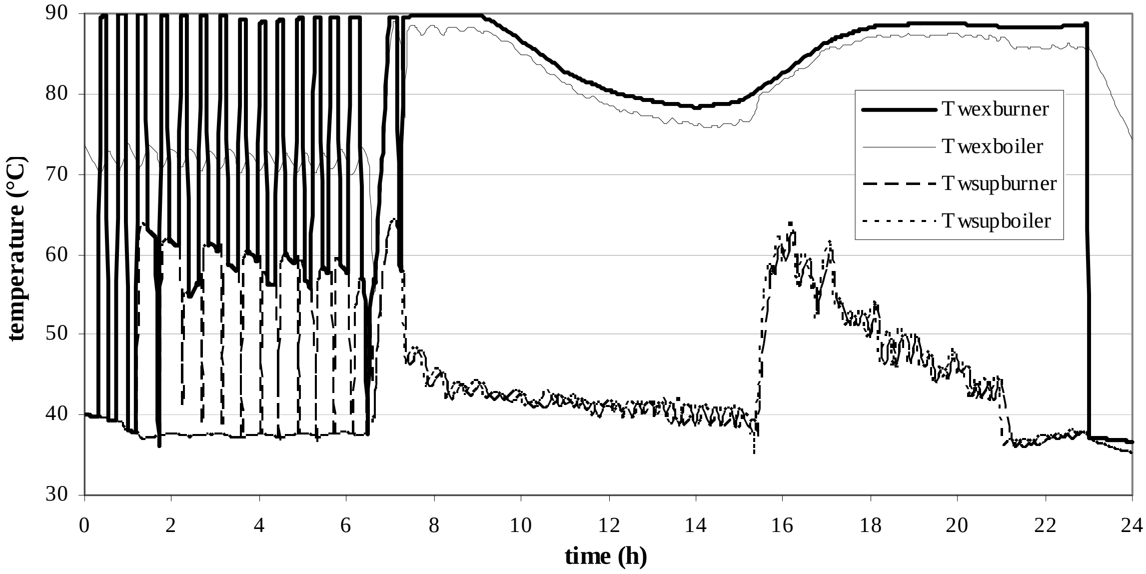


*Figure 3 Boiler water supply and exhaust temperature and burner supply and exhaust temperature for a modulating boiler coupled to an outside temperature sensor and HT-radiators*

depend mostly on the temperature of the air which is burned, the temperature of the supply water and the water flow through the heat exchanger. For condensing boilers the load itself is also a variable, as shown in Figure 4. The efficiency of the heat exchanger increases when the flow speed of gases decreases. For a modulating boiler, this efficiency is assumed constant at changing loads. Indeed, state-of-the-art modulating boilers can maintain their high efficiency over a wide range. Under the modulating range of 3 kW the burner efficiency drops due to inefficiencies during start up and stop.

As can be seen in Figure 3, the boiler set point temperature can be varied in function of the outside temperature. A power function is chosen between 50°C en 25°C for the LT-systems and between 90°C and 40°C for the HT-systems.

Finally, the system is turned off when the daily average temperature rises above 12°C.

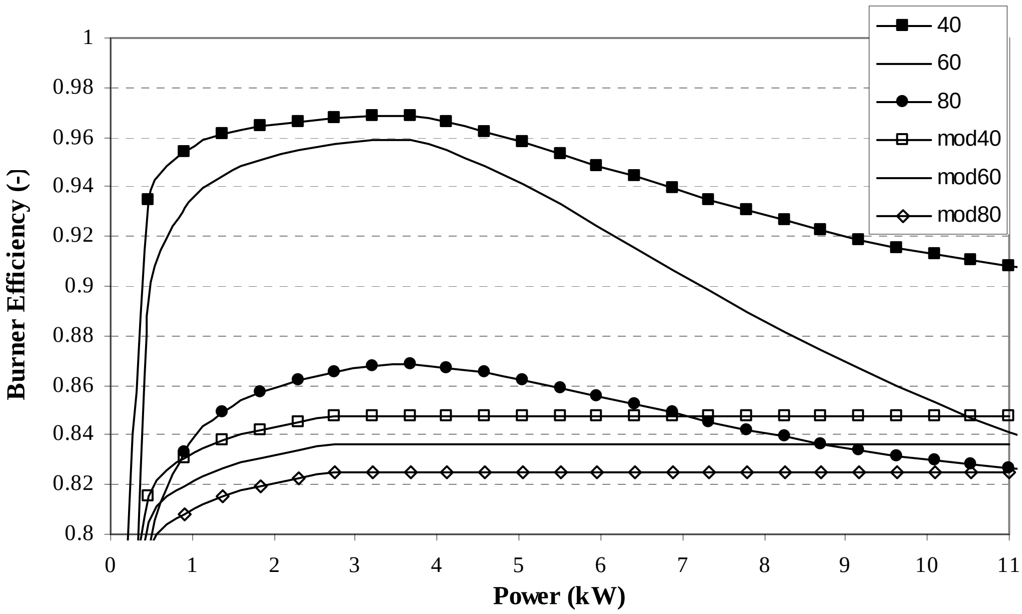


*Figure 4 Burner efficiency (at Higher Heating Value) of a condensing and modulating boiler at 4 boiler temperatures*

## RESULTS

### Modulating high-efficiency boilers

Table 1 (annex) summarizes the results for modulating high-efficiency boilers. The first three lines in the table are taken by the total heat consumption, the "energy into system" being the energy delivered to the distribution system, the "energy in zones" being the energy emitted by radiators or floor heating and the losses of the pipes in the zones that need heating, and finally the energy emitted only by the radiators or floor heating in the day zone. Further on, the total efficiency being the ratio of net heat demand and total energy consumption for heating calculated with respect to the Higher Heat Value of gas, the production efficiency being the ratio of heat to the distribution system and total heat consumption of the boiler and the burner efficiency being the ratio of heat to boiler water and total heat consumption, is given. The latter is a measure for the heat loss of the boiler through the chimney and the difference between burner and production efficiency suggests how much the boiler loses to the zone. Finally the yearly averaged temperature in the day zone and the whole building are presented.

If we compare the heating systems for this type of boiler, it is obvious that the floor heating systems consume more energy than the radiator systems. The difference is caused by the heat emitted in the day zone; the floor heating panels give off about 5500 kWh per year, while the HT-radiators only need 2300 kWh/a and the LT-radiators 3300 kWh/a. This is caused by the large thermal lag of the floor heating systems, as can be seen on figure 5. The temperature at night set back hardly drops 1°C while this is 4°C for the LT-radiators (figure 6). Nevertheless, to reach the set point temperature of 21°C in the morning, the heating has to be turned on 4 or 4.25 hours beforehand, depending on the capacity of the floor.

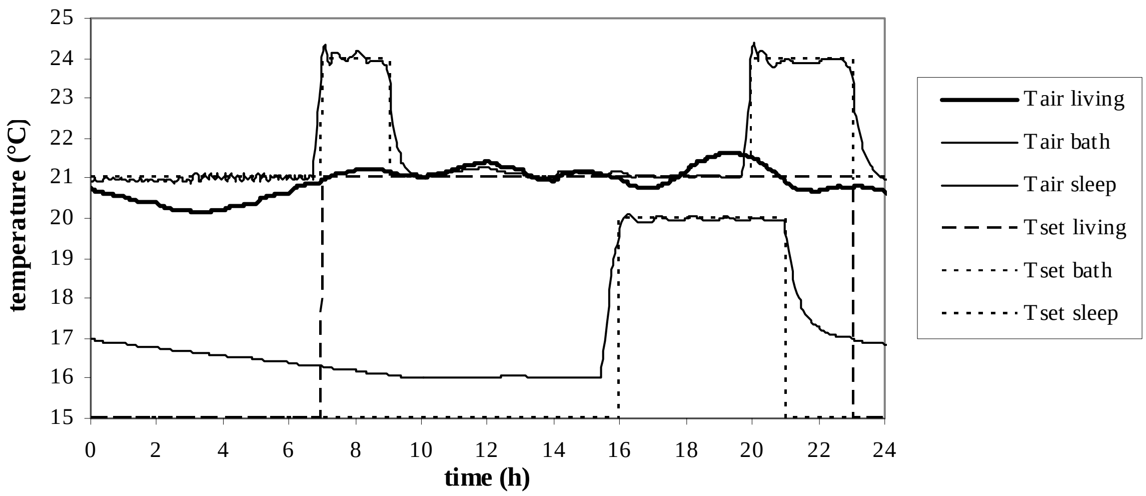


*Figure 5 Set point and simulated temperatures for the living room with floor heating; bed room and bath room with LT-radiators*

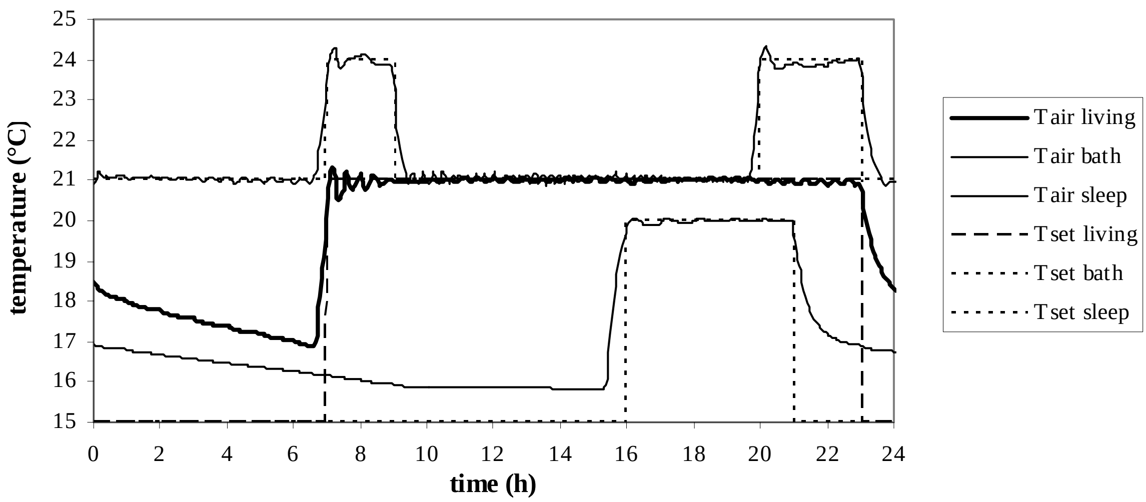


*Figure 6 Set point and simulated temperatures for the living room, bed room and bath room with LT-radiators*

Furthermore, when discontinuous solar heating and free gains enter the zone; the heating systems can not react fast enough and the temperature rises above the set point. The radiators are easier to control, although they show oscillations when temperature rises sharply, or when free gains are emitted in the zone, but this is typical for a proportional control (Ast, 1988). Consequently, the yearly averaged temperature in the day zone is about 0.6 degrees higher when floor heating systems are used, as shown in table 1.

LT-radiators need the same amount of energy in the distribution system as HT-radiators, although they enter more energy in the zones that are heated. This shows that the extra heat loss from the piping at high temperatures outside those zones is mostly recuperated. Nevertheless, the production efficiency of the HT-system is lower and not all the heat losses to the storeroom, where the boiler is placed, are recuperated. The extra losses at high temperatures are high for such a small zone and therefore, the average temperature is about 1.6°C higher, which leads to extra losses to the environment.

When the results of the modulating boilers with and without outside temperature sensor control are compared, the first perform a little better, partly due to increasing production efficiencies as lower water temperatures cause lower losses to the environment, and partly due to a better control, which is realized in a lower yearly averaged temperature across the building in table 1. The burner efficiency is hardly influenced by the variable boiler temperature.

**Condensing boilers**

Comparing Table 2 and Table 1 reveals that the distribution system reacts the same, which is logical since the modulating properties of both boilers are equal. However, the burner efficiency of condensing boilers is much higher at low temperatures, as figure 4 showed above. Floor heating systems coupled to condensing boilers will therefore perform better than HT-radiators. The latter hardly improve when a condensing boiler is installed because the burned gases will not condensate at these high temperatures. Moreover, if extra electricity losses from the ventilator would be taken into account, the small profit is quasi neutralized.

LT-radiators still outperform floor heating panels for the same reasons as with modulating boilers, but the introduction of an outside temperature sensor control has a higher influence since the burner is more temperature dependent. HT-radiators perform even 5% better with such a control, because in the heat exchanger temperatures can be reached at which condensation appears.

**Air temperature versus operative temperature**

The floor heating system radiates roughly the same amount of energy than it gives off with convection, depending on the actual floor, wall and air temperatures. The modern convecto-radiators used in our simulations, however, are much more relying on convection. Consequently, the operative temperature, the weighted average of air temperature and surface temperatures, is higher than the air temperature for floor heating and vice-versa for radiator heating.

Floor heating will therefore benefit from being controlled based on the operative temperature, which is illustrated in Table 3.

**No night set back**

Table 4 shows that using night set back in the day zone has practically no influence on the energy consumption of a floor heating system. The floor with large thermal lag consumes 0.1% less, the lighter version still just 0.5%. This contrasts with the 5% and 8% difference of HT and LT-radiator heating respectively. The increase of the average temperature is also much higher in these cases.

**Insulation around piping**

The small differences of total consumption in table 5 and the higher heat emission in the zones in the case of insulated pipes, proves that the majority of losses in adjacent zones is recuperated. The slightly higher temperatures give an idea of the non recuperated losses. The on/off-boiler and the modulating boiler on high temperature seem to be equivalent.

## DISCUSSION

The results of our case study show that LT-radiators outperform the floor heating alternative. Only floor heating systems that run on a condensing boiler and are used to maintain a constant temperature, equal to the operative temperature that the LT-radiators produce, can rival these radiators.

Problems arise when the desired temperature is not constant and solar and free gains create an intermittent heat load profile. Adaptive predictive control could improve the control of these systems with such a large thermal lag. Limiting the floor heating and just use it as base heating is another solution.

The losses of the distribution system seem to be almost completely recuperated in other zones of the building, but this is highly building (insulation) dependent. Scrutinizing this relation will be our main future research.

## ACKNOWLEDGMENT

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*Table 1*
*Modulating boilers with zone temperature control on dry air temperature and different boiler control systems*

| | | **HIGH CAP FLOOR** | **FLOOR** | **HT-RAD** | **LT-RAD** |
|---|---|---|---|---|---|
| **FIXED BOILER WATERTEMPERATURE SETPOINT** | **Total energy (kWh/a)** | **15024** | **14844** | **13639** | **13062** |
| | **Into system (kWh/a)** | 11789 | 11648 | 10593 | 10592 |
| | **Into zone (kWh/a)** | 10487 | 10355 | 8784 | 9747 |
| | **Day zone (kWh/a)** | 5763 | 5467 | 2300 | 3323 |
| | **Total eff (-)** | **0.678** | **0.686** | **0.746** | **0.779** |
| | **Production eff (-)** | 0.785 | 0.785 | 0.777 | 0.811 |
| | **Burner eff (-)** | 0.817 | 0.816 | 0.828 | 0.835 |
| | **Day zone Ta (°C)** | 21.72 | 21.64 | 21.09 | 21.05 |
| | **Building Ta (°C)** | 21.30 | 21.31 | 21.17 | 20.91 |
| **OUTSIDE TEMPERATURE BOILER CONTROL** | **Total energy (kWh/a)** | **14799** | **14504** | **13548** | **12943** |
| | **Into system (kWh/a)** | 11740 | 11514 | 10572 | 10531 |
| | **Into zone (kWh/a)** | 10729 | 10506 | 8931 | 9799 |
| | **Day zone (kWh/a)** | 4623 | 5623 | 2481 | 3481 |
| | **Total eff (-)** | **0.688** | **0.702** | **0.752** | **0.787** |
| | **Production eff (-)** | 0.793 | 0.794 | 0.780 | 0.814 |
| | **Burner eff (-)** | 0.818 | 0.819 | 0.826 | 0.834 |
| | **Day zone Ta (°C)** | 21.69 | 21.60 | 21.07 | 21.02 |
| | **Building Ta (°C)** | 21.18 | 21.15 | 21.09 | 20.83 |

*Table 2*
*Condensing boilers with zone temperature control on dry air temperature and different boiler control systems*

| | | HIGH CAP FLOOR | FLOOR | HT-RAD | LT-RAD |
|---|---|---|---|---|---|
| FIXED BOILER WATERTEMPERATURE SETPOINT | **Total energy (kWh/a)** | **12994** | **12826** | **13648** | **11571** |
| | **Into system (kWh/a)** | 11788 | 11648 | 10593 | 10592 |
| | **Into zone (kWh/a)** | 10487 | 10355 | 8784 | 9747 |
| | **Day zone (kWh/a)** | 5763 | 5467 | 2300 | 3323 |
| | **Total eff (-)** | **0.784** | **0.794** | **0.749** | **0.880** |
| | **Production eff (-)** | 0.907 | 0.908 | 0.779 | 0.915 |
| | **Burner eff (-)** | 0.945 | 0.946 | 0.831 | 0.924 |
| | **Day zone Ta (°C)** | 21.72 | 21.64 | 21.09 | 21.05 |
| | **Building Ta (°C)** | 21.30 | 21.31 | 21.17 | 20.91 |
| OUTSIDE TEMPERATURE BOILER CONTROL | **Total energy (kWh/a)** | **12747** | **12537** | **12928** | **11366** |
| | **Into system (kWh/a)** | 11740 | 11557 | 10572 | 10531 |
| | **Into zone (kWh/a)** | 10729 | 10546 | 8931 | 9799 |
| | **Day zone (kWh/a)** | 5893 | 5598 | 2481 | 3482 |
| | **Total eff (-)** | **0.798** | **0.812** | **0.788** | **0.896** |
| | **Production eff (-)** | 0.921 | 0.922 | 0.818 | 0.927 |
| | **Burner eff (-)** | 0.950 | 0.951 | 0.866 | 0.950 |
| | **Day zone Ta (°C)** | 21.69 | 21.60 | 21.07 | 21.02 |
| | **Building Ta (°C)** | 21.18 | 21.17 | 21.09 | 20.83 |

*Table 3*
*Condensing boilers with boiler water set point controlled by an outside temperature sensor and different zone temperature control*

| | | HIGH CAP FLOOR | FLOOR | HT-RAD | LT-RAD |
|---|---|---|---|---|---|
| ZONE TEMPERATURE CONTROLLED ON DRY AIR BULB TEMP | **Total energy (kWh/a)** | **12747** | **12537** | **12928** | **11366** |
| | **Into system (kWh/a)** | 11740 | 11557 | 10572 | 10531 |
| | **Into zone (kWh/a)** | 10729 | 10546 | 8931 | 9799 |
| | **Day zone (kWh/a)** | 5893 | 5598 | 2481 | 3482 |
| | **Total eff (-)** | **0.798** | **0.812** | **0.788** | **0.896** |
| | **Production eff (-)** | 0.921 | 0.922 | 0.818 | 0.927 |
| | **Burner eff (-)** | 0.950 | 0.951 | 0.866 | 0.950 |
| | **Day zone Ta (°C)** | 21.69 | 21.60 | 21.07 | 21.02 |
| | **Building Ta (°C)** | 21.18 | 21.17 | 21.09 | 20.83 |
| ZONE TEMPERATURE CONTROLLED ON OPERATIVE TEMP | **Total energy (kWh/a)** | **12647** | **12501** | **13619** | **12134** |
| | **Into system (kWh/a)** | 11740 | 11558 | 11190 | 11244 |
| | **Into zone (kWh/a)** | 10727 | 10550 | 9563 | 10511 |
| | **Day zone (kWh/a)** | 5386 | 5164 | 2870 | 3933 |
| | **Total eff (-)** | **0.805** | **0.815** | **0.748** | **0.839** |
| | **Production eff (-)** | 0.921 | 0.922 | 0.818 | 0.927 |
| | **Burner eff (-)** | 0.950 | 0.951 | 0.866 | 0.949 |
| | **Day zone Top (°C)** | 21.70 | 21.62 | 21.20 | 21.16 |
| | **Building Top (°C)** | 21.26 | 21.23 | 21.25 | 21.02 |

*Table 4*
*Condensing boilers with boiler water set point controlled by an outside temperature sensor and different night set back schedules*

| | | HIGH CAP FLOOR | FLOOR | HT-RAD | LT-RAD |
|---|---|---|---|---|---|
| **WITH NIGHT SET BACK** | **Total energy (kWh/a)** | **12747** | **12537** | **12928** | **11366** |
| | **Into system (kWh/a)** | 11740 | 11557 | 10572 | 10531 |
| | **Into zone (kWh/a)** | 10729 | 10546 | 8931 | 9799 |
| | **Day zone (kWh/a)** | 5893 | 5598 | 2481 | 3482 |
| | **Total eff (-)** | **0.798** | **0.812** | **0.788** | **0.896** |
| | **Production eff (-)** | 0.921 | 0.922 | 0.818 | 0.927 |
| | **Burner eff (-)** | 0.950 | 0.951 | 0.866 | 0.950 |
| | **Day zone Ta (°C)** | 21.69 | 21.60 | 21.07 | 21.02 |
| | **Building Ta (°C)** | 21.18 | 21.17 | 21.09 | 20.83 |
| **WITHOUT NIGHT SET BACK** | **Total energy (kWh/a)** | **12766** | **12601** | **13589** | **12299** |
| | **Into system (kWh/a)** | 11800 | 11639 | 11124 | 10706 |
| | **Into zone (kWh/a)** | 10627 | 10456 | 9299 | 10267 |
| | **Day zone (kWh/a)** | 5943 | 5692 | 2820 | 4034 |
| | **Total eff (-)** | **0.797** | **0.808** | **0.749** | **0.828** |
| | **Production eff (-)** | 0.924 | 0.923 | 0.819 | 0.931 |
| | **Burner eff (-)** | 0.957 | 0.957 | 0.863 | 0.952 |
| | **Day zone Ta (°C)** | 21.76 | 21.70 | 21.5 | 21.48 |
| | **Building Ta (°C)** | 21.22 | 21.22 | 21.23 | 20.95 |

*Table 5*
*Different boiler types without outside temperature sensor but with different insulated distribution system*

| | | ON OFF HT-RAD | MOD HT-RAD | MOD LT-RAD | CONDENS LT-RAD |
|---|---|---|---|---|---|
| **WITHOUT INSULATION** | **Total energy (kWh/a)** | **13683** | **13639** | **13062** | **11571** |
| | **Into system (kWh/a)** | 10406 | 10593 | 10592 | 10592 |
| | **Into zone (kWh/a)** | 8546 | 8784 | 9747 | 9747 |
| | **Day zone (kWh/a)** | 2252 | 2300 | 3323 | 3323 |
| | **Total eff (-)** | **0.744** | **0.746** | **0.779** | **0.880** |
| | **Production eff (-)** | 0.761 | 0.777 | 0.811 | 0.915 |
| | **Burner eff (-)** | 0.833 | 0.828 | 0.835 | 0.942 |
| | **Day zone Ta (°C)** | 21.1 | 21.09 | 21.05 | 21.05 |
| | **Building Ta (°C)** | 21.28 | 21.17 | 20.91 | 20.91 |
| **WITH INSULATION** | **Total energy (kWh/a)** | **13621** | **13532** | **13023** | **11541** |
| | **Into system (kWh/a)** | 10239 | 10419 | 10537 | 10537 |
| | **Into zone (kWh/a)** | 9465 | 9682 | 10211 | 10267 |
| | **Day zone (kWh/a)** | 3302 | 3347 | 3896 | 4034 |
| | **Total eff (-)** | **0.747** | **0.752** | **0.782** | **0.882** |
| | **Production eff (-)** | 0.752 | 0.770 | 0.809 | 0.913 |
| | **Burner eff (-)** | 0.830 | 0.826 | 0.834 | 0.941 |
| | **Day zone Ta (°C)** | 21.08 | 21.07 | 21.04 | 21.04 |
| | **Building Ta (°C)** | 21.17 | 21.07 | 20.86 | 20.86 |