Simulation Based Assessment of Heat Pumping Potential in Non-Residential Buildings – Part 3: Application to a typical office building in Belgium

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SUMMARY

The purpose of this paper is to describe the application of the tools presented in a companion paper [1] to a typical office building located in the Walloon Region of Belgium. This building is a mid-size (7000 m² on seven floors) office building constructed in the eighties and equipped with a classical HVAC solution: boiler and air-cooled chiller; all-air VAV system. An energy audit was conducted in this building and featured a number of management problems. Among the Energy Conservation Opportunities considered to improve the energy performance of the building, the move to a heat pump solution was considered.

The identification of energy savings potential offered by the implementation of heat pumping strategies confirmed what was already shown by the parametric analysis: in temperate climates, reversibility offers a by far higher potential than condenser heat recovery given the dominant non simultaneity of the yearly heating and cooling demands profiles. Calculations show that theoretically half of the heating demand could be satisfied by the reversibility of the chiller to run in heat pumping mode.

In a second step, a number of practical implementations of heat pumping solutions were evaluated by means of another software tool: reversible air/water HP, exhaust air HP, double condenser and water loop heat pump systems. These solutions are compared to the reference existing situation (boiler + chiller working independently) in terms of energy, CO_2 emissions and cost on a 20 years life-cycle basis. Calculations show that the air/water reversible chiller solution offers the most important energy savings and CO_2 reduction while staying at a reasonable level concerning the additional cost.

INTRODUCTION

This last paper of the series aims at applying the tools presented to a real building, in the frame of IEA-ECBCS Annex 48 project. Five general configurations will be evaluated and compared to the existing system. The results will be the basis of a proposal for the retrofit of the building.

BUILDING DESCRIPTION

The analyzed building is a medium size building built in Charleroi (central part of Belgium) at the end of the eighties (figure 1). It is a 9 storey building with 7220 m² of air-conditioned offices and meeting rooms and underground parking lots. It is surrounded by small buildings and streets.

Fig. 1: View of the analyzed building

The building is located at an altitude of 306 m where the climate is characterized by the following data:

Heating sizing temperature	- 10°C
Cooling sizing temperature	30°C with 50 % relative humidity
15/ 15 heating degree-days	2000 K*d

A four storey zone of the building for which energy balances can be worked out has been identified (storey n° 4, 5, 6 and 7). 40 people occupy each of these floors from 8 am to 6 pm, 5 days per week, the whole year. The HVAC system has an air handling unit (GP2-GE2) that supplies conditioned air through a duct work system to the different offices (see figure 2).

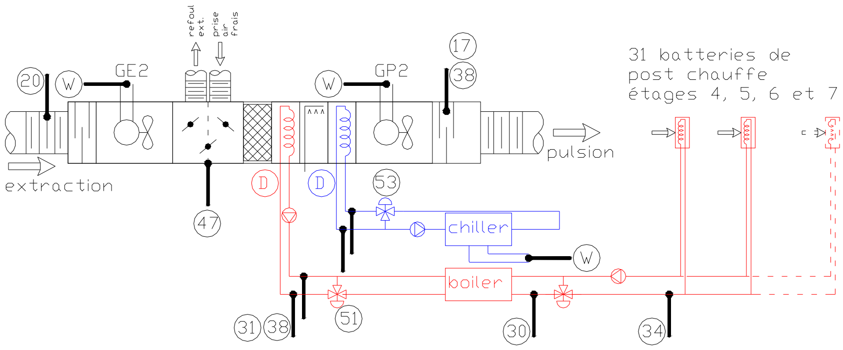
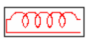


Figure 2: View of the HVAC system of the selected zone

Air can be post heated through a total of 31 local coils  distributed within the roof of the four floors. Local comfort temperature set points can independently be adjusted by occupants within a range of +/- 3°C around a fix value (21°C). A building energy management system (BEMS) handles all necessary data and implements the control strategies. The data can be remotely downloaded. The actual primary system is composed of 3 classical gas boilers (318 kW - no condensation) and 2 chillers. Nominal water temperatures at the boilers are 70/90 °C. The 2 chillers have 2 compressors (4X30kW motors).

RECOVERY AND REVERSIBILITY POTENTIALS

The first step of the procedure consists in computing the demands profile for the building. This was achieved thanks to the first simulation tool [1]. The result is shown in figure 3. As usually observed in temperate climates, this graphic seems to indicate a rather good reversibility potential and a poor recovery potential (the heating and cooling demands happen mainly at different times). This intuition is confirmed by the computed potentials:

- Recovery potential: 9,8%
- Reversibility potential: 50,0%

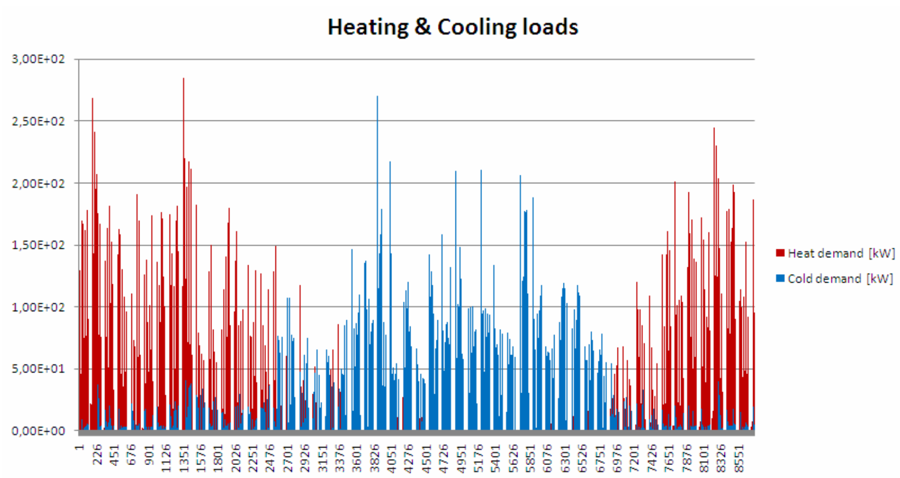


Fig. 3: Heating & Cooling loads

HEAT PUMP SYSTEMS ASSESSMENT

This section will explain the methodology used to perform the different simulations and the results. For each system, an EES (Engineering Equation Solver) application was developed and the different system configurations are described in [1]. The results are simply obtained by solving the equations for each hour of the year[1]. In this evaluation, the sizing of the heating and cooling devices was done by adding 20% to the maximal needs. Some general parameters had to be fixed for the simulations[2]:

HHV (Higher Heating Value) natural gas	43 MJ/kg	Electricity price (peak)	0,1669 €/kWh
Primary energy factor (electricity)	3,31	Gas price	0,04087 €/kWh
Primary energy factor (gas)	1,35	Actualization rate	8%
CO2 emission factor (electricity)	0,268 kg CO2/kWh	General inflation	2%
CO2 emission factor (gas)	0,231 kg CO2/kWh	Gas inflation	4%
Electricity price (off peak)	0,1037 €/kWh	Annual maintenance cost for a pump	100 €

[1] The hourly heating and cooling demands were computed in a detailed TRNSYS building simulation.

[2]The detailed calculation method used for the economical evaluation can be found in (3)

One important and general remark: the constitutive terms of the costs vary with time because the fuel inflation rate and the general inflation rate are considered as different. The proportional cost of gas is increasing with time. The results shown below are aggregated for the whole lifecycle.

Table 1: System 0 performances (Classical separated heat and cold production system)

	Lifecycle cost [€/m²]	Annual primary energy consumption [kWh/m²]	Annual CO_2 emissions [kg]
Gas	19,37	42,74	37271
Electricity	12,79	23,01	9493
Maintenance	3,71		
Investment	11,10		
Total	46,97	65,75	46764

The total lifecycle cost of the reference system reaches 47 €/m². This cost is mainly due to the fuel cost. The electricity, principally needed for the chiller and the pumps, represents 27%. The investment term is quite low, as the system is the simplest one. The primary energy consumption is 65,75 kWh/m², two thirds of which come from the gas consumption. 80% of the CO_2 emissions come from the gas.

Table 2: System 1 performances (Reversible air-to-water heat pump system)

	Lifecycle cost [€/m²]	Annual primary energy consumption [kWh/m²]	Annual CO_2 emissions [kg]
Gas	3,61	3,86	3366
Electricity	27,68	50,77	20948
Maintenance	3,78		
Investment	11,50		
Total	46,57	54,63	24314

The total lifecycle cost of this reversible system is comparable to the reference model. The cost here is largely dominated by the electricity which seems logical considering the use of the reversible heat pump. It is interesting to notice the gain in primary energy and in CO_2 compared with the reference system (respectively 17% and 48%).

Table 3: System 2 performances (Exhaust air heat pump system)

	Lifecycle cost [€/m²]	Annual primary energy consumption [kWh/m²]	Annual CO_2 emissions [kg]
Gas	3,89	4,56	3979
Electricity	27,16	50,08	20664
Maintenance	5,15		
Investment	15,13		
Total	51,33	54,64	24643

Here again the total cost is dominated by the electricity. The material cost rises as there are more parts in the system (cooling coil, cooling tower…). The primary energy consumption and the CO_2 emissions decrease by 17% and 47% respectively. On the other hand the overall cost is higher, which makes the system not so interesting.

Table 4: System 3 performances (Dual condenser heat pump system)

	Lifecycle cost [€/m²]	Annual primary energy consumption [kWh/m²]	Annual CO_2 emissions [kg]
Gas	18,78	42,26	36854
Electricity	12,83	23,07	9519
Maintenance	4,22		
Investment	14,17		
Total	50,00	65,33	46373

The system taking advantage of the recovery potential of the demand is not very helpful in this situation. The lifecycle cost is higher and the primary energy consumption and the CO_2 emissions are hardly reduced.

Tables 5, 6 and 7: System 4 perfomances (Water loop heat pump system)
Three variants are considered:

a) With heat rejector and boiler

	Lifecycle cost [€/m²]	Annual primary energy consumption [kWh/m²]	Annual CO_2 emissions [kg]
Gas	5,66	9,05	7891
Electricity	30,56	56,91	23484
Maintenance	3,25		
Investment	18,75		
Total	58,22	65,96	31375

In this first water loop system, the total cost increases. The CO_2 emissions decrease, but the primary energy consumption is comparable to the reference system because the electricity consumption is quite large.

b) With heat rejector and GHX

	Lifecycle cost [€/m²]	Annual primary energy consumption [kWh/m²]	Annual CO_2 emissions [kg]
Gas	0,00	0,00	0
Electricity	30,35	56,86	23461
Maintenance	0,89		
Investment	28,53		
Total	59,77	56,86	23461

This system is interesting because it doesn't use a boiler. The overall cost is high (mainly due to the GHX). The primary energy consumption and the CO_2 emissions are both decreasing.

c) With GHX and boiler

	Lifecycle cost [€/m²]	Annual primary energy consumption [kWh/m²]	Annual CO_2 emissions [kg]
Gas	3,54	3,67	3203
Electricity	30,21	56,60	23353
Maintenance	2,86		
Investment	30,89		
Total	67,50	60,27	26556

This is the most expensive system studied here. The primary energy consumption and the CO_2 emisisons are low, but still higher than the previous system. One interesting remark for all ground heat exchanger based systems: it has been designed to supply half of the demand. For this system, a boiler could have been a benefit if the ground heat exchanger was downsized to supply less than half of the demand. However, some comfort problems could occur in this case.

Table 8: System 5 perfomances (Ground coupled heat pump system)

	Lifecycle cost [€/m²]	Annual primary energy consumption [kWh/m²]	Annual CO_2 emissions [kg]
Gas	2,79	1,77	1540
Electricity	26,41	49,14	20277
Maintenance	3,98		
Investment	27,68		
Total	60,86	50,91	21817

The last system is expensive, like every system with a GHX. However, it is very interesting because it has the lowest primary energy consumption and CO_2 emissions. The idea to combine a ground heat exchanger with one main reversible heat pump instead of a water loop is a good choice in this case.

Comparison of the different system configurations

Fig. 4 to 6 show a comparison of the performances of the different system configurations in terms of cost, CO2 emissions and primary energy.

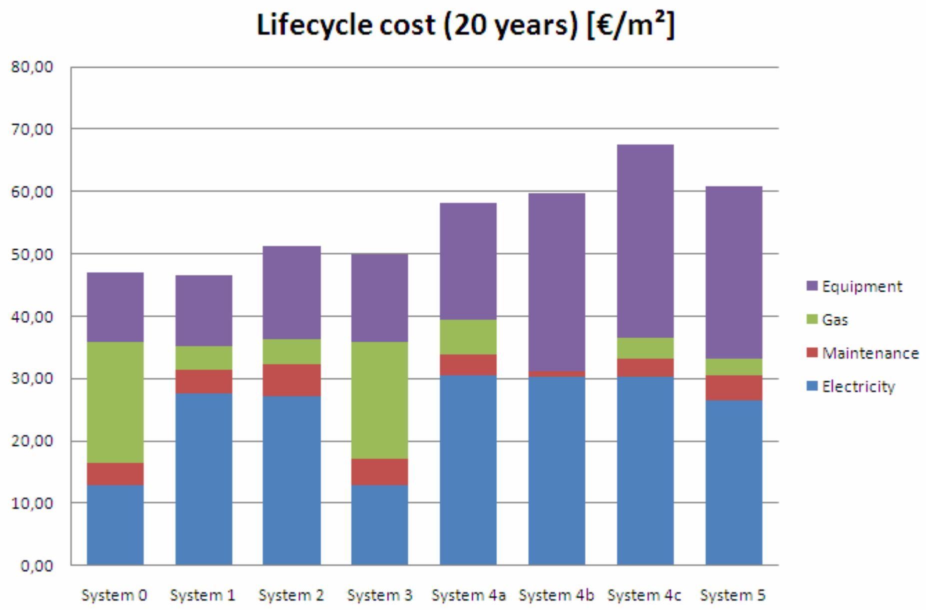


Fig. 4: Lifecycle cost

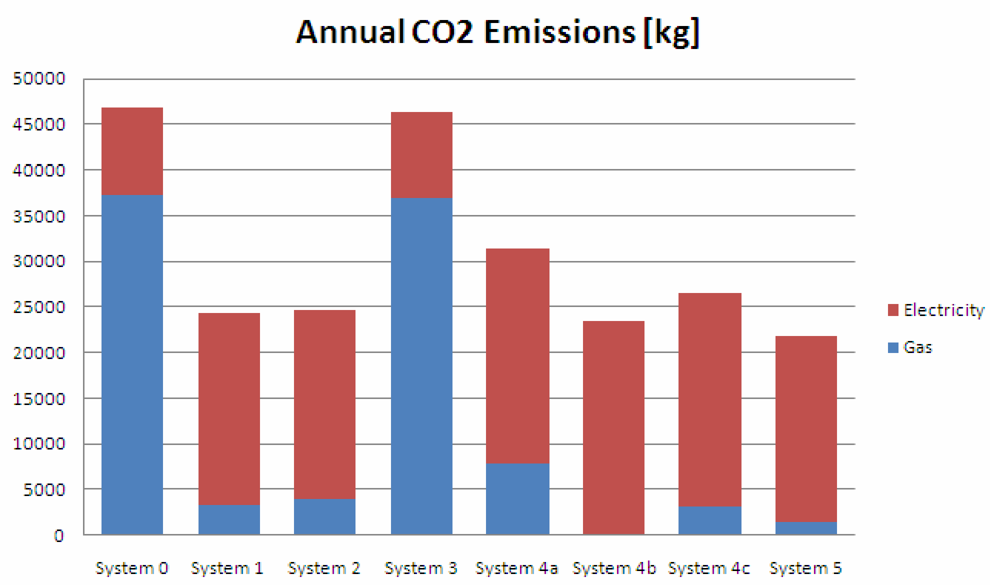


Fig. 5: annual CO_2 emissions

The comparison between the different systems shows that the less expensive one is the model 1, the reversible heat pump. The difference in the cost is not very important, but it allows a primary energy reduction of more than 15 % and a diminution of 50 % of the CO_2 emissions. Some other systems remain interesting in terms of primary energy and/or CO_2, but the lifecycle costs could easily dismiss these options. The “greenest” system is the system 5 but it is also one of the most expensive, mainly because of the GHX.

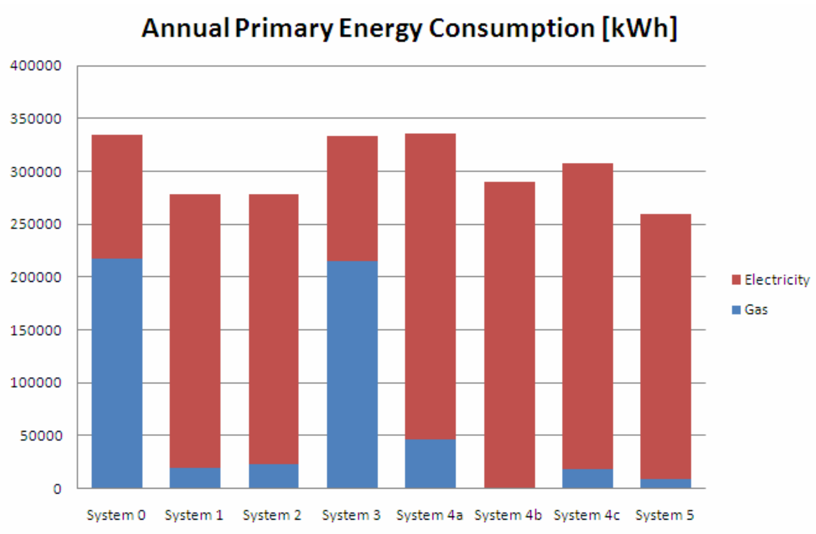


Fig. 6: annual primary energy consumption

DISCUSSION AND FURTHER WORK

As foreseen, the systems taking advantage of the reversibility potential give encouraging results. However, the results presented here are somehow not complete because they suppose a perfect transmission from the production to the building (no transmission losses, no regulation losses…). To cover this, the behavior of the complete system should be simulated.

TRNSYS based simulations including the primary system, the air handling unit, heating and cooling coils, hydraulic and aeraulic networks are currently being set up for that purpose. The goal is to confirm the results obtained with the tools presented here and to understand in which way the secondary system may increase the overall consumption in the particular case of the office building in Charleroi. 3 systems will be simulated in TRNSYS: the reference one, the reversible system 1 and the system 5. The results of these simulations will be the basis of a proposition for the retrofit of the existing building.

ACKNOWLEDGEMENT

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