Heat SET 2007
Heat Transfer in Components and Systems
for Sustainable Energy Technologies
18-20 April 2007, Chambery, France

HEAT PUMPING AND REVERSIBLE AIR CONDITIONING FIRST CASE STUDY RESULTS

Cleide Aparecida Silva, cj.hannay@ulg.ac.be
Stéphane Bertagnolio, stephane.bertagnolio@student.ulg.ac.be
Jules Hannay, cj.hannay@ulg.ac.be
Jean Lebrun, j.lebrun@ulg.ac.be

Thermodynamics Laboratory, University of Liège
Campus du Sart-Tilman, B49, B-4000 Liège
Belgium

ABSTRACT

This paper presents the main results coming from a first case study performed in the frame of the IEA_ECBCS annex 48 project. A laboratory building is submitted to a detailed energy audit in order to identify the most attractive retrofit potentials.
The first retrofit proposed is to replace the existing air-water chiller by a water-water one, which will satisfy not only the cooling, but also the heating demand. This strategy is completed by a "change-over" process, in order to take the best profit of all heat transfer areas available in the HVAC system. Simulation results are very encouraging: they confirm the possibility of getting significant reductions of primary energy consumption, CO2 emission *and* running costs.

INTRODUCTION

Substituting a heat pump to a boiler in space heating may save more than 50 % of primary energy, if electricity is produced by a modern gas-steam power plant (even more if a part of that electricity is produced from a renewable source).
Vapor compression heat pumping is, probably today, one of the quickest and safest solutions to save energy and to reduce CO2 emission.
Most of air-conditioned commercial buildings offer attractive retrofit opportunities, because:

1) When a chiller is used, the condenser heat can cover (at least a part of) the heating demand;
2) When a chiller is not (fully) used for cooling, it can be (at least partially) re-converted into heat pump.

The aim of IEA-ECBCS annex 48 is to promote the most efficient combinations of heating and cooling techniques in air conditioning.

Focus is given on optimal sizing of heat pumps, thermal storage, heat and cold distribution systems and control strategy required in the design of new systems and in the retrofit of existing ones.
Each participant of this project is documenting several case studies, on which methods and tools developed in the annex are being tested and from which reference data are extracted. Some results of a first case study are hereafter presented…

THE BUILDING

The present case study is dealing with a laboratory building erected in 2003 in the region of Liège. Five different zones can be distinguished (Figures 1 and 2):

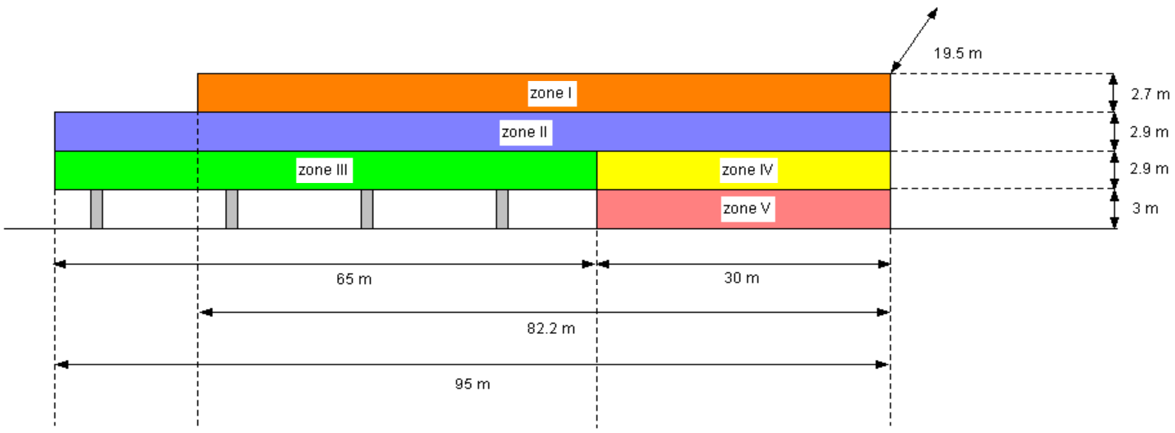

Figure 1: The five building zones

The first zone corresponds to the offices (about 1603 m²). It's surrounded by glazed frontages, partially shadowed by the roof cornice.

The second zone is the technical room, where all air handling units (AHU), chillers and boilers are installed. Its frontages are totally opaque.

The third zone contains all the laboratories; it's frontage is partially glazed.

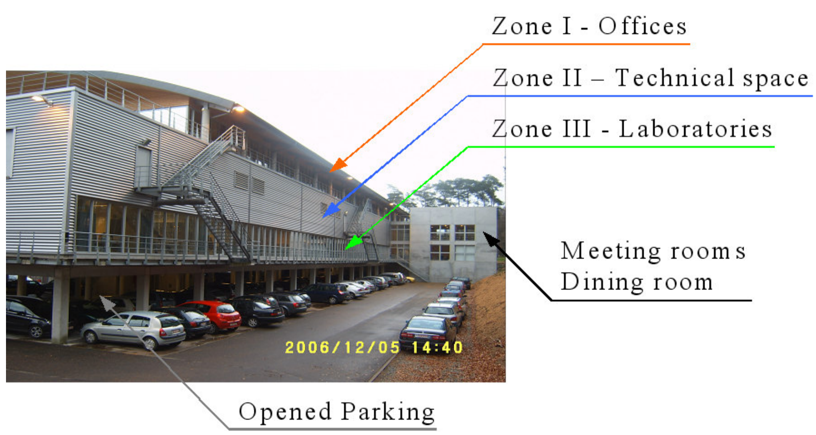

Figure 2: Building South frontage

The fourth zone contains several sanitary facilities and cloakrooms dedicated to the laboratory's employees. Its frontages are opaque.

The fifth zone regroups all "logistic" rooms (cold rooms, warehouse and storeroom).

The thermal characteristics of the building's envelope can be simply described by distinguishing two components only: double glazing (U=2.8 W/K.m²) and opaque walls (U=0.8 W/K.m²).

The UA values of all envelope parts are given in Table 1.

Table 1: AU values of all parts of the building envelope

	Double glazing windows	Roof	Ground/floor	Opaque external walls	Total UA
UA (W/K)	2 593	1482	1482	998	6 555

The distribution of these UA values among the five zones already defined is given in table 2. Focus will be given hereafter to the two most important zones (II and III); the other ones play a marginal rule in the building energy balance.

Table 1: AU distribution among the five zones

	Zone I	Zone II	Zone III	Zone IV	Zone V
UA (W/K)	2820	731	2115	184	705

DESCRIPTION OF THE HVAC SYSTEM & POWER PLANT

Zone I (offices)

The 2nd floor offices zone is supplied with 100% of fresh air, at a flow-rate of 5050 m³/h, thanks to one air handling unit. This air is filtered, heated or cooled, but not humidified, through an air handling unit and diffused in the rooms trough fifty fan coils (Figure 3). There is no humidity control in this zone.

The offices are occupied by about 70 people between 8:00 and 17:00, five days per week. The ventilation is working between 6:00 and 20:00 five days per week too.

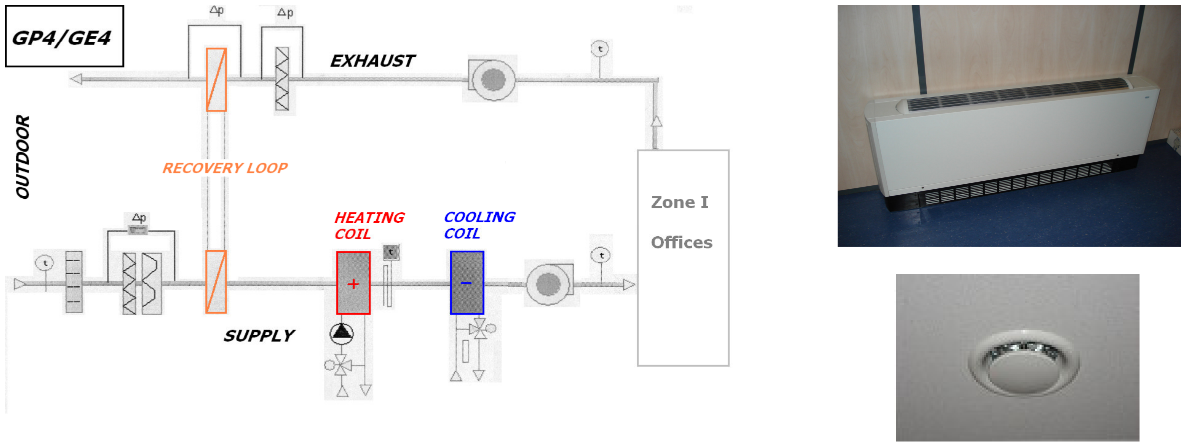

Figure 3: Offices (zone I) HVAC equipments

Zone III (laboratories)

The laboratories are supplied with 33000 m³/h of fresh air fully conditioned through three AHU's which are equipped with steam humidifiers (Figure 4).

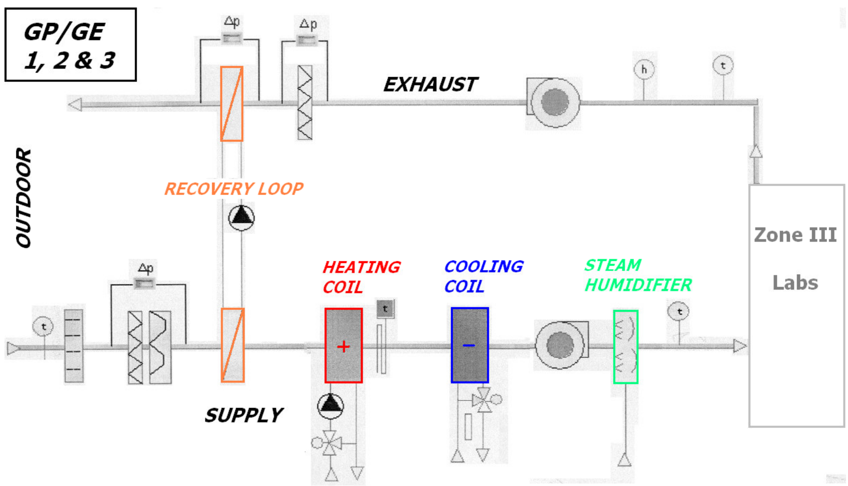

Figure 4: Laboratories AHU's

Ventilation and air conditioning of this zone is ensured 24h per day, 7 days per week all the year. About 60 people work in the laboratories during day (between 8:00 and 17:00) and, 6 other ones people are present in the zone 24h/24.

Power Plant

The hot water production is ensured, at a temperature of 70 to 80°C, by two modern condensing gas boiler of about 300kW each. The return temperature is about 55°C.
One R134a chiller of 400kW ensures the cold water production at 8°C. This chiller is equipped with air-cooled condenser; its EER is estimated to 3.1.

ENERGY AUDIT

A preliminary energy audit of this system was made on the basis of some monthly records of gas and electricity consumptions available (Figures 5 and 6).

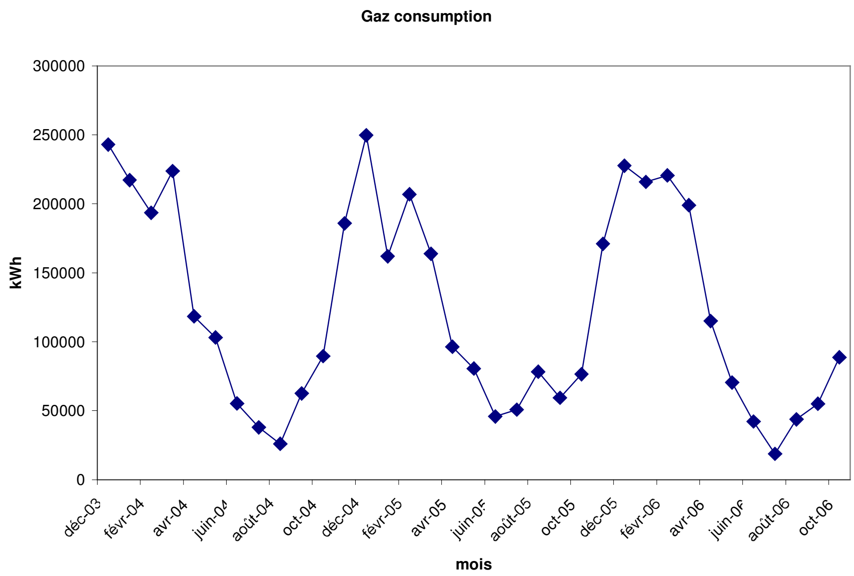

Figure 5: Gas consumption

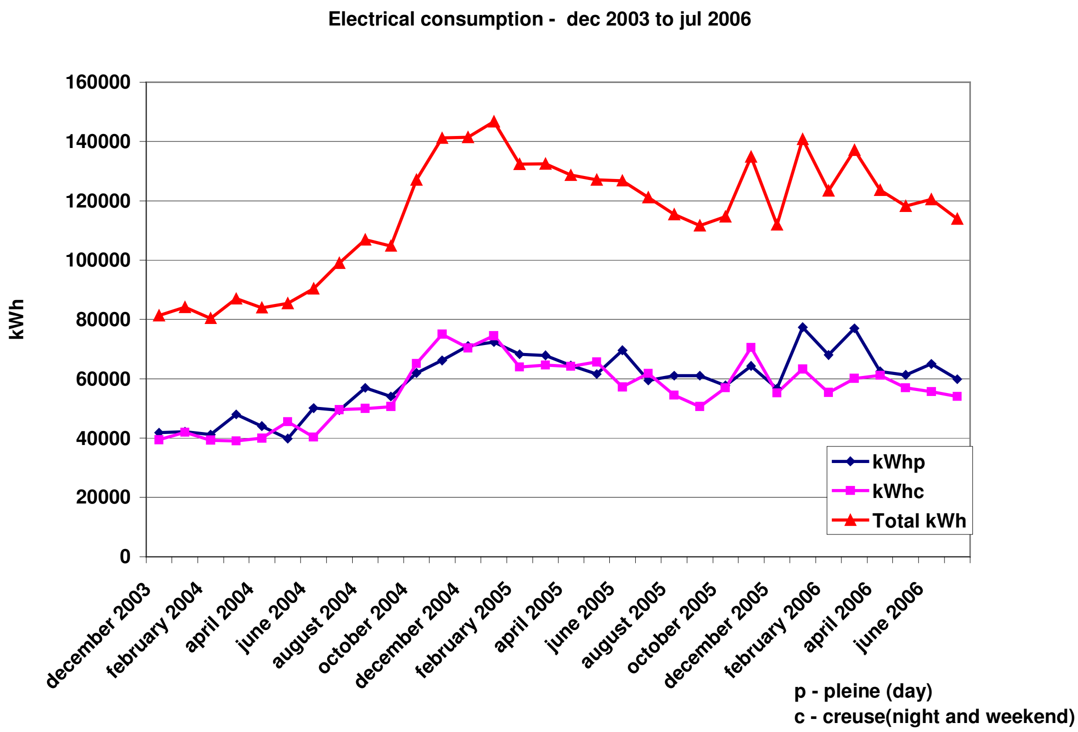

Figure 6: Electricity consumption (subscripts: "hp" and "hc" for peak and of-peak hours respectively)

Two "signatures" can be established on the basis of these recordings (Figure 7 and 8).
The first one (Figure 7) gives a fairly good confirmation of the heating demand calculation based on the building fabric and ventilation losses.
The second signature (Figure 8) is more surprising: the cooling demand, which is growing with outside air temperature, should produce a *positive* slope. The *negative* slope actually observed can be explained by a dominant effect of the electrical steam humidification, whose hypothetical signature is also indicated in both Figures.
A more rational way of humidifying the air should obviously looked for in the future…

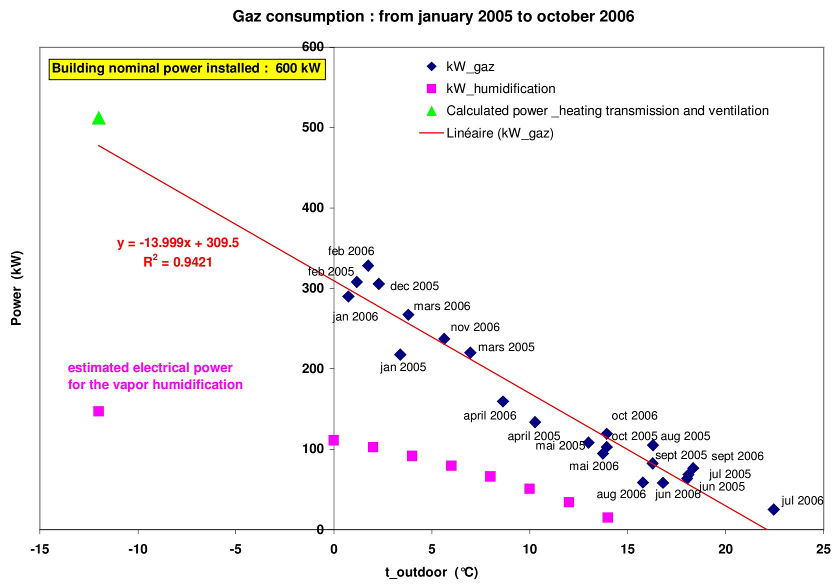

Figure 7: Gas consumption "signature"

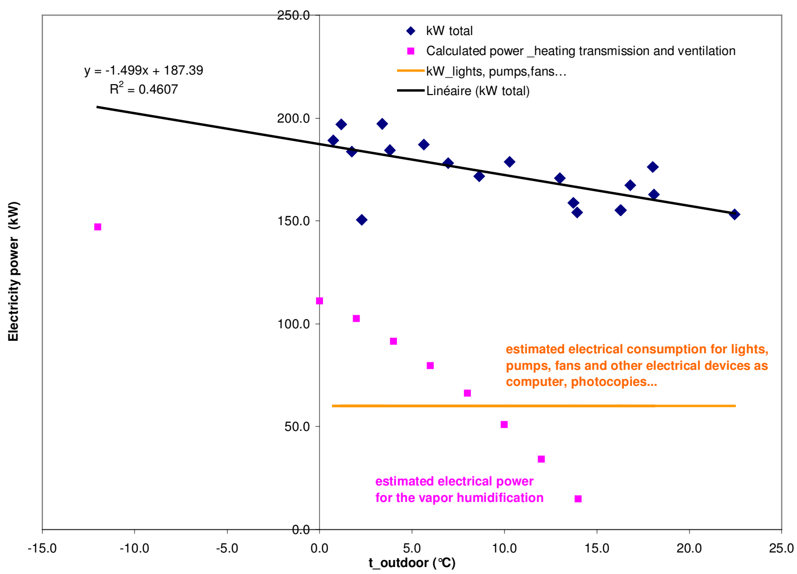

Figure 8: Thermal signature given by electricity consumption

More detailed records would be required to go further in this analysis: hourly records and/off separate records for HVAC and non-HVAC consumptions…

RETROFIT OPPORTUNITIES

Main idea and opportunities

The main idea is, in the present case, to use the extracted air as cold source for heat pumping and fresh air heating:

The idea is justified by the very large air flow rate (38000 m³/h) of hot and humid air (about 23°C/50%) extracted from the building.

First opportunity: replacing the air-cooled chiller by a water-cooled chiller/heat pump (a same machine for both functions) and supplying the terminal units with 50°C of hot water coming from the condenser.

Second opportunity (in addition to the first one): supplying the heating coils of the different AHU in the same way and introducing a "change-over" process to get additional heat transfer areas. The "change-over" will consist in using *all* heat exchangers available in a same mode when there remains only one (heating or cooling) demand. In the present case, the main issue is to use all cooling coil in heating mode when the cooling demand has disappeared.

Other opportunities:

- Installing stratified thermal storage to make possible some compensation between heating and cooling demands in mid-season.
- Reducing the air flow rates during low occupation periods (this has still to be discussed because of air quality and renewal rate requirements in laboratories).

Plant modification

The existing air-cooled condenser chiller will be replaced by one with water cooled condenser. The characteristics of both machines are summarized in table 3.

Table 3: Characteristics of both (existing and new) chillers

Chillers comparison	**Air Cooled Chiller**	**Water Cooled Chiller**	
Refrigerant	R407c	R134a	
Number of cycles	2	2	
Compressor type	Cylinders compressors	Screw compressors	
Evaporator water temperatures	12/7°C	12/7°C	
Condenser water temperatures		27/32°C	45/50°C
Cooling Capacity	380 kW	376 kW	
Heating Capacity			421 kW
Compressor consumption	117 kW	74 kW	106 kW
COP heating		6.08	3.97
COP cooling		5.08	

Feasibility of the first retrofit opportunity

The terminal units are presently supplied with hot water at 65-70°C by the boilers. With the heat pump system, the temperature will be limited to a maximum of 45-50°C.
Hopefully this should not make any problem in the present case: a simple comparison between building and fan coils AU values demonstrates that it will be possible to cover all the office

heating demand with without over-passing 35/45 °C and without any contribution of the boilers.

The different opportunities listed here-above were analyzed more in the details with the help of a new building & HVAC system simulation tool. The two main zones (offices and laboratories) were separately simulated.

SIMULATION MODEL

Brief description of the model

The simulation tool was developed in the frame of the european “AuditAC” project.
It’s based on a very simplified (second order) building model (Figure 9).

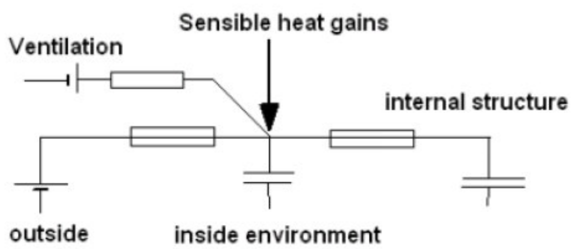

Figure 9: Building R-C model

This building model is coupled with a complete HVAC model, composed of several components :

- In the zone: heating and cooling terminal units, characterized by supposed-to-be constant heat transfer coefficients (AU);
- At the level of the air handling unit (AHU): heat recovery loop, return fan, economizer, filter, pre-heating coil, adiabatic humidifier, cooling coil, post-heating coil, mains fan and steam humidifier (Figure 10)
- At plant level: boiler, chiller and water pumps.

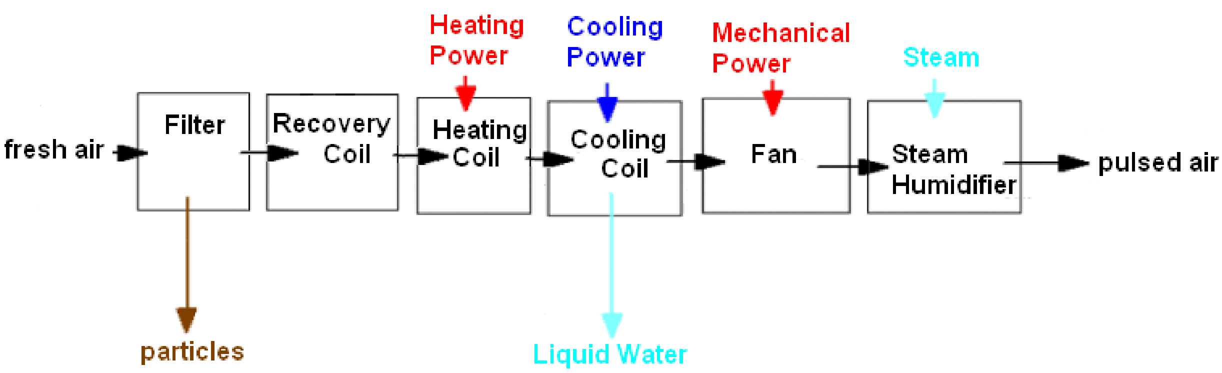

Figure 10: AHU model scheme selected for the present sutdy

Model Inputs

The main inputs required concern:

1) The weather
2) The occupancy and functioning rates
3) The requirements
4) The control laws

Proportional control is used almost at each level: a standard law is applied with the help of a non dimensional control variable X, varying between 0 and 1 in proportion to the difference observed between the set point and the controlled variable.
In the case of AHU's cooling coil, the control variable directly commands the "contact temperature".

Model Parameters

A few parameters have to be selected in order to fit the Building-HVAC system simulation model with the real system considered.
These parameters are identified with the help of as-built files and of manufacturer's data.

Model Outputs

The main outputs are:

1) Air quality and thermal comfort:
- Air renewal;
- Air temperature;
- Air humidity.

2) Power and energy consumptions.
- Hourly fuel and electricity consumptions, all along the simulation periods (1 to 8760 h);
- Integration and also splitting of the consumptions into separated components (terminal units, air handling units, fans, pumps, boilers, chillers, lighting, appliances).

SIMULATION RESULTS FOR ZONE I (OFFICES)

Functioning

- The zone is supposed to be heated by a water/water heat pump with extracted air as cold source.
- All heating and cooling coils are used as mutual "boosters" (by "change over" process) whenever required.
- The Heat Pump is simulated in two heating regimes (27/32 °C or 45/50°C) and one "cooling" regime (12/7°C).

This gives a COP varying between 4 and 6 in heating mode and around 5 in cooling mode.

Consumptions and costs

In the present situation and *before any retrofit*, the following gas consumption is found by simulation on a reference year:
Energy: 240 106 kWh
Volume: 20 878 Nm3
Cost: 8 356 €

The corresponding electricity consumption is:
Peak: 84 671 kWh
Off-peak: 3 136 kWh
Total: 87 807 kWh
Total cost: 10 000 €

After retrofit, there should not remain any gas consumption and the electricity consumption would become:
Peak: 119 450 kWh
Off-peak: 10 089 kWh
Total: 129 539 kWh
Total cost: 14 500 €

SIMULATION RESULTS FOR ZONE III (LABORATORIES)

Functioning

- This zone also is supposed to be heated in by the water/water heat pump, with extracted air as cold source.
- AHU heating *and* cooling coils are also supposed to be used simultaneously in heating mode when required.

The heat pump performances stay the same as for zone I.
Appliances and lightning are supposed to be switched on all the time.

Consumption and costs

Before retrofit, the following consumptions are found by simulation:

Gas:
Energy: 486 441 kWh
Volume: 42 299 Nm3
Cost: 16 928 €

Electricity:
Peak: 532 186 kWh
Off-peak: 518 960 kWh
Total: 1 051 147 kWh
Total cost: 10 000 €

Detailed simulation results indicate also that the chiller electricity consumption (19 MWh) is almost negligeable here, in comparison of other terms as steam humidification (373 MWh) , Lighting and appliances (350 MWh), fans and pumps (309 MWh).
It can also be shown that the existing ventilation heat recovery system is actually recovering a small part (488 MWh) of the heat actually available in exhaust air (2 902 MWh).
In short, this means that the use of the existing chiller in cooling mode has here a negligible impact on the energy budget and also that the use of this machine in heating mode would allow to recover a very large amount of heat…
Indeed, *after retrofit*, there would remain no gas consumption and the increase of electricity consumption would be marginal:

Peak: 553 564 kWh
Off-peak: 553 892 kWh
Total: 1 107 456 kWh
Total cost: 102 454 €

COMPARISONS WITH ACTUAL CONSUMPTIONS

Simulation results obtained before retrofit are summarized in Tables 4 and 5. A rough comparison can be done with actual consumptions of the whole building observed in the year 2005.
The comparison has still a limited value because:

- Only two zones are included in the simulation;
- The simulation is performed with Brussels reference weather data which doesn't correspond exactly to the actual weather of 2005 in Liège;
- An optimistic global efficiency of 90% is still considered for hot water production.

Nevertheless, this very first comparison indicates that:

- The global electricity consumption is probably well predicted in the simulation;
- The gas consumption is still strongly underestimated.

Table 4: Simulated and measured gas consumptions

Simulated Gas Consumption	kWh	€ (0,0348 €/kWh)
Offices	240106	8356
Laboratories	486441	16928
Total	726547	25284
Measured in 2005	1418478	

Table 5: Simulated and measured electricity consumptions

Simulated Electricity Consumption	kWh	€ (0,0928 €/kWh)
Offices	87807	9995
Laboratories	1051147	97555
Laboratories Humidification	373444	34656
Total	1512398	142206
Measured in 2005	1503676	

GLOBAL SAVINGS

After retrofit, the gas consumption is supposed to be cancelled; the electricity consumptions of the two zones considered is then given in Table 6.

Table 6: Electricity consumptions after retrofit

Electricity Consumption	kWh	€
Offices	129539	14495
Laboratories	1107456	102454
Laboratories Hum.	373444	34656
Total	1610439	151605

Actual Situation	1512398	142206

The comparison among tables 4, 5 and 6 gives the following savings:

- 0.48 GWh/year of primary energy, i.e. 10.6 % of the present consumption (4.51 GWh), if considering an average efficiency of 40 % of electricity production;
- 113 936 kg/year of CO2, i.e. 18 % of the present consumption (629 276 kg/year), if considering 0.2 kg/kWh for the gas and 0.32 kg/kWh for electricity;
- 15 885 €/year of energy costs.

CONCLUSIONS

- Using a chiller in heat pump mode appears as very valuable retrofit
- This is even more efficient if combined with a change-over process
- But all other ways energy savings have still to be tracked
- In the case considered, it would be urgent to replace electrical humidification by a more rational process.

Acknowledgements

This work is financially supported by the Wallonia Region of Belgium.