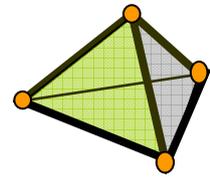




TETRAENER



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OPTIMAL BALANCING OF DEMAND AND SUPPLY THROUGH RES IN URBAN AREAS

REF. EC: TREN/05/FP6EN7S07.48739/513489

INTEGRATED PROJECT

FP6 Priority 6.1 -- "SUSTAINABLE ENERGY SYSTEMS"

Deliverable	GE WP 1.3 Del 2	<i>HCR Building: Measuring cooling installations and Auditing for Deep Lake Direct Cooling Network connectivity</i>
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Due date of deliverable: ... M24

Actual submission date: .. 14/01/08

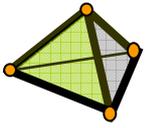
Start date of project: 30/11/05

Duration: 5 years

Organisation name of lead contractor for this deliverable: 5 - UNIGE

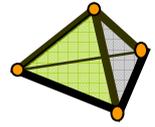
Revision: 0 (Draft)

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
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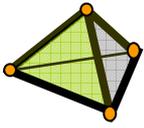
Acknowledgements

We thank Mr. Laurent Mathieu, technical manager of the FIPOI (Building Foundation for International Organisations), and M. Czapka, manager of the HCR building technical installations, for their valuable collaboration and the running data which they prepared and provided for this building analysis and auditing method elaboration. We are also grateful to Mr. Conus, chief of the Buildings division, for valuable discussion and his authorization for publishing these data.

We are especially grateful to the SIG (Service Industriels de Genève), manager of the GLN network, for the useful contacts and technical information about their first project management activities.

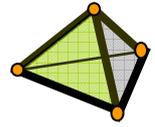
We thank Claude Villemin of EIG, for his contribution mentioned in Annex E.

Finally, we thank the French team of the Auditac European project, and especially Prof. Jérôme Adnot of the Ecole des Mines in Paris, for their fruitful collaboration on the problematic of air-conditioning auditing.



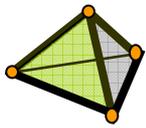
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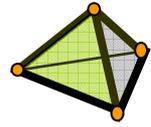


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1 Introduction

1.1 Framework of this study: the GLN project

In the framework of the **TETRAENER** European project, the "**Genève Lac Nation**" project aims to use the cold water of the Lake of Geneva for meeting the refrigerating needs of the administrative buildings (mainly international organizations) in a suburb district of the Geneva city. Cold lake water will be pumped at a depth of around 35m, and distributed through a district cooling loop without intermediate further cooling. The temperature stays at around 7-9 °C all along the year. Around 30 buildings of big or medium size will be concerned, covering an area of more than 1 km².

Geneva's Government has ruled in favour of "Genève Lac-Nations" by a decision of the State Council (Executive) in early 2003. The Parliament has also initiated various studies and building loans (by adopting *ad hoc* laws). The main partners are:

- The State (Canton) of Geneva,
- The City of Geneva
- The Building Foundation for International Organisations - FIPOI
- Services industriels de Genève – SIG (fluid distributors)

The latter (SIG), is the main utility in Geneva for Electricity, Gaz and Water distribution (including also District Heating networks). It is the executive organism which will construct and exploit the district cooling installations. As a semi-private company, it has to manage the installations and develop a commercial marketing in order to sell the GLN concept to the different potential customers, in a way that it can degage some profits.

The GLN network will be able to distribute a global power of 17 MW of renewable cooling energy (3'500 m³/h). It is expected to save around 1'500 tons/year of ultra-light oil (~ 20% of the heating capacity) and 4'800 tons of CO₂. As this network can also serve as a cold source for heat pumps in winter, in medium term the electricity savings in summer are expected to be compensated by the Heat pumps consumptions.

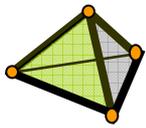
1.2 Specificities of the GLN network

There are several kinds of cooling energy distribution networks, using renewable cooling energy from a deep lake or sea.

The great majority are dedicated systems to a unique user (Cornell University, EPFL, etc). Only a few are public commercial installations addressing existing buildings, as for example in Toronto [*Toronto1995*].

On the other hand, most of these plants are closed-loop circuits, which include a big central cooling unit, ensuring a constant temperature fluid distribution. This is even the case for the Toronto project, connected through a heat exchanger to a deep lake feeding for drinking water (pumped at 83m depth in the Lake of Ontario, and never exceeding 4°C).

A remarkable feature of this GLN project is that it will not refresh the available deep water, so we will name it a **Deep Lake Water Direct Cooling (DLWDC)** network. Therefore the delivered temperature is given by the Lake behaviour, and cannot be controlled nor guaranteed. It is known that under some special meteorological conditions (during 1-2 days, 2-3 times a year) the



temperature may raise up to 14 or even 16°C, so that conventional cooling means have to be maintained. Fortunately these events seem to occur only after bad weather series.

Another consequence is that the usability of the available thermal power is strongly dependent on the effective operating temperature of the building cooling installations, which is traditionally below the distributed water level (most often 6-12°C in the primary distribution loop). This is the key point which motivates this specific auditing method for the buildings to be connected.

Finally, this network will operate in **open-loop** mode. This means that the water used in a building will not be reused by another one. This reduces the constraints on the return temperature into the network. In particular this allows a given user for using the water twice: first for the direct cooling; and secondly, when necessary, the water at the output of the main exchanger may be used for eliminating the waste heat of the condensers for eventual complementing cold machines. This has two big advantages: it avoids the cooling towers on the roof (with their maintenance and health safety problems), and this source - still less than 20°C - ensures a very high COP of the cooling machines.

The return temperature has no importance nor commercial value for the network manager: Only the global network rejection into the upper layers of the lake will be subject to legal temperature maximum level, which will probably never be reached.

From a hydraulic point of view, the open loop running necessitates a higher pumping energy. The water should be pushed up to the highest point of the installation, which is more than 60 m over the lake level. Nevertheless a turbine - coupled directly on the axis of the primary pump - will recover the potential energy at the rejection to the lake. In this way the global pumping energy is reduced to values near to the energy needs for a closed loop operation.

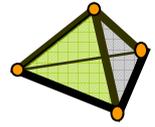
1.3 Objectives

In the Tetraener project, it was planned to perform a detailed study of two existing buildings involved in the GLN project, with the objective of identifying and understanding the problems and constraints involved by the connection of a given building to a Deep Lake Water Direct Cooling network, in order to establish the bases for an auditing method, oriented to this specific problem.

Before construction, the network manager needs to acquire a good knowledge of the potential energy to be distributed, which requires a specific analysis of the buildings (existing or to be built) in the concerned area. This is necessary on the one hand for determining the location and size of the pipes to be installed, and on the other hand for establishing the energy prices - according to investments - in order to attain the profitability. This price will be function of the volume of contracts, while the contracts are themselves dependent on the competitiveness of the energy price (which has to be fixed "a priori" through long-term contracts).

The auditing method proposed, using the detailed measurements and analysis of this building as a conducting wire, is fully described in the document "**Guidelines for auditing the existing buildings to be connected to a Deep Lake Water Direct Cooling Network**" [Mermoud 2008] , issued with this study in January 2008.

Due to the complexity of the objects and the variety of the situations, such a method cannot be a rigid step-by-step procedure. It leaves quite a lot of initiative to the expert who will conduct the study. Nevertheless it offers powerful tools (such as Excel workbooks) either for analysing data recorded on the cooling installations, and for establishing criteria aiming to improve or optimize the cooling installations in the optics of the connection to the DLWDC network.



This method is aiming to a "medium size" (say, 2-3 working-weeks) evaluation of building cooling needs and air conditioning installations, and especially to the study of the "connectivity" of the buildings to the network. In particular, this should evaluate the ability of the air-conditioning installations to increase the chilled loop operating temperature at as high values as possible, which is a very important challenge for optimizing the energy transfer from the DLWDC network.

Such an audit would rely to both partners. It should:

- help the DLWDC network manager to obtain the pertinent necessary information for sizing its network, and propose attractive contracts,
- lead the building owners to be aware of their actual cooling service price, and of possible improvements in the building concept or air-conditioning installations.

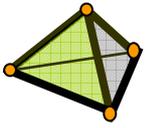
1.4 Methodology

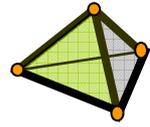
For the first step, this building of medium size (HCR - United Nations High Commissioner For Refugees), constructed in 1994-95 was chosen. Due to a good working relationship with the technical manager, a lot of information was collected, including:

- A detailed description of the building (drawings, surfaces and their use, technical installations).
- Monthly energetic consumptions over 10 years (1996-2006), with specific recordings of the electricity needs for Cooling, Ventilation, Heating, Kitchens and Lighting+Plugs.
- Detailed hourly measurements during summer 2006:
 - ✓ Temperatures, heat flows and electricity consumptions for the production/distribution of cooling installations, recorded by the centralised control system.
 - ✓ Ambient temperatures/moisture in some offices or air distribution/return pipes (15 points recorded with little autonomous data-loggers).
 - ✓ Meteorological data (irradiance, temperature) in a nearby representative site.
- Complementary measurements during September, with an artificial increase of the distribution temperature to 10°C instead of 6°C, in order to analyse the reactions of the building.

Using this rather complete information, we tried to identify the most pertinent one necessary for establishing this audit. The method indicates some means for getting the relevant information, and treating it in an optimal way.

While this auditing method has been established on the basis of the present study of the HCR building, it has also been applied to another very big object, the buildings of the United Nations (UN) site in order to assess its usability. This gave rise to another report, "**UN Building: Measuring cooling installations and Auditing for DLWDC connectivity**" [Mermoud 2008], also available in January 2008.





2 Description of the Building and Technical Installations

2.1 Building description

This HCR building was commissioned in 1995.

Architects: C. Steffen, A. Gallay, J. Berger, U. Tschumi, M. Heurteux

The building hosting the Offices of the United Nations High Commissioner for Refugees (HCR) is situated about five hundred meters south from the building from the United Nation Organisation (UN), at the intersection of two main streets, avenue de France and rue de Montbrillant.

It has a nearly triangular shape with two wings oriented north-east and west. The eight stories of the building are mainly devoted to offices, with a restaurant at the ground floor. There are 3 underneath levels, including namely 4 conference rooms, archives, technical premises and parking's. The main entrance is going through an impressive glazed atrium oriented north-west at the intersection of the two streets, which consists of an open space over the 8 stories.

Made out of steel and concrete, this massive building has façades made out of coloured concrete bricks with numerous small windows giving light to all the offices. The central part of the building is illuminated through a glazed roof or through a translucent facade connected to the atrium.

Internal spaces are luminous and open with the main part of these offices organised as open spaces. Some individual (closed) offices are situated on the top level and in the front part of the two wings.

2.2 Main basic indicators

The area of one office storey is 2'245 m². Conference rooms are rather small, 376 m² altogether. According to the Swiss norm 380/1 (2001) the full heated and cooled parts totalize **17'781 m²**.

The atrium part is an intermediate space, not heated nor cooled. But it includes the reception and security desks. Its area is around 740 m², but according to the swiss norm 380/1 (2001) the equivalent area should take the height into account, so that its contribution to the "Reference Energetic Area" (SRE in French) is 3'372 m². Therefore the total **SRE** for the main indicators will be **21'153 m²**. But as the atrium is not really cooled, we will also refer the cooling values to the **17'781 m²** above, which we will name a "Reference cooling area" (**SRC**).

Here are some indicators for benchmarking with other buildings (averages 2000-2006):

Global Energetic consumption	3'227 MWh	153 kWh/m ² SRE
Global Electricity consumption	2'698 MWh	127 kWh/m ² SRE
Global Electricity, lightings and plugs (contribution to internal cooling load)	1'615 MWh	76 kWh/m ² SRE 8.7 W /m ² SRE
Electricity for cooling (including pumps)	536 MWhe	30.2 kWh/m² SRC
Cooling energy	800 MWth	45 kWh/m² SRC
Cooling installed power: production	520 kW	29 W /m ² SRC
consumers (appliances)	1140 kW	64 W /m ² SRC

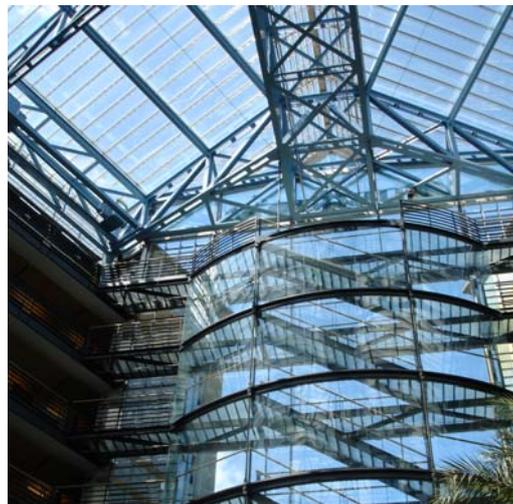
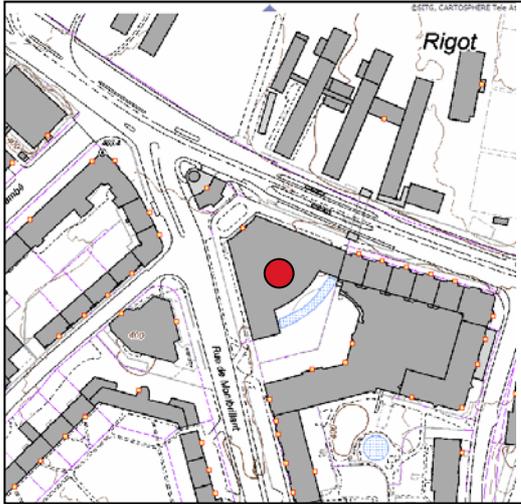
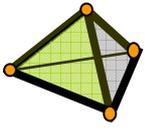
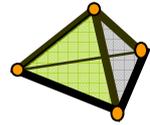


Figure 2.1. – Some views of the HCR building



2.3 Application of the pre-auditing tool to the envelope

We try to apply the pre-auditing tool proposed in the "**Guidelines for auditing the existing buildings to be connected to a DLWDC network**" [Mermoud, 2008]. This especially concerns the two wings of the building, hosting the offices.

Climate

In Geneva the climate is cold in winter and can be rather hot in summer (up to 32°C in country regions, and 35°C in urban environment).

Heating degree day for reference year	3072 DD base 12/20 °C
Cooling load for summer	95 DD base 22 °C
Days with temperature over 30 °C	12 in 2004
	45 in 2003

In summer, the temperature swing between night and day is often over 12 °C

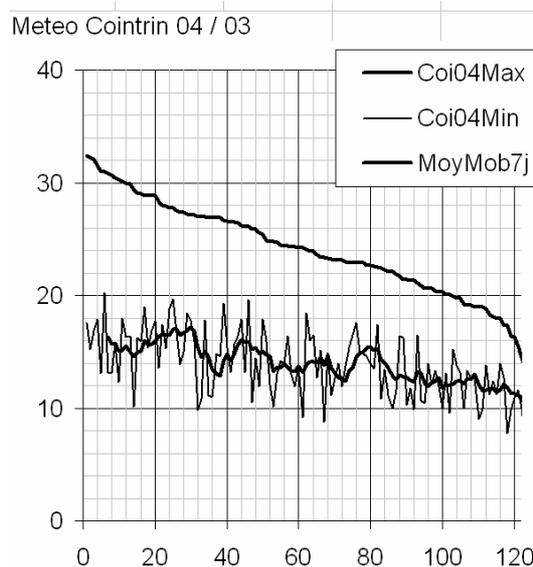


Figure 2.2. - Classified temperatures for the 120 hottest hours, and differences between night and day (average year at Cointrin).

Situation

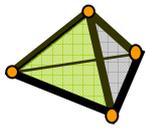
Surrounded by streets but not far from gardens and parks, the HCR building is located at the border of the town. We can qualify this location as suburban.

Internal gains (electricity consumption)

With 210 Wh/m²·day average power for lighting and appliances measured from 2000 to 2006, the building is in the medium range class of evaluation. An effort to lower the electricity demand in this sector should be possible.

Temperature expectation

As claimed by the technical personal, the HCR building is not "air-conditioned", but only "refreshed". It accepts large temperature swings, depending on the outdoor temperature. Our measurements showed that for hot days, with outside temperatures over 30°C, the ambient temperatures in the offices (expected to be 26°C) are in reality between 28 and 29 °C. We can



observe on the figures C.7 and C.8 of Annex C, that for the hottest days of 2006 the temperature in some offices raised over 30°C for external temperatures reaching 36°C. But we can wonder if the corresponding cooling inductors were properly working.

Clothing

During summer, light trousers and T-shirt are accepted, except in formal meetings that are usually organised in one of the cooled conference rooms.

Windows to wall

The window to wall ratio for the two main wings hosting the offices is slightly over 30%



Ratio wall to façade = 36%

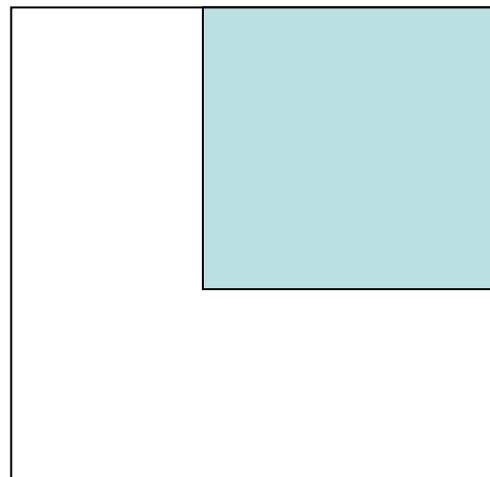


Figure 2.3. - Façade view of office wings

Solar protection

This building has external solar protection that allow to lower solar energy transmission under 15%.

Mass

HCR is a massive building. At least the concrete floor is connected to the office space (different situations in the building). This building may be classed between high and medium massive building.

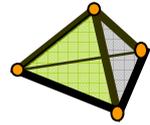
Regulation of solar protections

Regulation is automatic with opportunity for the individuals to adapt the sun screen as needed

Atrium and central part of the building

Temperature measurements in the glazed atrium (entrance) show an important stratification, around 5°C between the base and the top. It would be desirable to separate the corridor of the 6th and 7th floor from the atrium.

The glazed roof over the central part of the building enlightens the offices, which should be equipped with better solar protections.



Conclusion

This evaluation shows that the two wings mainly occupied by the offices are suitable for connection with the DLWDC network after a few minor changes, i.e.:

- Decrease the energy consumption for lighting and appliances
- Enhance contact of office space with mass of the building
- Envisage a better separation between the Atrium and the offices of the highest stages.

Finally, the figure 2.4 shows a flow chart which helps summarizing and assessing the potential of the HCR building to be connected to the DLWDC network.

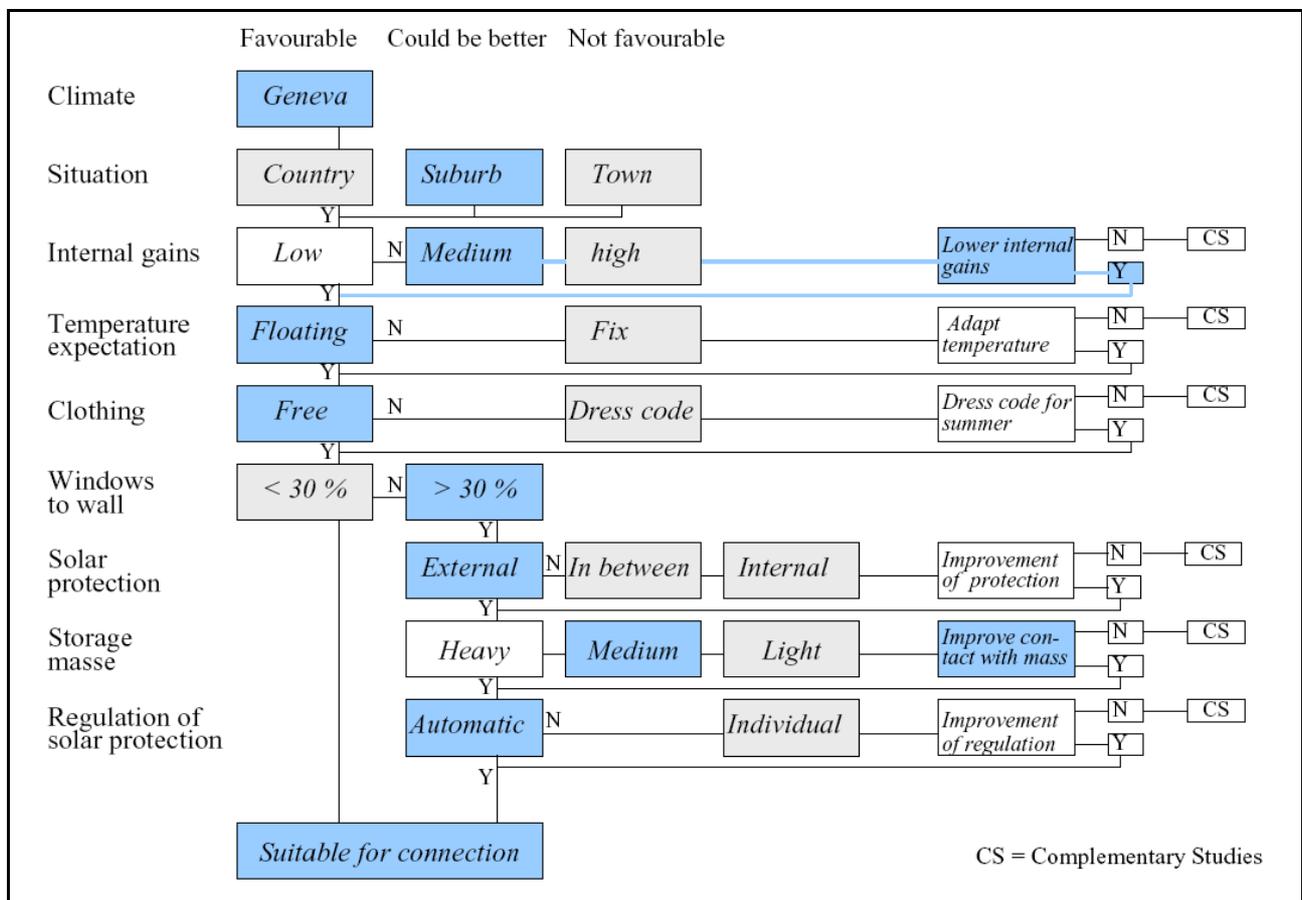
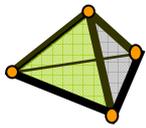


Figure 2.4. - Evaluation flow chart for the pre-auditing method on the envelope

An evaluation of the cooling possible options for a single office, according to the technical document [Cahier technique SIA 2021 (Zürich, 2001)], is given in Annex E.



2.4 Technical installations for cooling and air conditioning

Please refer to the Description Table in Annex A which gathers the main properties of the cooling installations. A template of this table is available in the "*Tetraener_Audit_MeasTool.xls*" tool.

2.4.1 Production and Distribution loops

The centralized cooling installation is splitted into two parts:

- The "**Building loop**", ensures the main new air cooling needs through centralized Air Handling Units (AHU). It is fed by a cooling machine of 140 kWe (380 kW cold), doubled by an ice storage of around 3'000 kWh capacity (5 ice tanks of 7 m³ each). This circuit operates at 6/12°C nominal, but the Ice Storage needs -6°C during night refilling.
- The so-called "**Information loop**" is a secondary installation, which mainly feeds the "inductors" in the offices. These are secondary cooling devices located on the new air input below the window in each office, and individually adjustable by the occupant. This loop also feeds the cold ceilings in the interior spaces, and several technical rooms. This secondary loop is fed either by an exchanger on the main "building" installation, and/or by a secondary cooling machine of 40 kWe (140 kW cold nominal, but never achieved).

A remarkable feature of this "Information" loop is that it operates at 12/16°C nominal, which makes this circuit immediately compatible with the GLN connection.

An heat exchanger of 550 kW nominal is used for transferring cooling energy from the main "Building" circuit to the "Information" circuit. One of the reasons for implementing this exchanger was that the "Building" loop, with the ice storage, is filled with an antifreeze mixture, when the secondary loop uses water.

The heat of the condensers of both cooling machines is normally evacuated through cooling towers on the roof (500 and 180 kW, at 40/46°C nominal). The heat of the main machine may also be recovered by an exchanger on the heat production for space heating and hot water. However in summer the hot water needs are far from absorbing the whole available energy.

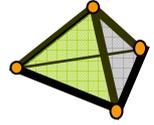
2.4.2 Consumer, secondary appliances and control

The "Building" loop consumers are essentially centralized air handling units (AHU), the biggest ones for offices, and little ones for conference rooms, restaurant and kitchen. These appliances behave rather well like exchangers, that is they may be fed by higher input temperatures when delivering partial load.

The cooling energy absorbed by each of these consumers is controlled by a two-way vane, which adjusts their individual flow rate at the suited value for just obtaining the required distributed air temperature. In the present state, the air distribution temperature for offices is set to 16°C.

The general chilled loop flow rate is controlled by a differential pressure sensor (ΔP), which drives the pump speed. This strategy ensures a flow rate proportional to the instant power, which is an optimum for the pump consumption. This results in a constant temperature difference between return and distribution temperatures (see fig 3.18).

The consumers on the "Information" loop behave in a different way. Their flow rates are controlled by individual additional pumps. All little consumers for technical rooms are grouped on the same pump, and therefore globally controlled.



The major part of the cooling needs is for offices. As previously mentioned, this is ensured either by the fresh air distribution, and by individual exchangers ("inductors") in each office.

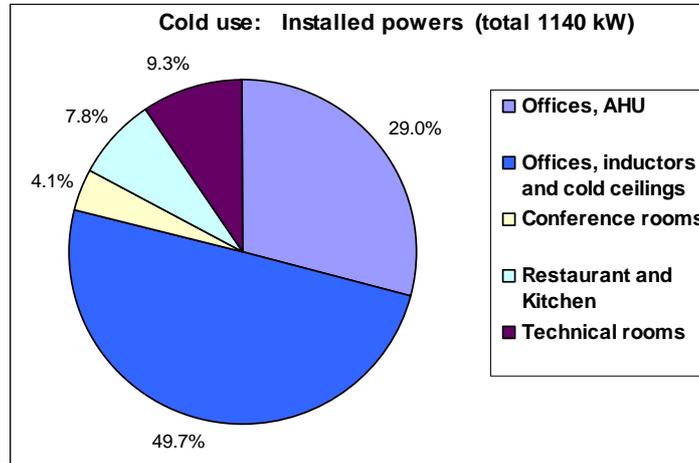
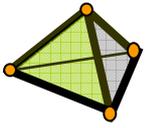


Figure 2.1. - Use of Cooling energy: installed powers

The installed power of consumers totalises 1'140 kW. This is far over the production cooling machines (380 + 140 = 520 kW capacity). In very hot conditions, when the whole nominal power is required, the ice storage (3'000 kWh) is able to compensate the deficit of 590 kW, during at least 5 hours.



3 Analysis of the building cooling service operation

3.1 Available measurements

The HCR cooling installations are exceptionally well instrumented. Unlike many other similar installations, they include several counters, either for the electrical consumption of each cooling machine, or heat counters in the cooling and condenser circuits. Even the pump's electricity consumption is available on a separate counter.

And even more remarkable circumstance, these counters have been carefully read by the technical services of the FIPOI, so that we avail of 11 years of reliable monthly data (since commissioning in 1995) !

The list of all sensors is detailed in annex B, and most of them are shown on fig 3.1.

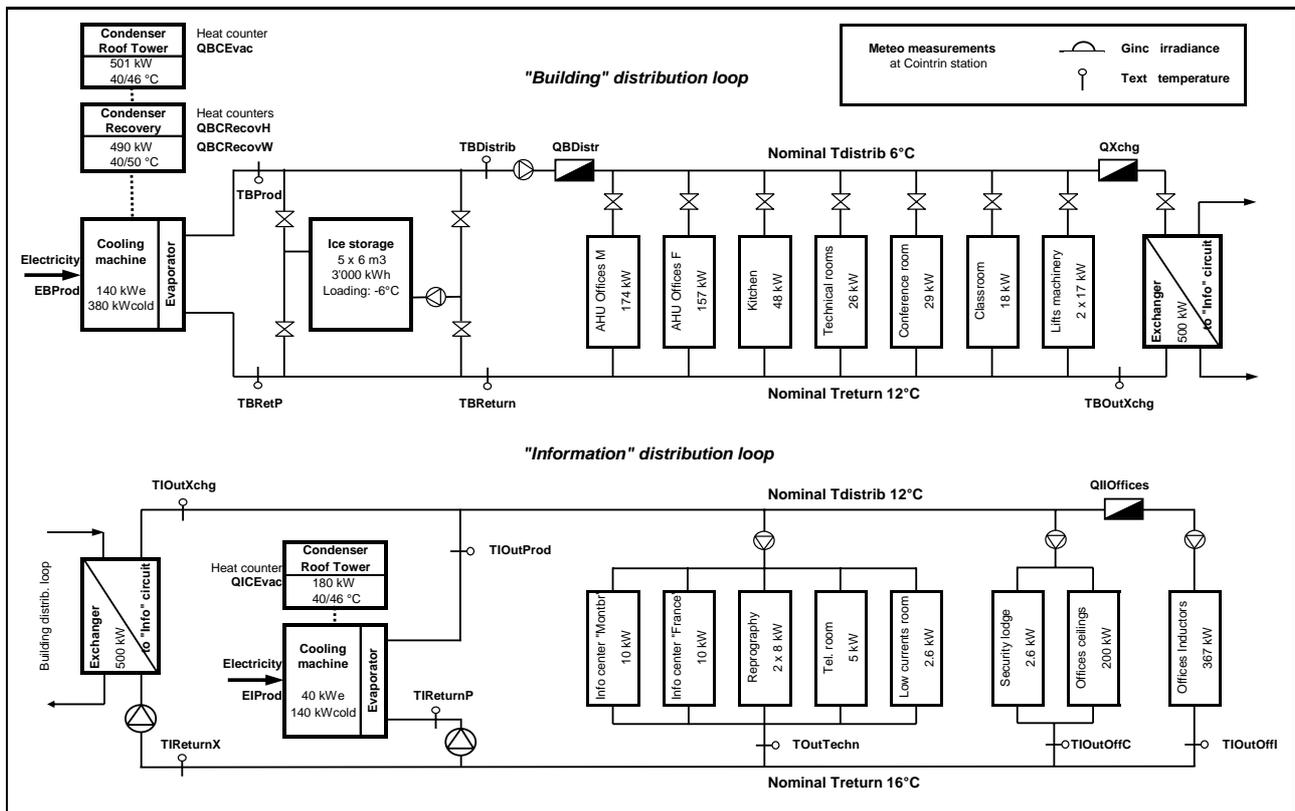
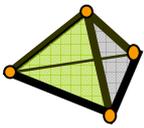


Figure 3.1. - Simplified hydraulic layout and measurement points



3.2 Global energetic flows in cooling installations

But unfortunately, some heat counters are missing for getting a quite coherent energy balance.

In the main "Building" loop, counters allow the evaluation of the distributed energy, as well as of the transferred energy to the secondary loop. But they don't give a complete view of the cooling machine running, nor the energy storage charging or balance. The COP can be calculated from the electricity consumption and the rejected heat. And the produced energy **QBProd** results from a balance between the condenser measurements and the electricity.

On the other hand, in hourly data the values of the recovery condenser are not well recorded, so that this balance is only possible under specific running conditions, i.e. when the recovery is not active.

Moreover the secondary "Information" loop gives more interpretation difficulties: while the energy from the primary circuit **QXchg** is in principle known from the measurements, the auxiliary cooling machine production **QIProd** is only calculated from the energy balance between the Condenser heat and the Electricity input. And only the cold energy distributed to the Office Inductors is individually measured, so that the consumption of the rest of the users (including the very important "Information centres") is calculated after many balances and therefore very badly known.

The figure 3.2 gives a detailed view of the energetic diagram. It shows a summary of the available measurements, mix of available information and necessary hypothesis.

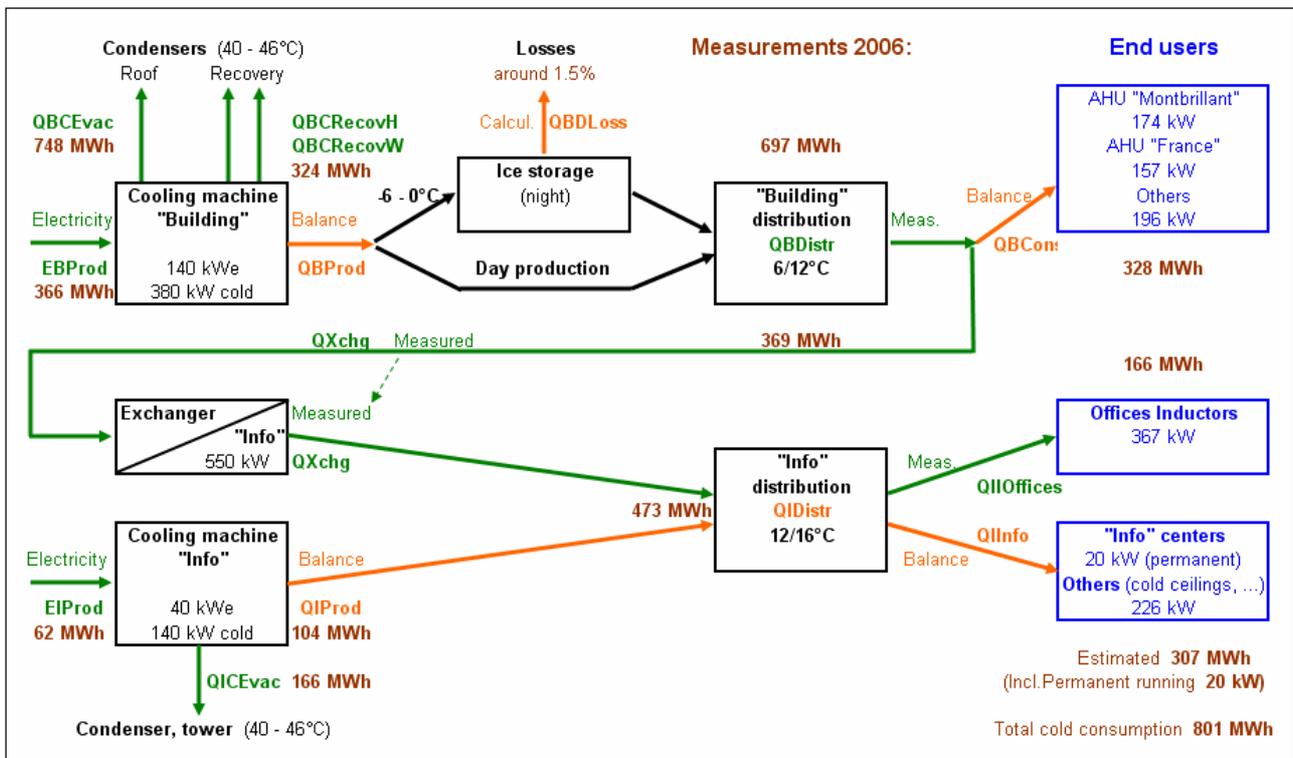
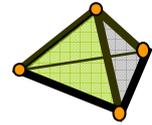


Figure 3.2. - Energetic diagram

- In green: effective available measurements from counters
- In orange: balances from other values
- In maroon: measured energies over one year, given as an example



3.3 Global and cooling energy consumption

It is interesting to have a feeling of the cooling energy by respect to the global energy consumed by the building. The electricity is largely dominant, with a ratio of 83% on an average. For thermal needs, gas and fuel share around 17% of the global energy in different ratios from year to year, probably according to tariffs.

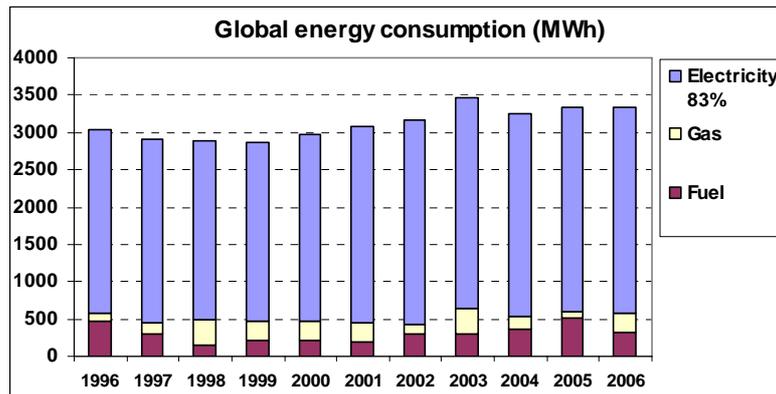


Figure 3.3. - Global energy consumption over 11 years

Referred to the Reference Energetic Area of 21'153 m², this corresponds to average Energetic indices of **153 kWh/m²**, or **551 MJ/m²**.

The energy consumptions are rather stable. The greater difference between 2003 - the exceptionally hot year - and 1999 reaches about 20%.

The next figure indicates the different uses of electricity. It can be noticed that the structural increase of the electricity demand is mainly due to the "Lighting+Plugs", i.e. the general appliances, including probably a large contribution of the information technologies.

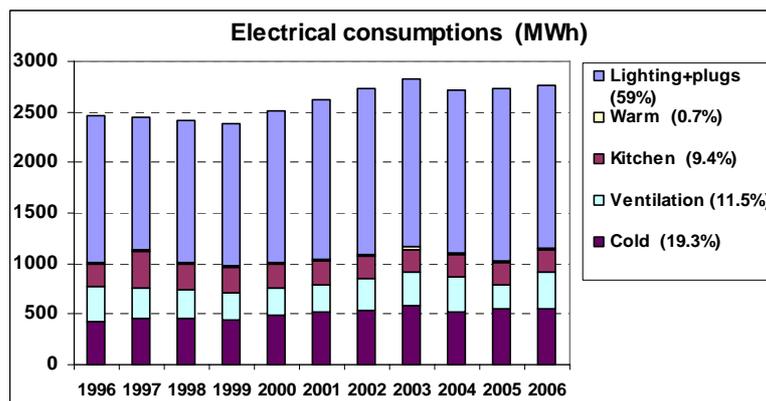
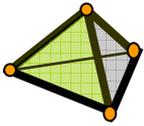


Figure 3.4. - Electricity consumption acc. to uses over 11 years

The cooling service represents 19.3% of the whole electricity consumption on an average.

It contributes for **25.3 kWh/m² SRE** (91 MJ/m²). But when referred to the cooled areas only (SRC, 17'781 m²), this amounts to **30.2 kWh/m² SRC** (109 MJ/m²).



Finally we can zoom on the specific electricity for the cooling installations.

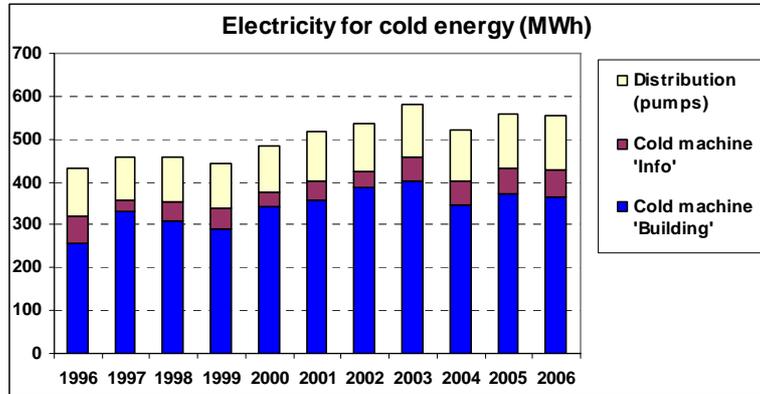


Figure 3.5. - Electricity for cooling installations

On an average, the secondary "info" machine absorbs about 10% of the total, when the pump's contribution is 22.5%.

The "pumps" contribution includes all circulating pumps in both chilled circuits, and also the fans for the cooling towers. One can notice that the pump's consumption is equivalent to a continuous running at 5.4 kW (to be compared to 57 kW for the global cooling energy needs).

3.4 Monthly evolution

Let us now analyse the monthly evolution. First we have to mention that the reading of all counters is performed by hand, during working days. Therefore there may be uncertainties or discrepancies from one month to the other, due to some possible irregularities in the reading intervals. The date of each reading is unfortunately not mentioned in the available data. But of course the annual sums remain quite correct.

3.4.1 Electricity consumption

The figure 3.6 shows the global electricity consumption, which amounts to 2'760 GWh in 2006.

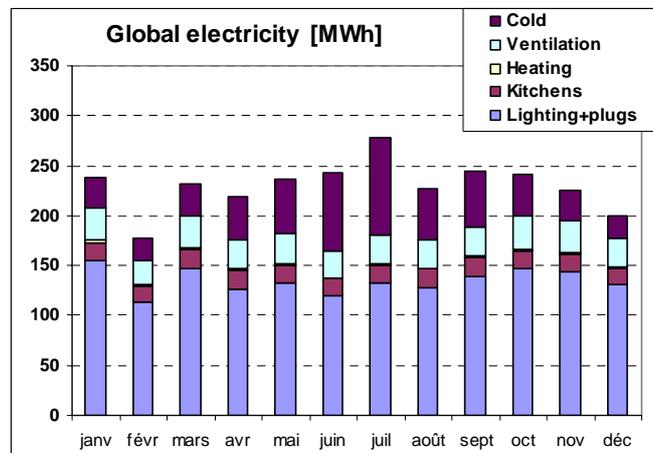
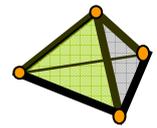


Figure 3.6. - Electricity uses, monthly evolution



We can observe that the lightings+plugs, i.e. all the lights and appliances (including information technologies like computers, printers, photocopiers, etc) are of the order of 130 MWh/month, not very different in summer and winter. This should be representative of the internal loads besides the occupants themselves. If these contribute to the heating in winter, they require of course cooling energy compensation in summer.

Let us now focus on the electricity for the cooling installations, which is 20% of the total in 2006.

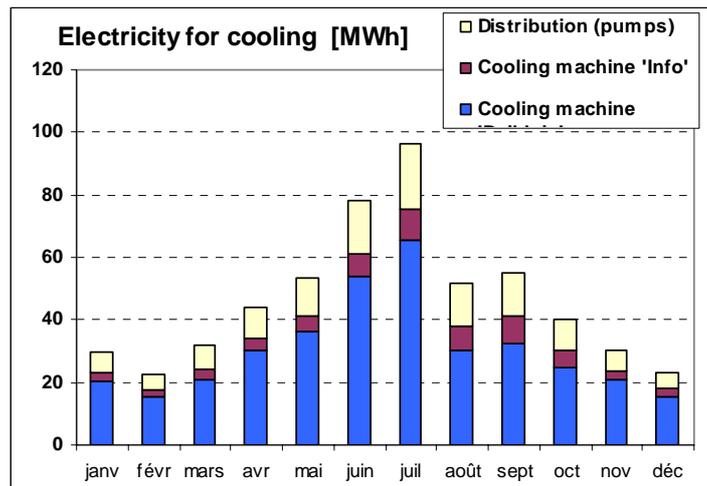


Figure 3.7. - Electricity for the cooling installations

The cooling energy is mainly ensured by the main cooling machine. And we can notice that the cooling needs are still very important during the winter months.

We observe that even in winter the cooling installations are running in a significant way, and absorb an important amount of electricity. This can also be seen on the global electricity consumption of the cooling machines (figure 3.8). A residual monthly consumption of 20 MWh corresponds to a permanent power of 28 kWe.

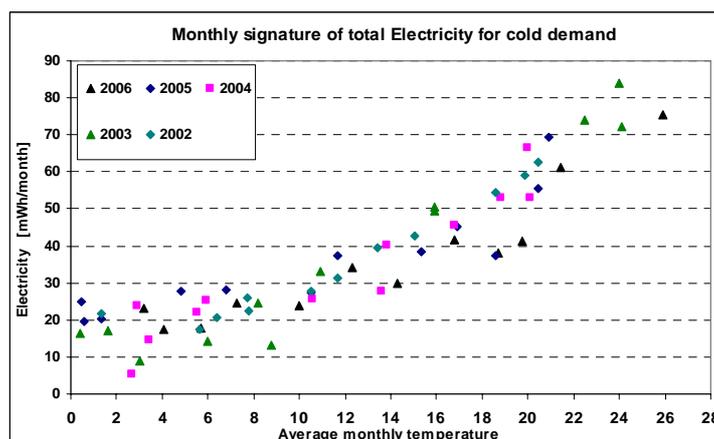
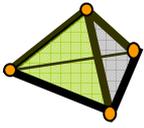


Figure 3.8. - Electricity for the cooling installations

But remember that the condenser heat is recovered for the DHW and heating needs, so that we may consider that the main cooling machine act as a heat pump.



3.4.2 Cooling energy consumptions

If we have a look at the consumptions (fig 3.9), we observe a normal seasonal behaviour for the "building" loop and the inductors in the offices depending on the "Info" subsystem. The "building" loop feeds essentially centralized air handling units (AHU), which pulse refreshed air in summer and heated air in winter. As the HCR installations are modern and well controlled, these appliances don't of course inject warm and cold energy at the same time in the treated air! But if the reference output air temperature requirement is too strict, these may use alternatively cool and warm energy during the same day, which could explain the not negligible consumptions during inter-seasons.

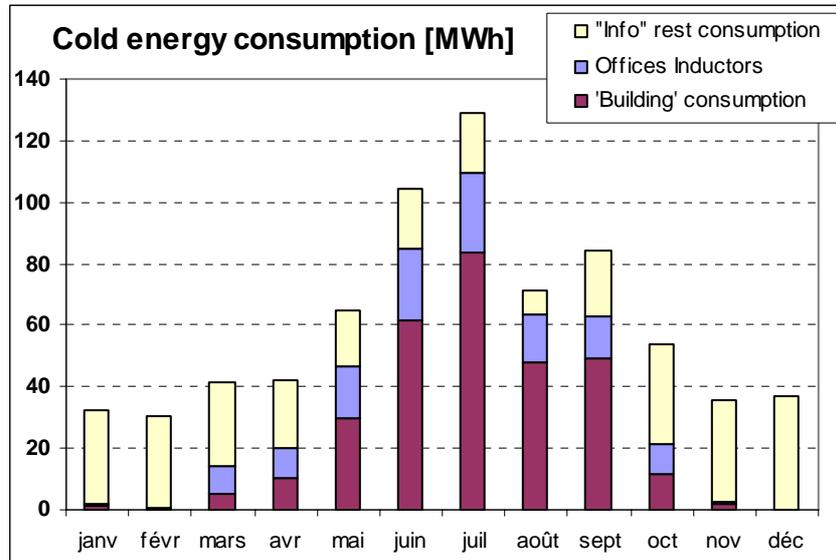
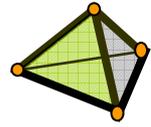


Fig 3.9. - Cold energy consumption

But the "rest" consumption of the "Info" circuit seems to be quite constant over the year. This concerns 2 Information technology rooms, located in the first underground, which totalize 20 kW of nominal installed cooling power. If running at full power, this represents 14.4 MWh/month, which explains less than half of the observed value.

Feeding the cold ceilings in the central part of the building at all office stages is the second contribution. These spaces are refreshed even in winter, because they content many appliances for reprography, representing high internal load, and don't have interfaces with external conditions. Nevertheless we can wonder if a reinforced action on the air treatment would not be more efficient regarding energy savings.



3.4.3 Note on the counter's values interpretation

The so called "**QIInfo**" contribution, which ensures feeding of the Information centres, cold ceilings and other technical rooms, is not directly measured. It results from several energy balances which yield high uncertainties. Regarding the loop consumption, it is the complement of the "**QIOffices**" value which is measured by a counter. But the energy produced by the "Info" secondary machine is only known from the balance between the measured condenser energy and input electricity (see fig 3.2).

And more important, the rough data of the counter **QXchg** - which evaluates the energy through the exchanger - seems to be false by a factor of 3.33. This factor is mainly attested by the fact that in winter months, the building operators claim that the energy consumption in the "Building loop" should be zero, so that the whole distributed energy (counter **QBDistr** on fig 3.1) should be the energy transmitted to the secondary loop through the exchanger (measured by **QXchg**). The 3.33 factor is the most appropriate for getting values around 0 during the November to February months, all over the 10-years of measurements. Ignoring this correcting factor leads to deep inconsistencies in the general system balances. This value is probably a bad setting in the counter electronics reading.

According to the Building technical manager, the winter running strategy is the following: during each night, the main machine stores cooling energy in the ice storage, using night cheaper electricity. But as the "Info" loop feeding cannot be interrupted, the secondary machine is activated during this operation. This explains the winter behaviour on fig 3.7, where most of the energy is yielded by the main machine, but a little contribution is ensured by the secondary one.

3.4.4 Heat recovery for heating and hot water

A very important feature of this installation is the recovery of the condenser heat for space and hot water heating. This yields a contribution of 365 MWh, to be compared to the Fuel+Gaz consumption of 606 MWh. Therefore the cold installations yield around **38% of the total thermal energy need** of this building (or even **42%** if we take the furnace efficiency into account).

Nevertheless we have to mention that there is also a counter interpretation problem here. The main cooling machine production **QBProd** is not directly measured. It may be estimated by an energy balance between the condenser heat and the electrical input energy.

The energy to each condenser is measured by 3 heat counters:

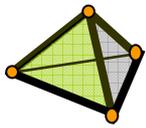
- **QBCEvac** measures the heat to the roof tower.
- **QBCRecovH** is the heat recovered for space heating
- **QBCRecovW** is a special recovery device operating at high temperature, for DHW.

On the other hand we avail of the measurement of the distributed energy **QBDistr**.

The problem is now that the discrepancy between **QBProd** and **QBDistr** is extremely high, of the order of 33%. It cannot be explained by the losses in the Ice storage, which have been estimated to around 1.1% to 2.1% by calculation (for 16 or 8 cm insulation).

As previously, we tried to manipulate the calibrations of each recovery counter. And we found that the only correction which gives acceptable monthly balances is to affect the **QBCEvac** counter data by a factor of 0.75. This means that the **QBCRecovH/W** counters are not concerned, so that the evaluations for the recovered energies are correct !

NB: This heat recovery will of course be suppressed with the GLN connection. Therefore the global balance of this connection has to be carefully evaluated.



3.5 Specifically measured hourly data

3.5.1 Required Measurements

As previously mentioned, the final objective of this study is to identify the minimal information required for a good estimation of the connectivity to a DLWDC network.

In these first sections we have analysed monthly data, which are exceptionally available. In many cases the engineers in charge of the audit will probably not have such data at disposal. Moreover the main information related to the DHLDW connectivity - namely the operating temperatures - is not part of these data. Therefore they will have to perform specific measurements with a reasonable time and material investment.

We will try to show that a good measurement of the chilled loop behaviour over a restricted, but significant time period, along with the knowing of hourly meteorological reference year data (especially external temperature), is sufficient for roughly predicting the yearly needs of the system, and also the connection properties to the network.

These measurements should be performed with a short time step, ideally of a few minutes. They should include the following parameters:

- Electrical consumption of the cooling machine (not quite necessary, but easy to measure and highly recommended),
- Distribution and return temperatures of the chilled loop,
- Flowrate in the chilled loop; this is the more difficult to obtain,
- These data should allow the calculation of the instantaneous cooling power,
- Meteorological conditions: external temperature and global irradiance if available.

These measurements may either be measured by a specific temporary equipment, or recorded using the central control system when possible (see ["Guidelines...", Mermoud 2008]).

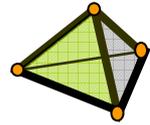
This information should be completed by comfort measurements (temperature, sometimes humidity) at the end-user level. This can be achieved using little independent logger sensors, which are cheap apparatus now widely available on the market.

3.5.2 Measurements of the cooling installations

In the HCR building almost all required sensors are present, and the technical managers of the building could record detailed data using the central control system. For the synchronized meteorological data, we used our own measurements on a building in the town of Geneva, not far from the HCR building (around 4 km).

Nevertheless - as it is often the case - these measurements proved to be not quite perfect for our analysis.

The flow rate measurements are not directly available in the data, they are replaced by heat counters. The main problem was that the energies provided by these counters are given as pulses of accumulated energy, and the value of each pulse was very high (for example: **QBDist** as 140 kWh/pulse, **QXchg** as 140 kW, corrected to 105 kWh/pulse) so that one pulse covers several measurement time steps. This was also the case of the electrical counters (30 and 10 kWh/pulse). This prevents analysing instantaneous energy balances correctly, and produces high ripple even in the hourly data.



When analysing the data in hourly values, this also makes difficult to identify the real operating time of each apparatus (cooling machine, heat exchanger opening vane).

And we don't have any idea of the measurements accuracy and sensor calibration. For example, referring to fig 3.1, logically **TIReturnP** and **TIReturnX** should give the same values when both pumps are running. But they show a discrepancy of 1 to 2°C over the period. It seems that **TIReturnX** is measured with an error of -1.5°C or more: in most exchanger production situations it is very near from the **TIOutXchg**, leading to unrealistic (or negative) calculated flow rate.

However this is not significant for the system running, as these sensors are not used in the control process; nor for the heat counters, which have their own temperature sensors. But this will have consequences on our connectivity study, which is strongly related to this return temperature.

For this study, the system data were recorded with 10 minutes time interval, from June 8th to August 31th, 2006. An additional run was recorded from Sept 22nd to October 1st, with increased distribution temperature of 10°C (instead of 6°C nominal), for analysing the building behaviour with higher distribution temperatures as delivered by the Lake network.

For ease of analyse, and synchronization with other variables (meteo, ambient temperatures), the data were gathered into hourly values. In this process the power pulse were distributed on several time intervals for diminishing the ripple; but this gave of course uncertainties on the time.

3.5.3 System behaviour: time evolution

When dealing with such data, it is essential to have a look on the time evolution of all recorded variables, in order to check their consistency, and to well understand the control behaviour. This is especially true with this rather complex system, with ice storage and two chilled loops, one feeding the second in some situations.

As an example of typical day we choose the hottest day of our sample, reaching more than 35°C around 16-17h, and not lower than 23.5°C in the morning.

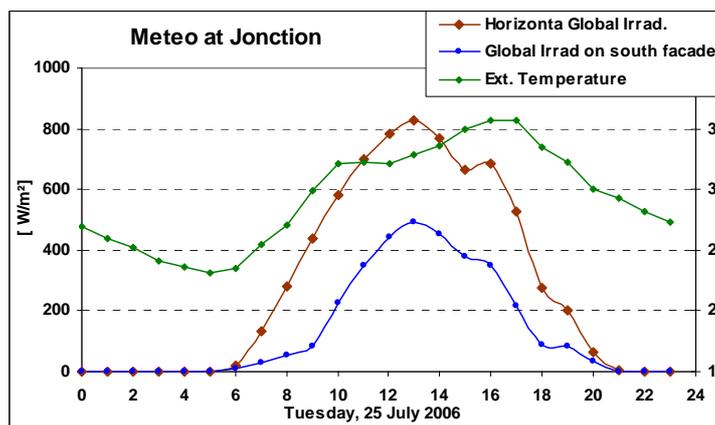


Figure 3.10. - Meteo variables for our typical day

During this day, the main cooling machine run at nominal power (140 kWe) during almost the whole day. Until 7 o'clock, it stored energy in the ice storage, and then it switched to the main distribution cooling loop. The loop temperatures when storing were around -4°C/0°C.

The COP is evaluated from the measurement of the condenser's evacuated heat. We observe that is seems not significantly degraded when producing at -4°C. This will be analysed later.

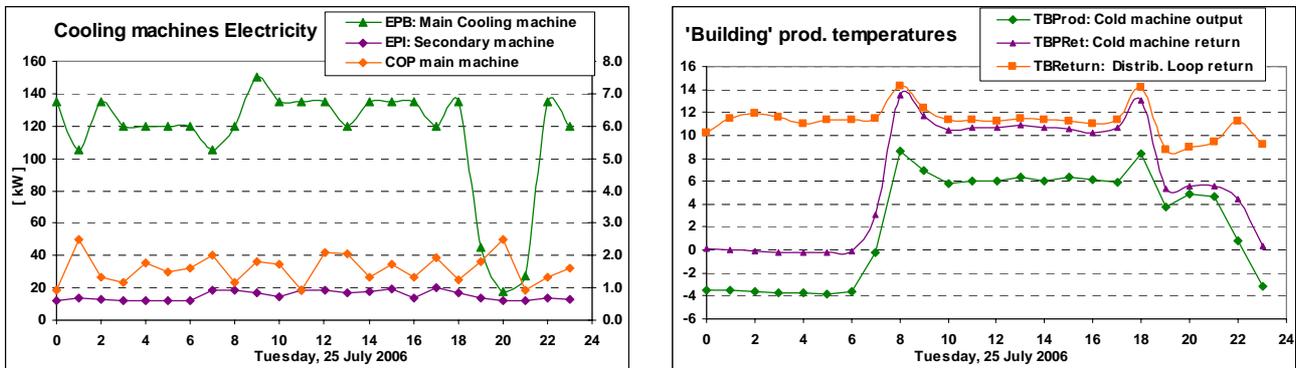
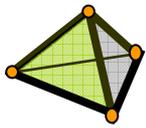


Figure 3.11. - Electricity consumption, and production circuit temperatures

Logically, during the day, the TBRetP and TBReturn temperatures should be the same, as they are bathed in the same flow. On fig 3.11, we observe a little discrepancy which probably indicates a calibration error on one of these sensors.

The second machine in the "Info" circuit, of 40 kWe nominal, runs at less than half its power all over the day. We have to notice that during our logging period, we never observed a consumption over 23 kWe on this machine (figure 3.15).

Let us now analyse the "Building" loop distribution behaviour.

With a COP of about 2, we can estimate the energy produced by the cooling machine on the basis of the electrical consumption. This should be of the order of 280 kW, which is about the half of the demand (*QBDist*r on figure 3.12). The complement of 300 kW should be yielded by the ice storage. Therefore with a total capacity of 3'000 kWh, a full charge would ensure about 10 hours of complement.

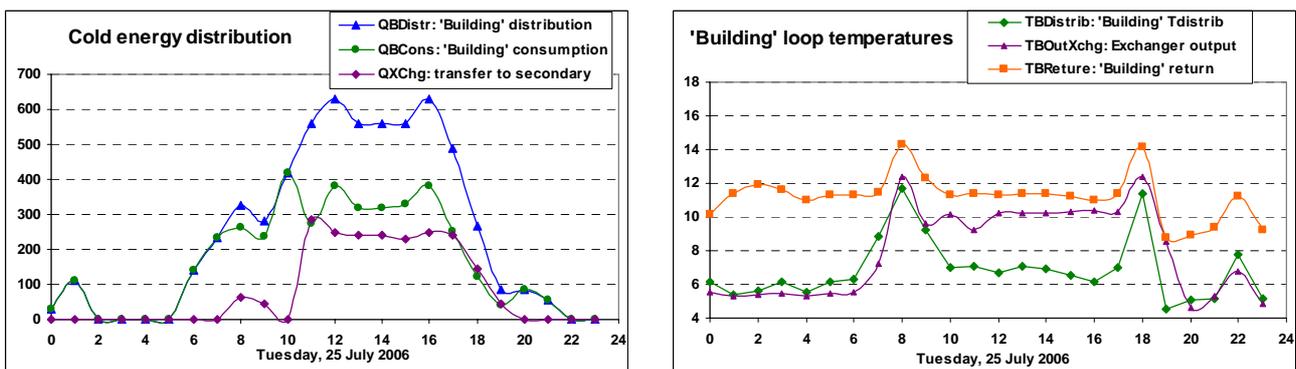
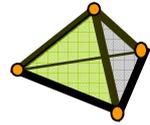


Figure 3.12. - "Building" cold energy distribution, and chilled loop temperatures

During the day, the centralised air handling units of the "Building" circuit absorb about 320 kW (for an installed power of AHU of more than 500 kW). Additional 250 kW are transferred to the secondary loop, mainly for use in the "Inductors" and cold ceilings. Refreshing the offices stops around 18h.

The distribution temperatures are at about 6.5°C/11.5°C, i.e. $\Delta T=5^{\circ}\text{C}$, a little lower than nominal. This corresponds to a flow rate of 105 m³/h.



Finally, the secondary "Info" loop distributes its cooling energy either to the inductors of the offices, and in the technical rooms and cold ceilings in the central part of the office spaces. As seen on figure 3.11, the "Info" cooling machine runs during the whole day.

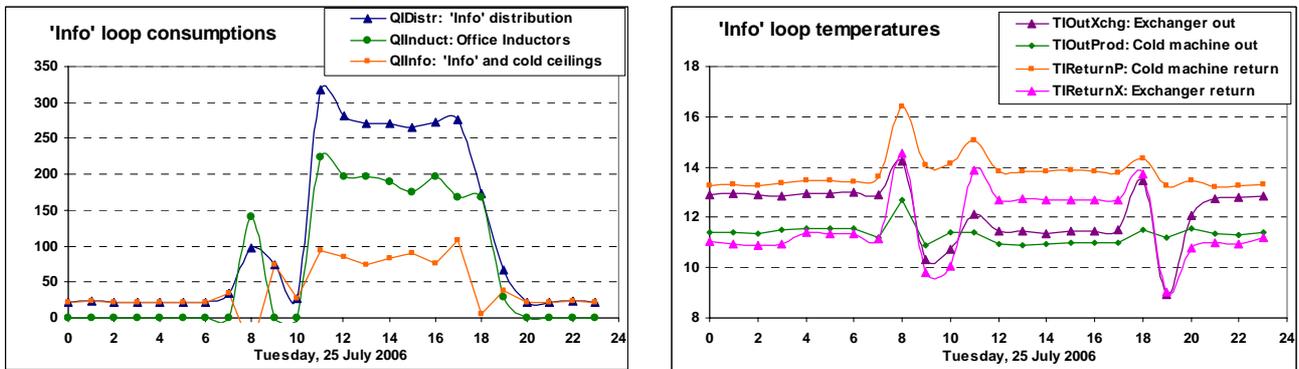


Figure 3.13. - "Info" circuit cold energy distribution, and loop temperatures

Again, when both sources are running, the return temperatures should be the same. This is clearly not the case here, where $T_{ReturnX}$ is about 1.5°C lower than $T_{ReturnP}$, indicating a calibration problem.

According to the installation plans of the engineer, the nominal operating temperatures of this loop are 12/16°C. This is not respected here, where the fluid is distributed at around 11°C, and returns at less than 14°C only. This represents a ΔT of 3°C, corresponding to a flow rate of 75 m³/h.

NB: We don't understand well the origin of the transients in the temperature values when regime is changing.

3.5.4 Cooling energy consumptions

We will see in paragraph 3.5.9 that the usual comfort conditions are not met during such a hot day. The temperatures in some offices reach up to 29 or even 30°C, when the accepted limit is 26°C. The technical personal in charge of the building is thinking that the **production** installations are undersized.

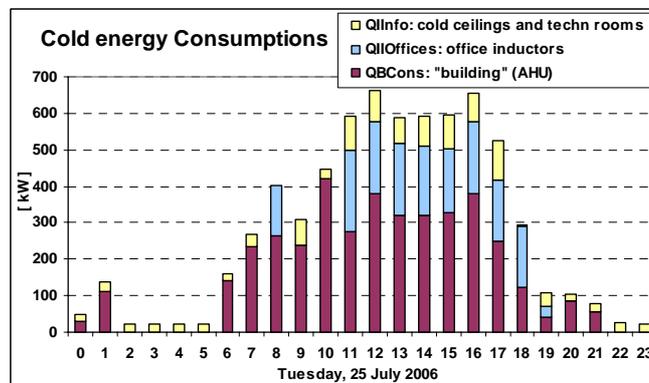
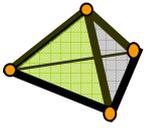


Figure 3.14. - "Info" circuit cooling energy distribution, and loop temperatures



But if we analyse the repartition of the consumptions during this hottest day, we can see that:

- The cooling energy consumption in the "building" loop **QBCons** is limited to around 350 kW. Then, according to the specifications, the *installed* AHU nominal powers totalize about 530 kW for a 6/12°C alimentation. This means that under standard conditions, these transfer devices are not able to draw and deliver their nominal power.
- The feeding for the auxiliary "inductor" devices located in each office has a nominal power of 367 kW. According to the measuring counter on this specific consumption, they use only 200 kW. Therefore either many of these devices stay "closed" and don't deliver their normal post-cooling energy, or they are not sized as specified. Fig 3.21, and especially Fig C8/C10 in annex C, indicate that some of these inductors may stay in an "inactive" state.
- The last contribution **QInfo**, feeding technical rooms for about 45 kW and cold ceilings for 200 kW nominal, delivers a total of the order of 80 kW. Once more, these transfer units seem to transfer far less cooling energy than their specifications.

Therefore, we think that the cold energy **production** means are sufficient. The cooling machines can yield $380 + 140 = 520$ kW nominal, when the consumption during this hot day attains about 600 kW. The complement is ensured by the ice storage, which may probably yield much more if required. The distribution temperatures are near to their nominal level. The problem seems to be either in the transfer devices control, or in their ability to deliver their nominal power.

3.5.5 Energy production sharing between the 2 machines

We notice that the "Info" cooling machine runs continuously, but at a reduced rate. The stops are exceptional, and it runs at **average** powers of 10 to 15 kWe (up to 25 kWe) for a nominal power of 40 kWe. This is the case in our whole data sample (June 1st to October 1st), and seems to be also valid during winter months, when the main machine stores the energy complement in the ice storage using night electricity. We don't know the reason of this control strategy.

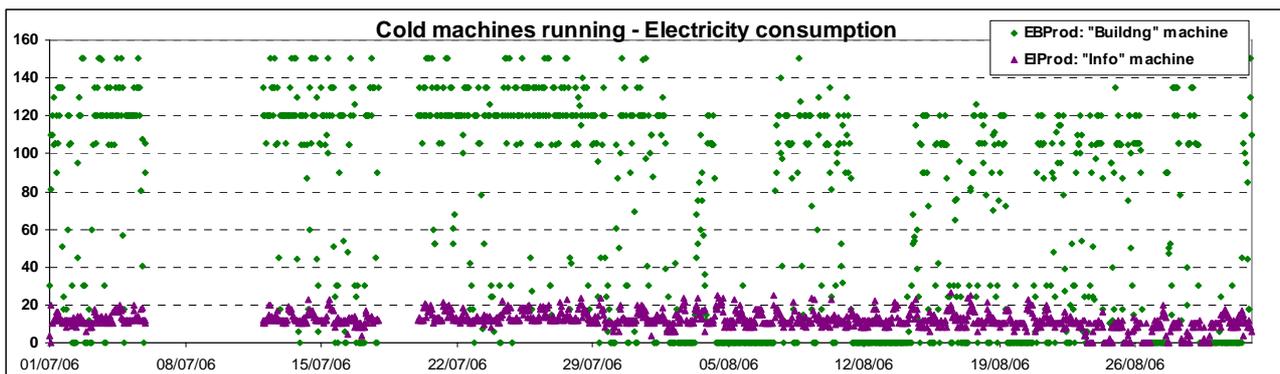
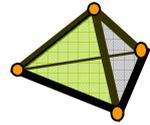


Figure 3.15. - Electricity for both machines over 2 months (hourly values)



3.5.6 COP analysis

We tried to compare the COP obtained in both regimes, during the night for ice storage charging (-4 to -6°C) and during the day for production at +6°C. The COP is deduced from the electricity consumption and the energy at condensers, averaged over 0H-5H or 12H-18H.

On an average over the daily points on fig 3.16, the night charging COP is 1.62, when the day distribution one is 1.84, i.e. 13% over.

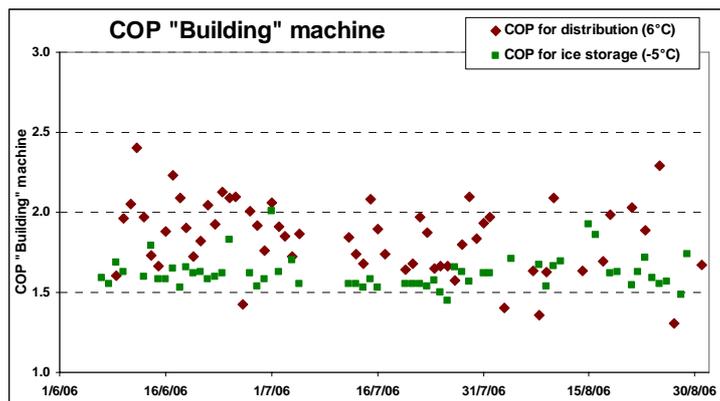
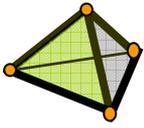


Figure 3.16. - COP evaluated at two different regimes (calculated without *QBCRecovW*)

Nevertheless this calculation cannot be quite reliable, for two reasons:

- firstly due to the pulse quantification of each energy measurement,
- secondly because we don't avail of the *QBCRecovW* counter data in our hourly data.

This contributes to give higher COP values. We could check with the monthly data over this June-August period that **the average COP is 1.9**, but without taking the *QBCRecovW* into account the calculated COP drops to 1.73, i.e. by a factor of around -9%. The problem is that from the monthly data, we cannot know whether the *QBCRecovW* is used preferably by night or during the day.



3.5.7 Signature in hourly values

The most fundamental result of our analysis is the "Signature" of the installation, which determines a correlation between cooling energy demand and external temperature.

From a restricted sample of hourly data, we draw the measured cooling energy by respect to the external temperature. If the sample is sufficiently representative - i.e. it should hold running data for a broad external temperature range - we usually observe a distribution which may be roughly represented by a linear expression (figure 3.17).

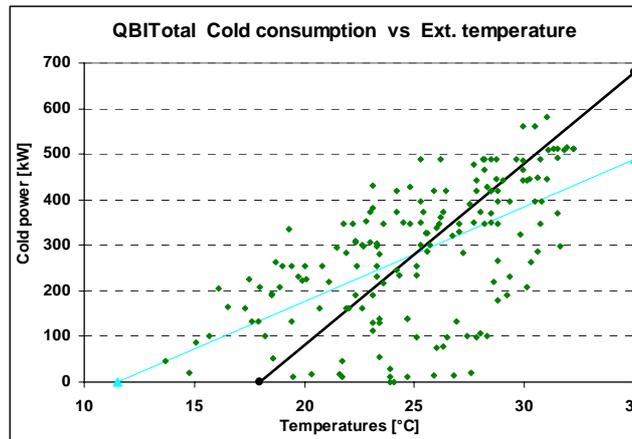


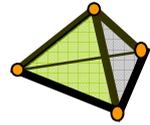
Figure 3.17. - Signature of the whole cold demand (QB Distr+QI Prod)

This sample includes values from June 7th to 20th 2006, 9h to 20h. A mathematical fit may of course be calculated, but it is "pulled" by unwanted points which are not representative of the "normal" system operating. In such a dispersed distribution, we prefer drawing an average line "by eye". This yields a very simple parametrization of the cooling power consumption, as a function of the external temperature:

$$Q_{Cold} = (T_{ext} - T_{thresh}) \cdot P_{slope}$$

here with $T_{thresh} = 18^{\circ}C$ and $P_{slope} = 40 kW/^{\circ}C$.

As we will see in the next chapter, used in conjunction with a reference year of external temperatures in hourly values, this allows for the estimation of the maximum operating power, as well as the total yearly energy needs. This will also give valuable information about the power distribution, which is a key point for the evaluation of the connection properties to the Lake network.



3.5.8 Temperature analysis for Control Strategy and Lake connectivity

For understanding the control strategy, we look at the distribution temperatures, by respect to the effective power delivered by the chilled loops.

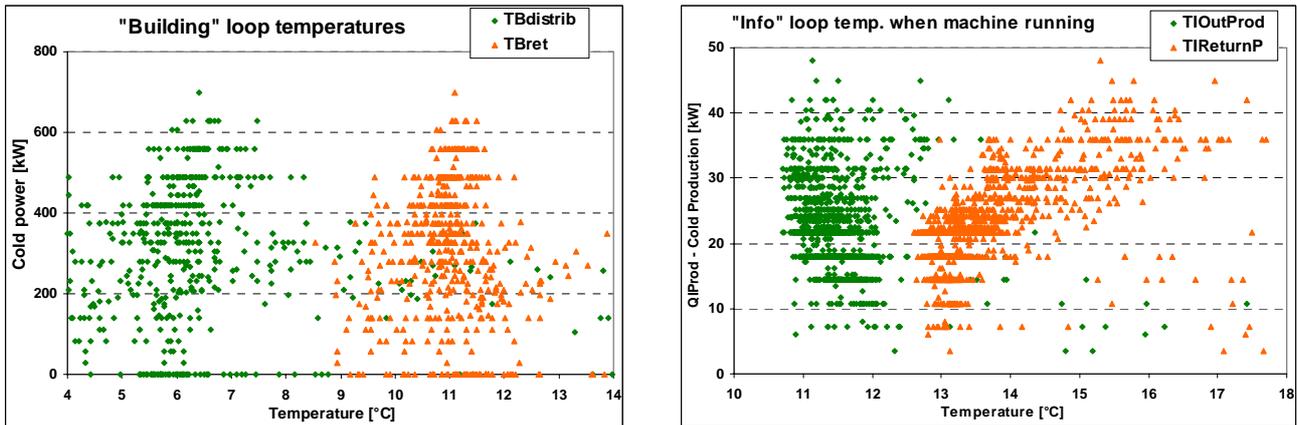


Figure 3.18. - Distribution temperatures, "Building" and "Info" loops

In the "Building" loop, although not very stable, the return temperature distribution stays parallel to the distribution, whatever the power. This means that the flow rate stays quite proportional to the delivered power, which is the best figure for pump energy savings.

Nevertheless the return temperature is around 11°C instead of 12°C foreseen, that is the ΔT is 5°C instead of 6°C, leading to an effective flow rate 20% higher. As the pump energy grows with the square of the flow rate, this increases the pump's energy needs by more than 40%.

In the "Info" circuit, the return distribution above 20 kWth shows a ΔT proportional to the power, which is characteristic of a **constant flow rate**. The flow rate is only reduced under 20 kWth, but staying at a very high value with an operating ΔT around 1.5°C. Substantial pump energy savings could be achieved by developing a control strategy with a proportional flow, ensuring the nominal ΔT of 4°C at any power.

Please remind that pump's energy accounts for around 120 MWh/year. Saving 40% of this energy (48 MWh) would correspond to a money saving of the order of 4'800 euro/year. This would be well invested in a complementary study of the control system.

These considerations about the flow rate - and therefore the return temperature - will be of great importance for the Lake network connection, where we will need to increase the return temperature as high as possible at each power, at the limit for meeting the cooling energy needs requirements of each appliance.

NB: The equivalent graph for the feeding of the "Info" loop by the exchanger is given below. But due to the probable calibration error of the *TIReturnX* sensor, this cannot give us much information.

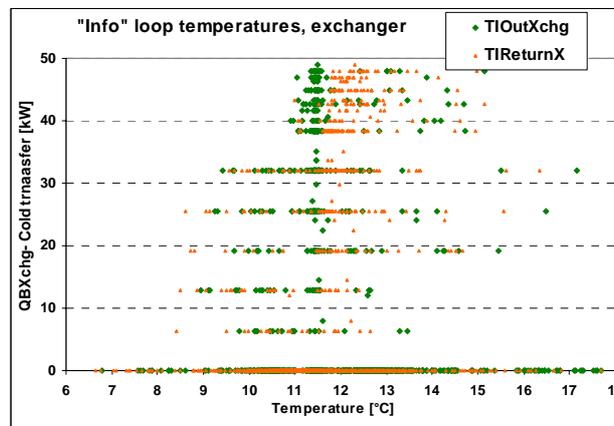
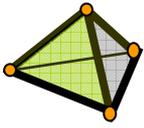


Figure 3.19. - Distribution temperatures for Exchanger transfer
TIReturnX is probably erroneous (underestimated by 1.5°C or more)

3.5.9 Measurements of the comfort conditions

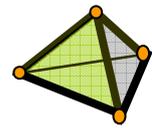
Our monitoring campaign of the summer 2006 also included the measurement of temperatures and humidity at the end-user level, that is in some offices and in the atrium. We avail of continuous measurements from June to mid-September, recorded in 10-minutes time steps by little independent dataloggers, which may be left anywhere (in air ducts, inductors, under desks, etc).

We recorded the following points:

- In an office at the 4th floor, representative of the majority of the offices in the HCR building.
- In two offices at the 7th floor, under the roof which is not completely protected against solar irradiance. One of these offices, facing west, is "closed", occupied by important persons, the other one is open (as most of the offices), situated in the south part.
- In the Atrium, which is a big open and glazed volume next to the office part, not air-conditioned and not quite well protected against solar irradiance. Nevertheless it is situated at the north-west of the building, and therefore not too much exposed to the sun.
- In the "Information technology" room, which is one of the critical points of the air-conditioned installations in HCR. Note that the air distribution mode in these rooms has to be improved (for example, should be distributed directly in the computer's racks).
- We also put sensors in the viciated air ducts, in the corridors of the 4th and 7th floor. This should be representative of the average air temperature at these floors.

Unfortunately we don't avail of recordings during the last experimental phase of the measuring project, when the distribution temperature of the main loop was increased to 10°C. Nevertheless this corresponds to a late summer period, with no excessive external temperatures.

We give here some recordings for the reference "hot" day taken previously as an example. We checked that this day is representative of the hottest days in our sample (see annex C).



The figure 3.20 shows the ambient temperatures measured in 3 different offices. One can observe that all of them overcome the usually admitted comfort limit of 26°C during the working period.

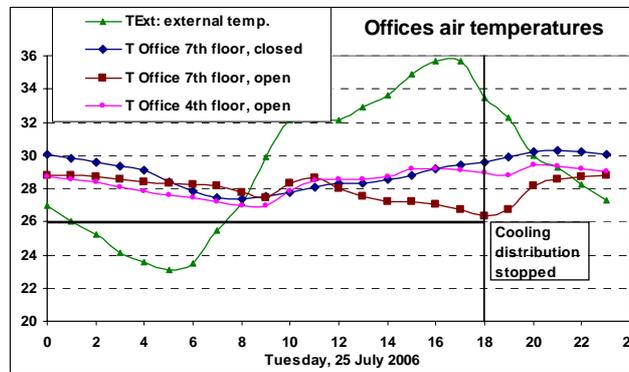


Figure 3.20. – Offices ambient temperatures

But when the 4th and 7th floor "west" increase up to almost 30°C during the day, the one at 7th floor south decreases.

This is probably due to the state of the "inductors", which may in principle be adjusted by the occupants. The figure 3.21 indicates that the pulsed air, measured inside these appliances, goes down to 18-19°C in the cooler office, but stays at just 2-3 degrees below the ambient in the "west" office. Unfortunately we don't have the pulsed temperature in the 4th floor office.

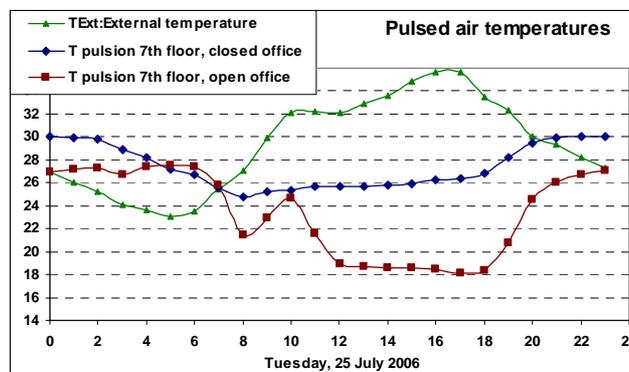


Figure 3.21. – Pulsed air in the offices

The real behaviour of these "inductors" has still to be investigated. It seems that either they don't distribute well the general ventilation air from the centralised AHU, at nominal 16°C, or their flow rate is very low. We have also noticed that the event slots of several of them were obstructed by documents or other things. By the way we can reasonably think that number of them are not set correctly during the hottest conditions, and some information about their use has to be done among the office's occupants. This could explain that the available cooling energy for the "inductors" is far from being completely used by respect to the nominal installed capacity.

The next figure shows the pulsed air temperature in the 7th floor south office over the whole monitoring period. The settings of this "inductor" have clearly been open at beginning of July, and closed mid-August with bad weather.

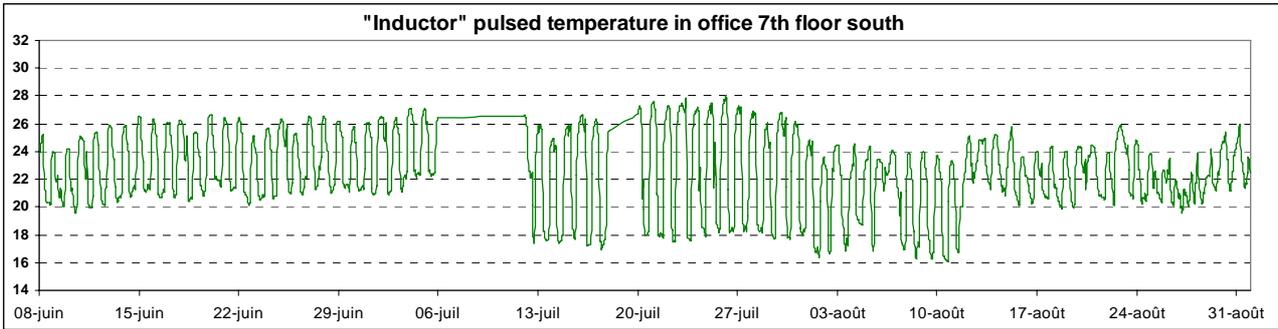
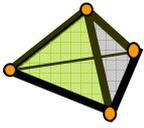


Figure 3.22. – Pulsed air in the office of 7th south

The figure 3.23 shows the viciated air temperature measured in the output ducts of the 4th and 7th floor. These are likely to be representative of an average of the general air in the couloirs (and in offices with less relevance). It can be seen that when the performances are about acceptable at the 4th floor, with a temperature reaching hardly 29°C at the end of the afternoon, this is not the case at the 7th floor where it raises up to 33°C.

This can be explained by the fact that at the 7th floor there is no separation between the office spaces and the atrium, so that the hot air heated in this wide open volume is penetrating at least the couloirs of the 7th (not necessarily the offices).

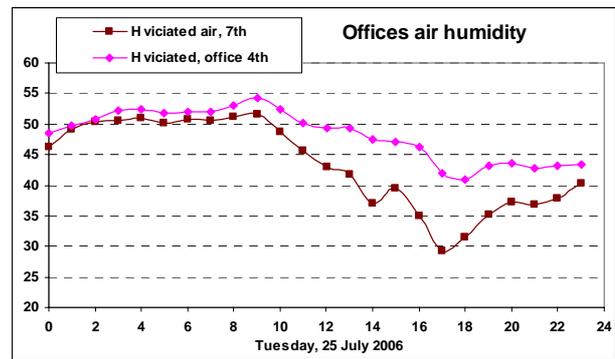
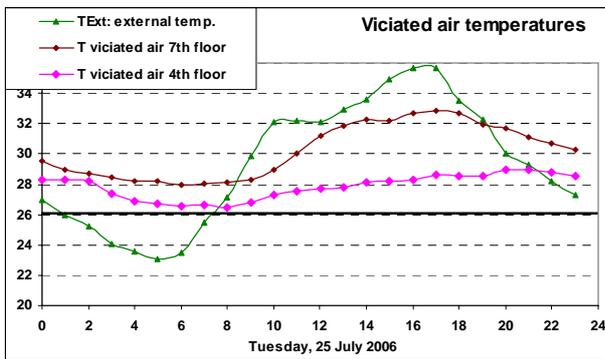


Figure 3.23. – Viciated air temperatures in couloirs and IT rooms

We have also recorded 7th temperatures at different heights of the atrium.

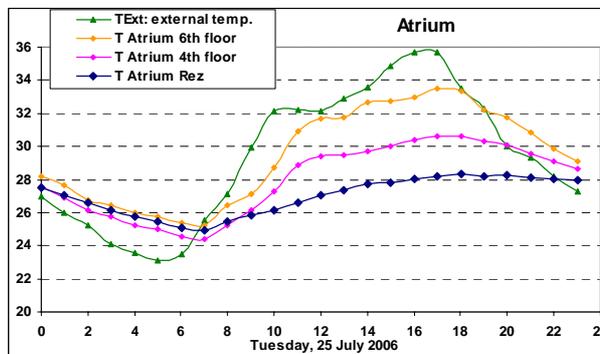
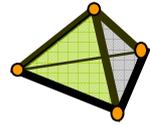


Figure 3.24. – Air temperatures at different levels in the Atrium



This shows of course the stratification of the temperatures, with an acceptable 28°C at the reception desk, and almost 34°C at the top (but still less than the external temperature). Please remember that this space is not refreshed nor heated. This is a "free" space at the north of the building, with partial sun protections on the glazed roof.

3.5.10 Information technology rooms

Finally the figure 3.25 shows the pulsed and viciated air in one information technology room. Although representing a low contribution in the cooling system (2 x 20 kWth), this is one of the crucial points of the installations as it has to be maintained with very high reliability all over the year. These needs stay quite constant over the day, independently of the external temperature, as the installation has mainly to evacuate the heat produced by the computers.

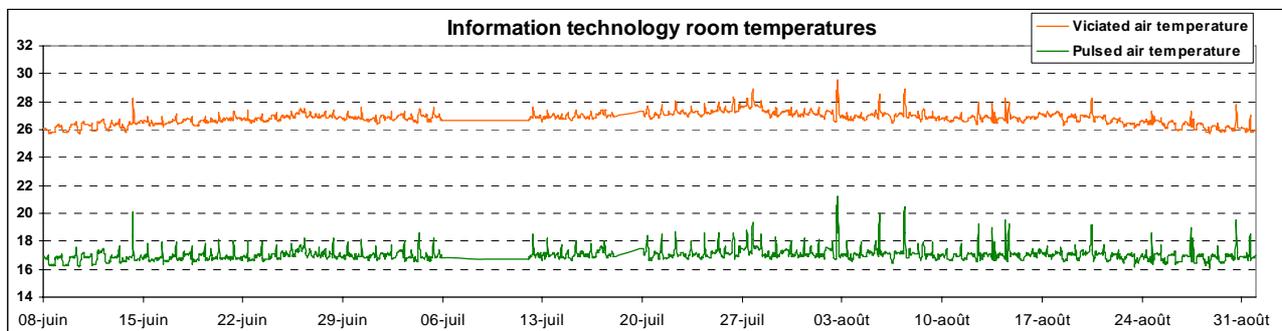


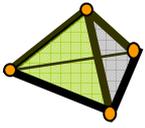
Figure 3.25. – Cooling of the Information technology rooms.

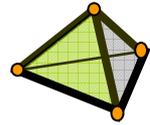
The present cooling device is now hardly able to fill the increasing technical requirements, and should be retrofitted very soon. Care should be taken to foresee the compatibility of the new equipment with the Lake Network. But it should not be very difficult since the present equipment already works at very high temperatures.

NB: In 2007, an independent cooling system, with heat rejection in the nearby parking, has been installed in both information rooms for safety. In the same time the existing cooling installation has been retrofitted. So that these rooms should not present any limitation more for the GLN connection.

In conclusion, we see with these examples that the air conditioning service is somewhat under-sized for these extreme conditions, and is not able to provide ambient temperatures within the limit of the usually required temperature of 26°C.

Nevertheless it could be only a problem of the control system or better use of the existing equipment. Then we can notice that when the nominal global installed power of the cooling distribution devices totalizes 1'140 kW, the effective distributed power during this particular day was only about 350 kW in the "building" air handling units, and 270 kW in the secondary "info" loop (see figures 3.12 and 3.13), i.e. globally around 620 kW.





4 Connection to the DLWDC network

4.1 Auditing method

On the basis of this analysis, and the study of the connecting constraints to the Lake network, we established an auditing method for evaluating the main characteristics of the connexion of any building.

This method is described in the document **Guidelines for auditing the existing buildings to be connected to a Deep Lake Water Direct Cooling Network** [Mermoud and al, 2008], and completed by two computer tools under Excel:

- **Tetraener_Audit_MeasTool.xls**, which is a template for analysing the specific hourly measured data,
- **Tetraener_Audit_StrategysTool.xls**, develops simple methods for calculating the possible transferred energy and corresponding water lake consumption, according to different control strategies. This also calculates the yearly price of the energy consumption according to the specific GLN tariff's rules.

The method will be applied here to our detailed HCR study, mainly for estimating its accuracy.

It's applicability will also be tested using our measurements on the United Nations (UN) big building, which were conducted in 2007 mostly in accordance to the principles established here, and for which we have gathered significantly less information. This will give rise to another document: **UN Building: Measuring cooling installations and auditing for Deep Lake Direct Cooling Network connectivity** [Mermoud and al, 2008].

4.2 Signature - Yearly cooling energy

The first step is to evaluate the yearly cooling energy consumption and distribution, using the "Signature" parametrization and a reference year of meteorological data file (especially external temperatures).

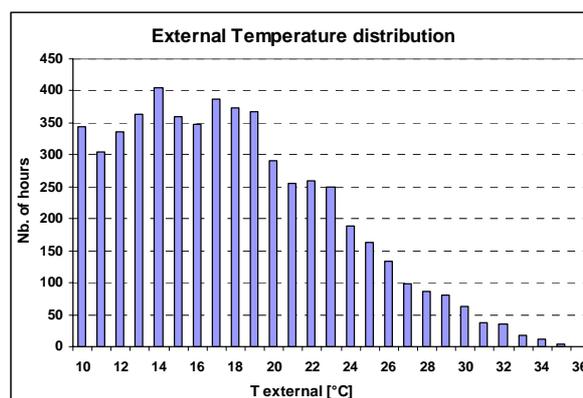
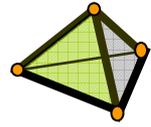


Figure 4.1. - "Jonction" 2006 temperatures distribution

The basic meteo data are those of year 2006, recorded at our Jonction meteo station. These data should be recorded *in the same conditions* as those used for establishing the "Signature" parameters, which is the case here. These are not necessarily quite representative of the HCR building situation, which is located in a more extended Geneva suburb. Data of the Cointrin airport,



4.3 Lake temperature

The next steps will require an estimation of the available temperature delivered by the network, closely related to the Lake water temperature.

According to our calculations, even without insulation the temperature loss in the pipes from the intake in the Lake to the building input should not exceed 0.1 to 0.2°C.

We give here some of our measurements performed in 2006 and 2007, at the intake pipe in the lake at 35m depth.

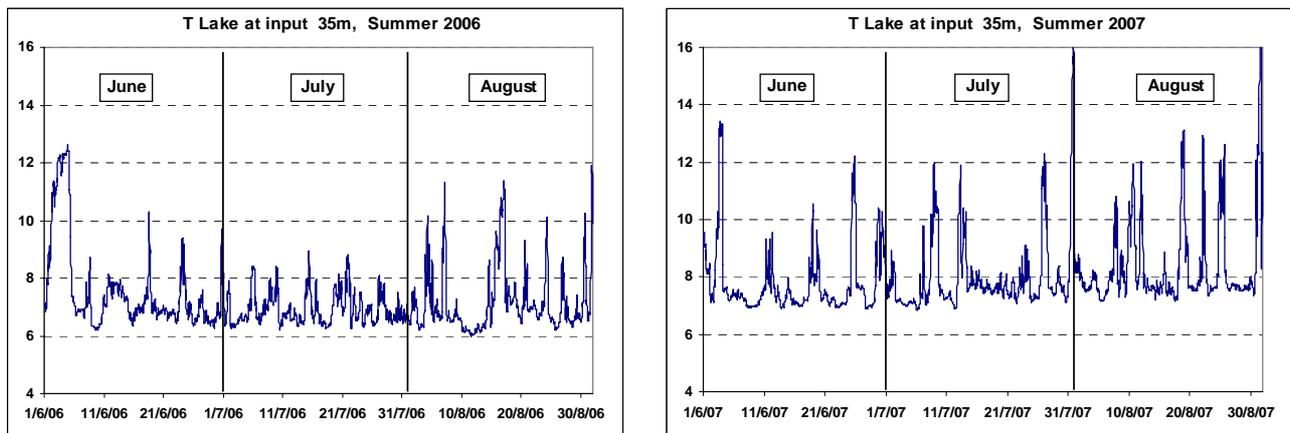


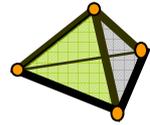
Figure 4.3. - Lake of Geneva: temperatures at the picking point

We see a systematic difference between both years, of the order of 1°C. This seems to be compatible with the usual variations of the historical measurements in the Lake.

We see also that the temperature peaks are more numerous and pronounced in 2007. This is probably due to the fact that the weather was more perturbed in the Summer 2007 than in 2006. And according to our first analysis, the temperature increase events usually don't happen during hot calm periods.

Then, for applying our tool, we have to choose a reference Lake input temperature, constant over the year. This simplified tool doesn't allow for temperature evolutions.

In the further study, we choose a reference temperature **TLake = 9°C**. If we look at our measured data, this threshold was exceeded 7.2% of the time in summer 2006, and 15% in summer 2007. We verified that during the periods reaching 12°C, the external temperature in Jonction did not exceed 26-27°C, which corresponds to a cooling power demand of less than 50% by respect to nominal.



4.5 Control strategy

Let us now analyse the energy transfer properties from the DLWDC Network to the chilled loop, according to the control strategy.

The "**Meas Distrib**" sheet in the Excel "**Strategy Tool**" defines the present operating parameters. It also asks for an acceptable distribution temperature level which would meet the required needs according to power (See Annex D.2). This shows the corresponding diagram:

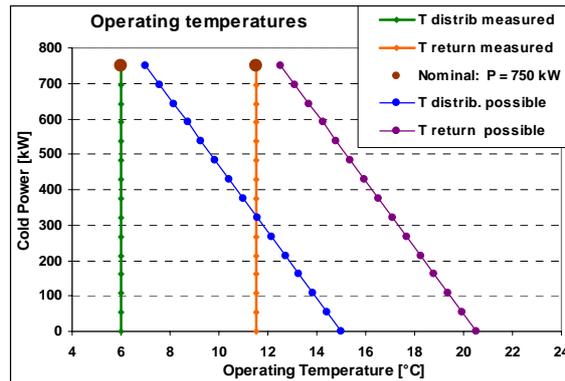


Figure 4.5. - Present state and possible temperature levels

The next sheet "**Control Strategy**" establishes a model of temperatures involved by the connection to the GLN through the exchanger (see Annex D.3).

With lake feeding, the temperature at the output of the exchanger **Tout_exch** will be governed by the lake flow input temperature **Tlake**, with an additional temperature ΔT_{exch} due to the exchanger efficiency. Depending on the exchanger size and flows, this ΔT_{exch} is of the order of one degree C at full power. The **Tout_exch** temperature slightly decreases up to the lake temperature when the power goes to zero.

If the **Tout_exch** is greater than the "possible" **Tdistrib** defined above, then the lake itself is not sufficient for ensuring the required cooling energy, and the spare cooling machine has to supply the complement energy.

The **final control strategy** is then defined by two additional parameters only, which will characterize the whole system behaviour. These are:

- The return temperature at nominal power **Treturn_Norm**. With the distribution temperature (from Lake exchanger output or **TDistrib_Possible**, whatever the lower one), this defines the nominal flow rate.
- The Flow Rate behaviour when the power decreases (**FR_slope**). This will determine the return temperature.

With **fixed Flow Rate**, the difference **Treturn-Tdistrib** will decrease linearly up to zero, which is catastrophic either for the pump's consumption, and much more for the GLN transfer performance.

With **flowrate purely proportional** to the power, this results in parallel **Treturn** and **Tdistrib** values. This is the present state of the "Building" energy at HCR (but not the "Info" loop, which is nearer to the previous case, see figure 3.18).

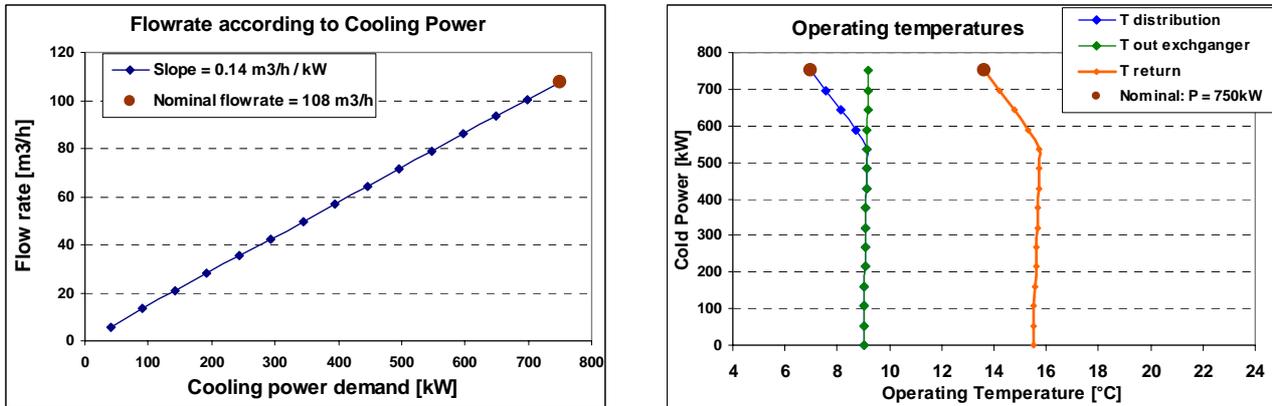
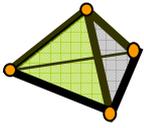


Figure 4.6. - Proportional flow rate and resulting temperatures

We propose a third solution, with flow rate decreasing more rapidly than the power demand. The decreasing slope should be adjusted in order to meet the cold energy demand at any power. With this extreme option we still have to define a threshold from which the flow becomes proportional, otherwise the flow would become zero and the return temperature infinite! This threshold may be estimated using the return temperature figure.

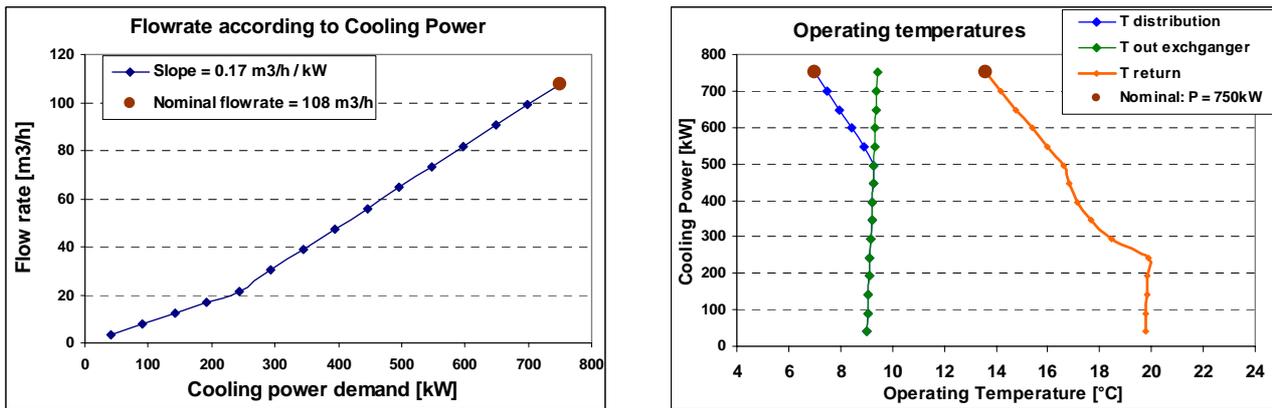
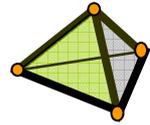


Figure 4.7. - Under-proportional flow rate and temperature increase

In practice, the flow rate (at least in the HCR installation) is controlled by a pressure sensor between the distribution and return branches, which drives the pump's speed in order to keep the ΔP . The fact that the flow rate is proportional to the cooling demand is a result of the end-user's devices (AHU) control behaviour, which draws just the required flow in order to maintain the output service parameter (usually the pulsed air temperature) at its required level, using a two-way valve.

Therefore after the GLN connexion, the control strategy of all final user's devices should be studied in order to obtain this desirable result. In fact each of them should draw just the minimum flow rate sufficient for ensuring the required energy transfer.



4.6 Connexion: Energy, Water needs and Costs

The next sheet "**Lake_Balance**" of the Excel tool calculates the main properties and balances of the connexion under the previously defined operating conditions.

4.6.1 Parameters

This asks for defining the following parameters, all related to the contract with the Network Manager (the SIG):

- The maximal flow rate allowed, i.e. subscribed in the contract. In the reality the SIG will specify a subscribed power. But this is defined for a standard ΔT of 6°C , therefore equivalent to a flow rate by the relation: $\text{Subscr_FlowR} = \text{Subscr_Power} / (\text{cpw} * 6^{\circ}\text{C})$ where $\text{cpw} = 1.16 \text{ kW/m}^3\text{C}$.
- The size of the exchanger, which is chosen by the SIG, owner of this device. This should be largely sized in order to limit the temperature drop to less than 1°C .
- The price of the connexion, a fixed tax proportional to the subscribed power.
- The price of the energy. This is indexed to the return temperature of the building circuit, in order to take the real water consumption into account. The price of the kWh is fixed until a temperature value ("*Derating_Thresh*"), and then decreases linearly when the return temperature increases. In this tool all prices are expressed in Euro.
- The price of the conventional complementary energy, i.e. the electricity price divided by an admitted average COP. This price is indeed far lower than the GLN energy price. This doesn't include the maintenance costs of the cooling machine, which are usually very high.

NB: In this report all prices are set at example values. The real cost will be established according to the real prices defined in the contract.

4.6.2 Calculations

Using now a simple model for the exchanger, it is possible to calculate the transfer characteristics, including the power, the lake flow rate and the cost, for any level of the power demand.

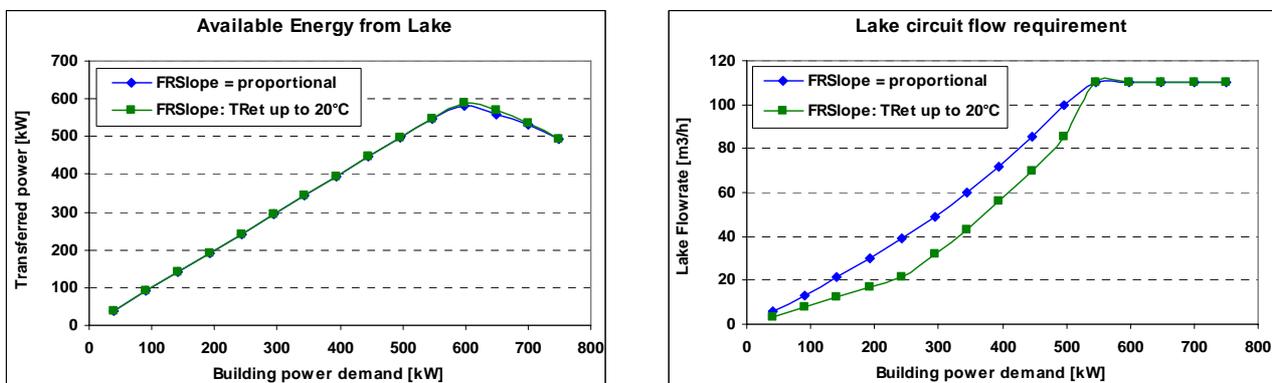
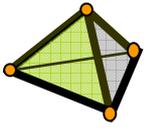


Figure 4.8. - Transferable energy and Lake Flow Rate requirement



As we have seen on figures 4.6 and 4.7, above around 550 kW the lake temperature is not sufficient for feeding the AHU devices, so that the cooling machine has to be activated for yielding a complementary temperature drop. The result can be seen on figure 4.8a: the lake is no more able to give the whole required cooling energy. Nevertheless the difference between both control strategies is very small as the return temperatures are not very different at these levels.

The required flow rate is much more dependent on the control strategy used: when the "proportional" figure consumes about 145'000 m³ annually, the improved strategy with higher return temperature requires only 101'000 m³, i.e. an economy of 30%. The full subscribed flow is attained when the Lake cannot meet the needs anymore.

This has consequences on the Lake return temperature, as shown on figure 4.9. This temperature reflects the Chilled loop return temperature, which is a basis for the invoicing: a decrease of the kWh price of 0.3 ct€ for each additional degree above 14°C.

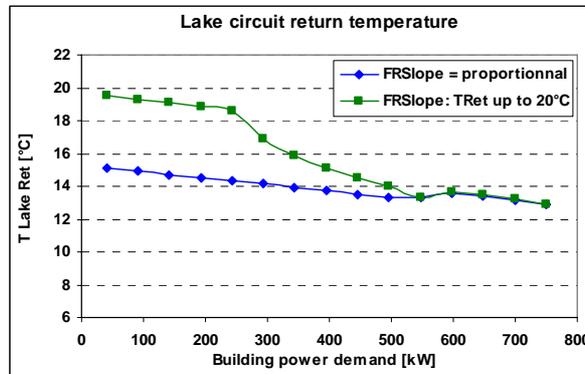
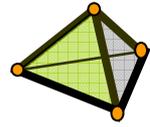


Figure 4.9. - Lake circuit return temperature

4.6.3 Energy and Water annual balances, costs

Transferred energy and Lake water consumption are calculated for each step of external temperature, and accumulated according to the meteorological data, yielding namely the annual energy needs, the energy transferred, the lake flow and the costs.

These numerous results appear on the "Lake_Balance" sheet for a given configuration, and are immediately updated after any input parameter change (see annex D.4).

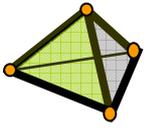


4.7 Scenarios

Finally the next sheet **"Scenarios"** gathers all the parameters and results for several scenarios on a single table (and comparative graphs), allowing for comparisons and parameter sensitivity analysis.

Scenario descriptions			Current values				
#	Scenario description		#1	#2	#3	#4	#5
#1	Basic case: possible Tdistr nom = 7/13°C, FR slope optimized, subscribed power = 600 kW						
#2	Basic case + Increase subscribed power to 750 kW						
#3	Basic case + Decrease exchanger size to 300 kW/k						
#4	Basic case + FR slope kept purely proportional						
#5	Basic case + Possible Tdistrib = 7/13°C whatever the Power						
"Signature" of the Cold Power demand							
Constant consumption (e.g. information technology appliances)	PCold_const	kW	40	40	40	40	40
Threshold on external temperature for starting cooling installations	TextThresh	°C	18	18	18	18	18
Slope of the Power needs as function of the external temperature	PCold_Slope	kW/k	40	40	40	40	40
Derived:							
Maximum temperature in the meteo data sample	Max. Ext. temp.	°C	35.7	35.7	35.7	35.7	35.7
Maximum power demand (for this max. temperature)	Max. power	kW	708	708	708	708	708
Present Control Strategy (measurements)							
Nominal power for meeting the worst external conditions	PCold Nom.	kW	750	750	750	750	750
Corresponding external temperature	Text_Nom	°C	36.8	36.8	36.8	36.8	36.8
T distribution temperature at nominal power	Tdmeas_Nom	°C	6.0	6.0	6.0	6.0	6.0
T return temperature at nominal power	TRmeas_Nom	°C	11.0	11.0	11.0	11.0	11.0
Loop heat capacity (if water: 1.16 kWh/m ³ k)	Loop Heat Cap	kWh/m ³ k	1.05	1.05	1.05	1.05	1.05
Flowrate at nominal power	FlowR_Meas_Nom	m ³ /h	129.3	129.3	129.3	129.3	129.3
New Control strategy with Lake feeding							
T distribution possible at nominal power (for meeting requirements)	TDposs_Nom	°C	7	7	7	7	7
T distribution possible at null power (for meeting requirements)	TDposs_0kW	°C	14	14	14	14	7
Effective chilled loop temperatures							
T distribution at nominal conditions	Tdistrib_Nom.	°C	7.0	7.0	7.0	7.0	7.0
T output exchanger at nominal conditions	TOutExch_Nom	°C	9.4	9.4	10.0	9.4	9.4
T return at nominal conditions	Treturn_Nom.	°C	13.0	13.0	13.0	13.0	13.0
T distribution at P = 0 kW (normally = TLake)	TDistrib_0 kW	°C	9.0	9.0	9.0	9.0	9.0
T slope at exchanger output	=> TSlope_Xchg	m°C / kW	0.58	0.53	1.32	0.58	0.58
Effective Loop Flowrate							
Flow rate at nominal conditions	Flow Rate Nom	m ³ /h	108	108	108	108	108
Flowrate decrease when power decreases	FR slope	m ³ /h/kW	0.170	0.170	0.170	0.142	0.142
Minimum from which Flow decreases linearly to 0 (elbow)	FR threshold	m ³ /h	22	22	22	22	22
Corresponding Power from which FlowR prop. to power	P (FR thresh)	kW	243	243	243	143	143
Lake temperature							
Maximum Flowrate subscribed	FR Lake_Max	m ³ /h	86	108	86	86	86
Exchanger size	Xchg_KS	kW/K	500	500	300	500	500
Contractual conditions							
Power subscribed by the user	Subscr Power	kW	600	750	600	600	600
Price of the subscribed flowrate	Abonnt price	€/ kW	15.8	15.8	15.8	15.8	15.8
Basic price of the cold energy delivered	Energy basic price	ct€/kWh	6.5	6.5	6.5	6.5	6.5
Derating according to Return temperature	Derating price	ct€/kWh	-0.33	-0.33	-0.33	-0.33	-0.33
Temperature limit for the basic tariff	Derating thresh	°C	14	14	14	14	14
Electricity for auxiliary cooling machines	Electricity cost	ct/kWhe	10	10	10	10	10
	Average COP		2.5	2.5	2.5	2.5	2.5
Yearly results according to temperature distribution							
Total building demand of cold energy	Energy needs	MWh	790	790	790	790	790
Operating time (excluding PCold_Const contributions)	Operating time	hours	2342	2342	2342	2342	2342
Equivalent operating time at nominal power	Oper. Time Nom	hours	1053	1053	1053	1053	1053
Energy drawn from the Lake network	Energy from lake	MWh	784	786	779	783	591
	Lake energy yield	%	99.2%	99.5%	98.6%	99.1%	74.8%
Corresponding Flow in the lake circuit	Lake water needs	m ³ *1000	82.7	85.7	85.5	122	755
Water needs relative to permanent subscribed Flowrate	relative	%	40.9%	33.9%	42.3%	60.5%	374.0%
Financial balance							
Tax on the subscribed maximum Flowrate	Abonnement cost	€	9 483	11 853	9 483	9 483	9 483
Energy cost with depressive tariff	Lake energy cost	€	38 314	38 486	37 737	46 994	38 426
Electricity for Auxiliary cold energy	Aux. energy cost	€	251	153	430	298	7 957
Total cost of the cold service	Total annual cost	€	48 048	50 492	47 650	56 774	55 866
Specific cost	Average cost	ct€/kWh	6.1	6.4	6.0	7.2	7.1

Figure 4.10. – Results for different parameter configurations



First please note that the prices defined here are taken **as an example** for the use of our auditing method. The real prices will be defined in the contracts between the building's owner and the SIG, and this study should be reanalysed using these real data.

According to our present assumptions, the price of the cooling energy from the Lake (supposed 6.5 ct€/kWh up to Tret = 14°C, down to 4.5 ct€/kWh at Tret = 20°C) is not really competitive with respect to the traditional production by cooling machines (supposed 10 ct€/kWh, divided by the COP). These energy prices do not include, for the GLN connexion the tax proportional to the subscribed power, and for the cooling machine the maintenance costs, about constant whatever the back-up cooling energy produced.

Therefore it is not possible to define an optimal parameter configuration, as from a purely financial point of view the best situation would be to produce the whole cooling energy with the electricity. So that the desirable part of Lake energy depends on the willingness of the building owner to use renewable energy, which is a consequence of his engagement in the GLN project.

We have defined a reference case (scenario #1), and we will observe the effect when modifying one parameter after the other.

The **reference case** assumes:

- o a subscribed power of **600 kW**, corresponding to a Lake max. flow rate of 86 m³/h,
- o a *possible* Tdistrib going from 7°C at nominal power to 14°C at zero power,
- o Treturn from chilled loop = 13°C at nominal power, inducing a nominal flowrate of 108 m³/h,
- o a "under-proportional" flowrate decrease of -0.17 m³/h / kW until 22 m³/h, thus limiting the Treturn temperature to around 20°C at low powers.

This will yield **99.2%** of the required cooling energy for a consumption of **82'700 m³** of Lake's water. The total energy costs, including power tax and back-up energy, but excluding maintenance costs, will amount to **48'048 euro (6.1 ct€/kWh)**.

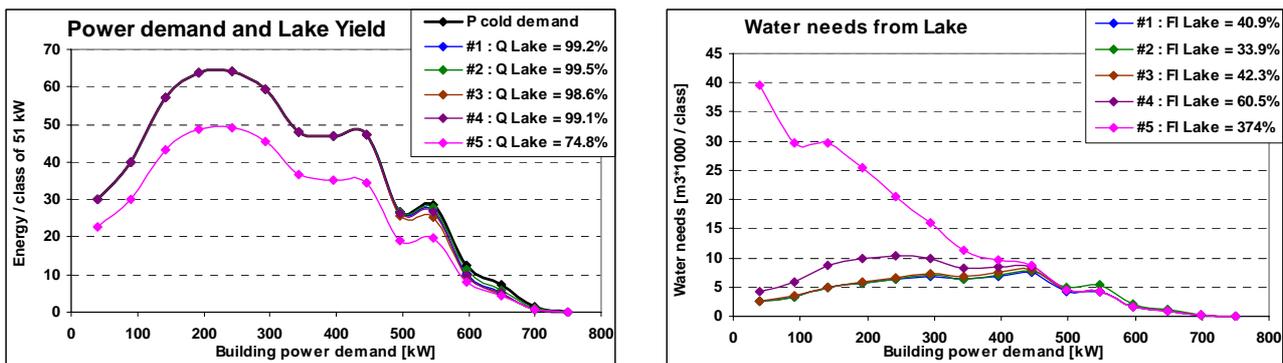
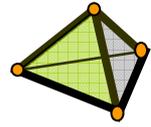


Figure 4.11. – Power yield and Lake water needs

The first try is to analyse the effect of an increased **subscribed power**, up to the nominal power of **750 kW**. This will lead the maximum lake flow rate to 108 m³/h. This allows the transfer of 99.5% of the required cooling energy from the network, but will increase the energy price to 50'492 Euro (6.4 ct€/kWh, +5%), due to the power tax. The Lake water consumption is slightly increased (85'700 m³, +3.6%).



Next we analyse the effect of the **exchanger size** (remember that this device is the property of the SIG, who is supporting the investment costs). Passing from 500 kW/k to 300 kW/k will slightly increase the T_{distrib} (from $T_{\text{Lake}}+0.43^{\circ}\text{C}$ to $T_{\text{Lake}}+1^{\circ}\text{C}$ at nominal power), and therefore slightly penalize the transferred energy (which passes to 98.6%). Surprisingly, this will diminish the global cost to 47'650 Euro (-0.8%), due to the fact that cheaper traditional energy is substituted to the Network energy.

The next scenario shows the consequences of a **purely proportional flow rate**, which limits the return temperature to around 15.5°C . Here the transferred energy is 99.1% for water needs of $122'000\text{ m}^3$ (+ 44%), and the cost raises to **56'774 Euro** (+18%). This shows the necessity and advantage of carefully optimizing the return temperature, by special measures on the control strategy.

Finally, the last scenario shows the catastrophic situation if really **nothing is done**, the distribution temperature being kept at its nominal value of 7°C whatever the power. In this situation the network is only able to yield 75% of the required cooling energy, for a total consumption of $755'000\text{ m}^3$ of Lake water. For the building owner the energy cost would be only 55'866 Euro, but for the SIG the cost in water pumping becomes prohibitive !

Important notice: Heat recovery

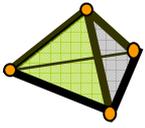
The cooling installations of the HCR are modern and well designed. In the HCR general concept, the residual heat at the condenser of the main machine is recovered for space heating or Domestic Hot Water whenever possible. In 2006 this led to around 325 MWh of thermal energy savings.

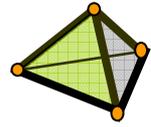
After the connexion to the GLN project, this energy will be produced by fossil energy, fuel or gas (roughly 33'000 litre of fuel).

From a financial point of view, this represents an additional cost of the order of 20'000 Euros, which has to be added to the cooling energy costs.

For the environment, the saved 428 MWh of electrical energy for cooling will be balanced by this fossil consumption, penalizing the CO_2 balance of the GLN project for this building.

Nevertheless, a great part of this recovered energy is due to winter cooling installations operating, especially for the cold ceilings in the central part of the building. These are fed simultaneously with the heating of the other premises, so that this cooling energy probably implies an increased heating load. We can wonder if this strategy is optimal, or if it could be replaced, for example, by a reinforcement of the ventilation.





5 Conclusions

The "**Genève Lac Nations**" project aims to use the cold water of the Lake of Geneva to meet the refrigerating needs of administrative buildings in the international organizations suburb of the Geneva city. The Lake water is pumped at a depth of 35m, and is available at temperatures of 7 to 9°C in the summer. This commercial GLN network (managed by SIG) will distribute the Lake's cold water to the customer buildings without complementary cooling; thus we called it a **Deep Lake Water Direct Cooling** network.

This should feed the chilled loop of each building - traditionally operating at 6/12°C - through a heat exchanger, property of the Network manager. When the available cooling energy is not sufficient, the existing cooling machine should yield the required complement. The GLN manager offers the opportunity to reject the condenser residual heat to the network, avoiding the need and maintenance of cooling towers.

Specific problems are linked to the direct connexion, especially concerning the operating temperatures. The transferable energy, as well as the flow rate required from the network, are very dependent on the operating temperature of the chilled loop. The SIG therefore proposes a degressive tariff of the energy, according to the building loop return temperature.

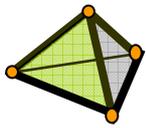
When developing such a project, the ability of each candidate building to be connected to the DLWDC network should be evaluated, as well as the properties of this connexion. Using data of a typical building of the GLN perimeter - the UN High Commissioner for Refugees (HCR) building - we have established an auditing method addressing this problematic. A further work applies this auditing method to another big building, the complex of the United Nations, aiming to check its applicability.

This auditing method proposes:

- Rules for gathering pertinent information about the building, including analysis and optimization of the building envelope and cooling needs, cooling installations, air-conditioned distribution.
- Methods for the acquisition and analysis of specific data about the cooling system operation and end-user service.
- Using this restricted set of data, the method provides an information technology tool for the evaluation and the optimization of the operation with sight on the connexion to the network. This tool gives advices to improve the control strategy, and calculates the energy transferred, the flow rate required from the network, and the general costs according to the evolving energy tariffs.

We performed a rather complete study of the cooling installation performances of the HCR building. This took advantage of the numerous measurements available in this building (namely several heat and electricity counters for detailed service analysis), and the fact that these counters were carefully read (each month) by the technical personal since the commissioning of the building in 1994, thus giving the long-term evolution. But availability of such data is exceptional, so that the auditing method should not make use of them.

As the cooling installations are well equipped with sensors, we have asked the technical personal for recording the specific data required for our auditing method; that is, mainly the temperatures and flow rates (or energies) of the chilled loops in sub-hourly time steps. The measurements were recorded from June to August 2006, but we used ten significant days as basis for our analysis, as proposed in the auditing method for establishing the energetic "signature". These allowed the extrapolation of the energy need over the whole year, with an accuracy of the order of 13%.



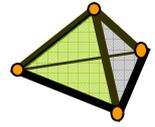
Then we established our Excel tool for calculating the Energy needs as function of the power, the energy transfer from the Lake network, the required flow in the GLN circuit and the final yearly costs. This tool gives the opportunity for the comparison of several parametrized control strategies, and the evaluation of their consequences on the final energy use and costs.

The method gives guidelines for the improvement of the control strategy, especially at the end-user's level (air-handling units control). This is quite necessary for the efficiency of the connexion to the GLN network. These general rules - not in conformity with the usual practice - should also be useful for the energy consumption optimization of any air-conditioned system. These rules concern mainly the control strategy, without modification to the hardware system. But we cannot give an estimation of the real cost of their implementation.

As the main challenge of the control strategy is the increase of the operating temperatures at partial loads, we experienced an increase of the distribution temperature from 6°C nominal to 10°C, for observing the effects on the end-user's service, during 10 days in September. This did not give raise to any complaint of users, except for an information technology room, of which the cooling installation is known to be under-sized (and which has been equipped with a complement cooling device since this date).

Finally, we observed that the HCR installations were designed with modern concepts. Especially the recovery of the condenser energy of the main cooling machine for hot water and space heating leads to significant fuel or gas savings. These savings will of course be discarded with the GLN connection. For the environment, the saved 428 MWh_e of electrical energy for cooling machines will be balanced by a fossil additional consumption of 325 MWh_{th}, penalizing the CO₂ balance of the GLN project for this building.

However, a major part of this recovery takes place during winter, as by-product of the cooling energy production namely for the cold ceilings. We can wonder if this operating mode could be replaced by some other one (for example an increased ventilation). In this case of course the recovered energy would be lowered, but also the heating energy needs would decrease.



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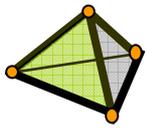
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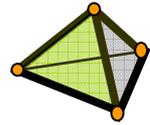
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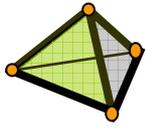
Annex A - Table of Description of the existing installations

This table gathers the main parameters of the cooling system.

The EXCEL tool "**Tetraener_Audit_MeasTool.xls**" includes a template of this table. This may be used as a guiding form when performing the visit of the installations.

Project name		Example-project for TETRAENER Audit Method					
Question / Item		Units					
General configuration							
Centralized cold energy production		Y/N	Yes	If NOT Centralized or NOT Water: Connexion to DLWDC network impossible !			
Distribution fluid (water / refrigerant)		W/R	Glycol				
Cold production			Total	Machine#1	Machine#2	Machine#3	Machine#4
Number of cold machines	nb		2				
Technology (Piston, Turbo, Screw compressor, Absorption)							
Electrical power	kW		190	140	50		
Cold energy power	kW		520	380	140		
COP in normal operating conditions				2.71	2.8		
Cooling towers	kW		681	501	180		
Production Flowrate	m3/h			57.3	30.2		
Commissioning year				env. 1992	1997 ?		
Distribution				Main circuit	Info circuit		
Distribution temperature, nominal	°C	Fixed		6	12		
Return temperature, nominal	°C			12	16		
Main loop Distribution Flowrate	m3/h			57.3	30	Specific Heat at 8°C	
Working Fluid	Propylenglycol <input type="checkbox"/> Concentration	% V/V		20	0	1.11 kWh/m3K	
Main loop flowrate control strategy (ΔP on pumps, Tret, ...)				ΔP on pumps			
Ice storage				Comments			
If present: number of tanks	nb		5	Corresponding to $\Delta T = 15$ °C 92 kWh/m3			
Volume	m3		30.7				
Stored Energy, sensitive	kWh		525				
Stored Energy, latent	kWh		2820				
Losses	kWh/h						
Nominal charging temperature	°C		-6				
Control System				Comments			
Centralized MCR	Y/N	Yes		One missing for coherent energy balance			
Control strategy: modifiable by the technical services	Y/N	Yes					
Monitoring capabilities	Y/N	Yes					
Circuit Temperature measurements	Nb	Yes					
Flowrate counters	Nb	Yes					
Electrical counters for cold machines consumption	Nb	Yes					

Fig A.2. - Main parameters of the HCR cooling system



Secondary user devices - "Building" loop		Total	kW	527	Comments
Offices "Montbrillant side", air conditioning AHU			kW	174	Regulation by 2-way vanes
Offices "France street side", air conditioning AHU			kW	157	
Conference room (underground)			kW	29	
Class room			kW	18	
Kitchen			kW	48	
Restaurant			kW	41	
Technical rooms			kW	26	
Elevators machinery "MontBrillant"			kW	17	
Elevators machinery "France"			kW	17	
Secondary user devices - "Information" loop			kW	613	
Inductors in offices (individually adjustable air temp. input)			kW	367	Auxiliary pump 3 kW
Offices internal zones (cold ceilings)			kW	200	Auxiliary pumps 2 x 1.1 kW
Information room "Montbrillant"			kW	10	Auxiliary pumps 2 x 1.1 kW
Information room "France"			kW	10	
Reprography			kW	16	
Telephone room			kW	5	
Security room			kW	2.6	
Technical room low current			kW	2.6	
Practical implementation of the network					
Cold machines location (underground / room / roof)		comment			2nd floor Underground
Distance (tubes) to the main loop		m			
Ease of incoming into the building		comment			
Room for Exchangers		m2, m3			At the place of the second cooling machine
Available Documentation					
Schema of the cold production/distribution available ?	Y/N	Yes			
Specifications of the Cold machines	Y/N	No			
List of the cold energy receivers, with nominal power	Y/N	Yes			
Consumption data of the preceding operating years (month, year)	Y/N	Yes			Detailed monthly data over 11 years

Fig A.2. - Main parameters of the HCR cooling system (continued)

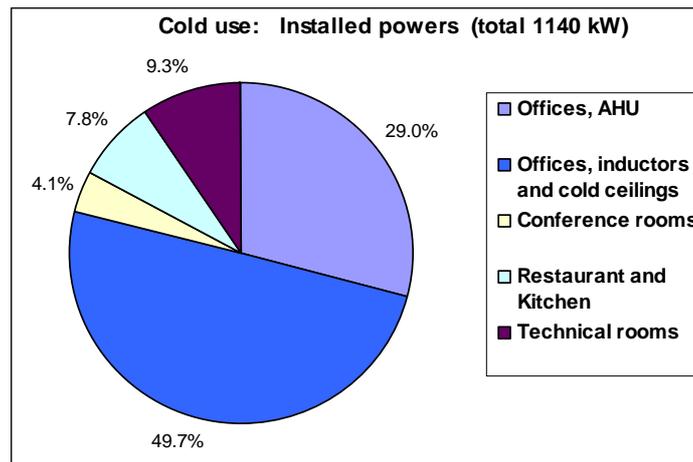
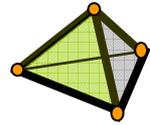


Fig A.3. - Use of Cold energy: installed powers

NB: the installed power totalises 1140 kW, for a nominal cold production capacity of around 520 kW, i.e a deficit of 590 kW, which may be sometimes compensated by the 3'000 kWh storage.

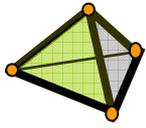


Annex B. - List of variables and sensors

For ease of analysis, this table displays all the involved variables, as well as their availability in the data. Most of them (referenced as **"Hour"**) are available in the data sample recorded during the monitoring campaign from May to October 2006. The counter data available in the 11-years monthly database are referenced as **"Month"** or **"M"**.

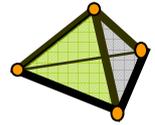
Variable	Description	Availability	Calculation / Remarks
Meteo measurements from Cointrin (5 km apart)			
Ginc	Global irradiance, horizontal	Hour	
Dinc	Diffuse irradiance, horizontal	Hour	
Text	Ambient external temperature	Hour	
HRel	Relative Humidity	Hour	
"Building" circuit production			
EBProd	Electricity for main cold machine	M, H	
QBCEvac	Condenser heat => evacuation	M, H	
QBCEvac	Condenser heat => recovery for heating	Month	
QBCEvac	Condenser heat => recovery for DHW	Month	
QBProd	Cold machine production (evaporator)	Calc.	$(QBCEvac+QBCEvac) - EBProd$
COPBProd	COP rel. to production	Calc.	$QBProd / EBProd$
TBOProd	Temper. OUT cold production	Hour	
TBIProd	Temper. IN cold production	Hour	
TBEIEvac	Temper. IN evacuation tower	Hour	
TBEIEvac	Temper. OUT evacuation tower	Hour	
TBEIRecov	Temper. IN recovery Xchg.	Hour	
TBEIRecov	Temper. OUT recovery Xchg.	Hour	
"Building" circuit distribution			
QBDist	Distribution loop flow rate	M, H	
QBDist	Distribution + Storage loss	Bal.Month	$QBProd - QBDist$
COPBDistr	COP rel. to distribution (average)	Calc.Month	$QBDist / EBProd$
TBDistrib	Temper. IN distribution	Hour	
TBXchg	Temper. OUT Xchanger => info circuit	Hour	
TBDReturn	Temper. return distribution	Hour	
QXchg	Heat to the exchanger	M, H	Apply correcting factor of 3.33
"Information" secondary circuit			
EIProd	Electricity for secondary cold machine	M, H	
QICEvac	Condenser heat => evacuation	M, H	Apply correcting factor of 0.75
QIProd	Cold energy production	M, H	$QICEvac - EIProd$
QIDistr	Cold energy distribution	M, H	$QXchg + QIProd$
QIIOffices	Cold energy for office inductors	M, H	
QIInfo	Cold energy for Info and cool ceilings	M, H	$QIDistr - QIIOffices$
TIOutXchg	Temper. OUT Xchg (import "Building")	Hour	
TIOutProd	Temper. OUT cold machine	Hour	
TIOutOffl	Temper. OUT offices inductors	Hour	
TIOutOffC	Temper. OUT offices cold ceilings	Hour	
TIOutTechn	Temper. OUT technical rooms	Hour	
TIReturnP	Temper. Return to prod. machine	Hour	
TIReturnX	Temper. Return to Xchg.	Hour	
TIOutCond	Temper. OUT condenser (roof)	Hour	
TInCond	Temper. IN condenser (roof)	Hour	

Table B.1 - Variables in the HCR analysis (black = measured)



Variable	Description	Availability	Calculation / Remarks
Ambiant temperatures - Minilog measurements			
TAttr1	Atrium, rez	Hour	7-stages open atrium not heated, glazed roof, with poor solar protections
TAttr4	Atrium, ground of 4th floor	Hour	
TAttr6	Atrium, ground of 6th floor	Hour	
TVicAir4	Viciated air duct, corridor 4th floor	Hour	Representative of the global floor
TOffice4	Ambient, office 4th (west)	Hour	
TDistr4	Inductor air distrib, office 4th (west)	Hour	
HOffice4	Humidity office 4th (west)	Hour	
TVicAir7	Viciated air duct, corridor 7th floor	Hour	Representative of the global floor
HVicAir7	Humidity Viciated air duct, 7th floor	Hour	
TOffClosed7	Ambient, closed office 7th	Hour	One of the few closed offices
TDistr7	Inductor air distrib, closed office 7th	Hour	
TOffSud7	Ambient, open office 7th (south)	Hour	Most offices are open as "landscape"
TDistrSud7	Inductor air distrib, open office 7th	Hour	
TDistrInfo	Information room, distrib (upper pos.)	Hour	Cold installation to be refurbished in a very short delay.
TRetInfo	Informatic room, viciated air (lower pos.)	Hour	

Table B.1 (continued) - Variables in the HCR analysis - Mini datalogger measurements



Annex C. - Some values over the measuring period

We give here a sample of some significant measured values during our monitoring period from June 8th to end August 2006. This gives an overview of the weather conditions and the building operation.

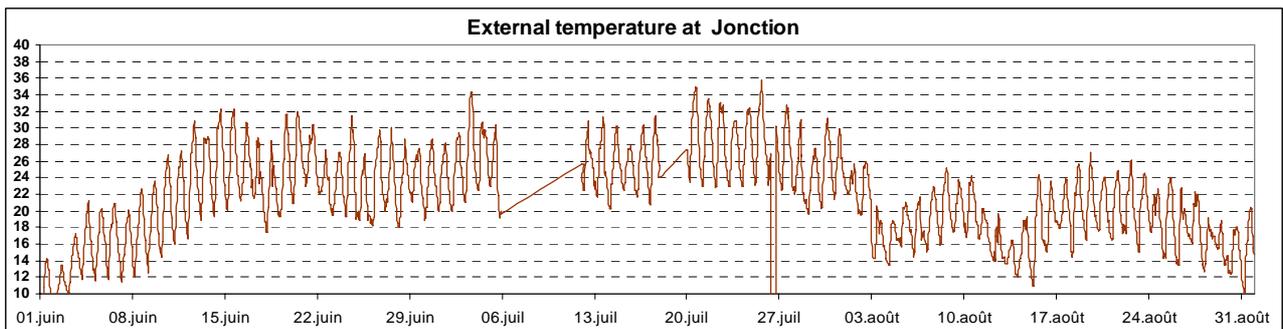
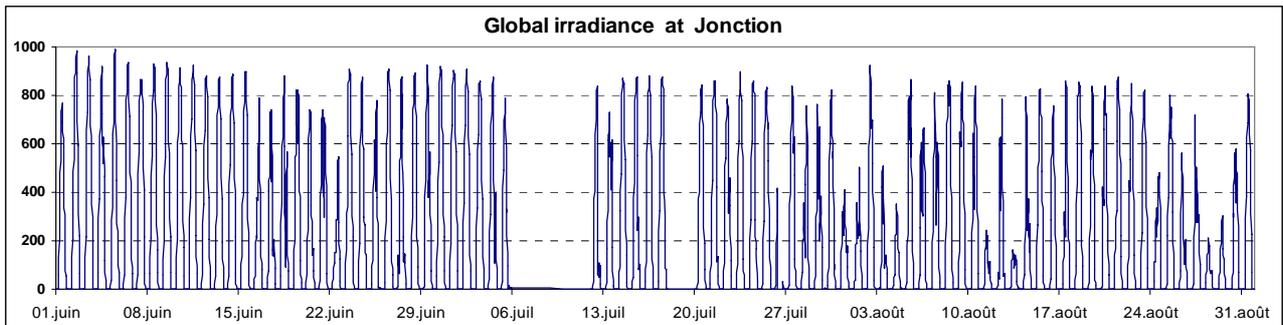


Fig C.1 and 2. – The weather was very sunny in June and July. Much less in August, with a significant drop of the temperatures.

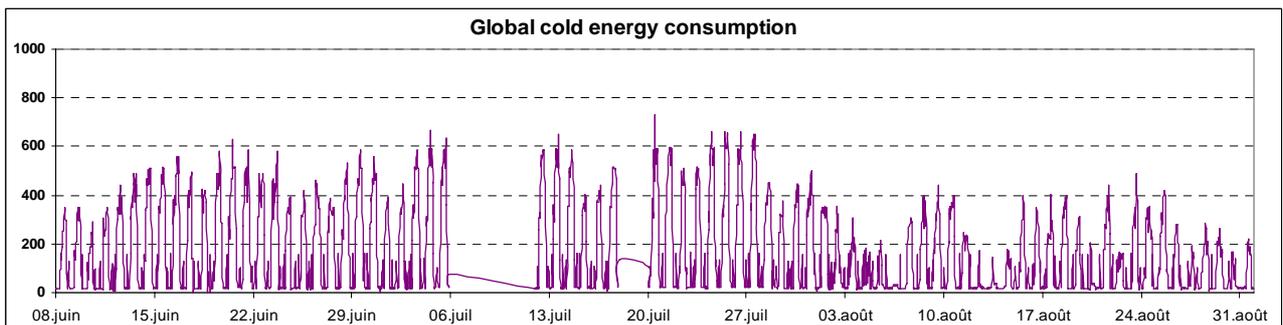


Fig C.3. – The cold energy consumption attained 650 kW shortly, during 4-5 days only.

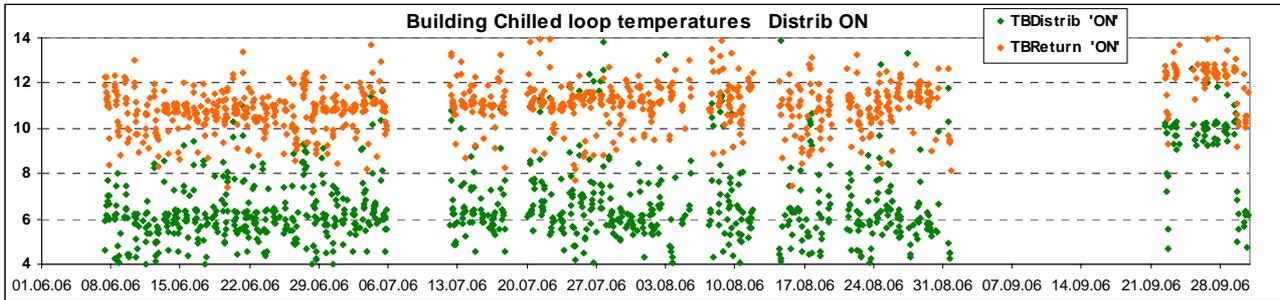
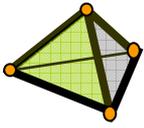


Fig C.4. – The "building" loop distribution temperatures were dispersed around 6-8°C and 10-12°C. It has been raised to 10/13°C in September for tests, without noticeable effect on the building service nor on the secondary "Info" loop

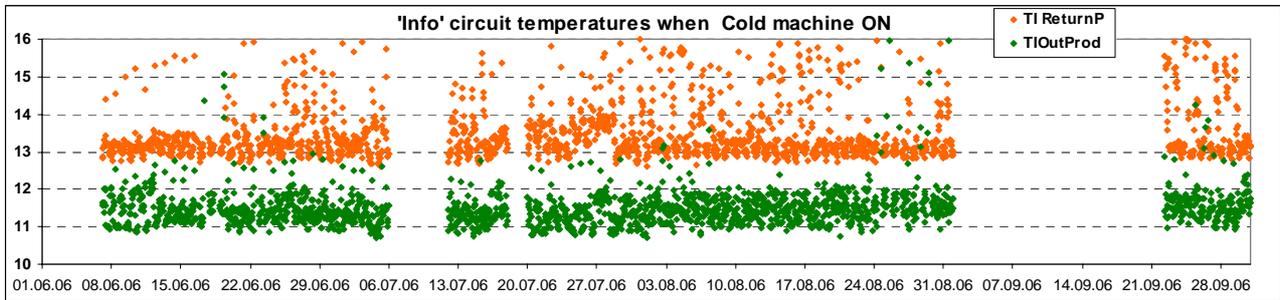


Fig C.5. – The "Info" loop distribution is around 11°C / 13.5°C, i.e. a ΔT of 2.5°C only.

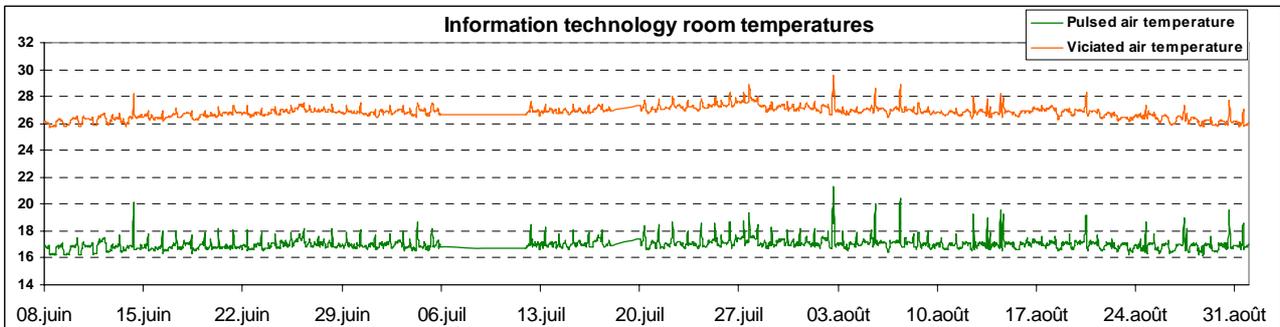


Fig C.6. – The distribution in the Info rooms is high, but quite stable.

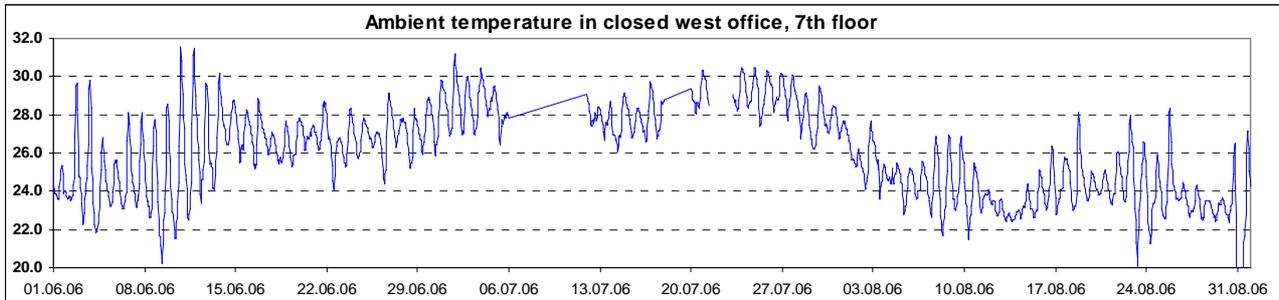
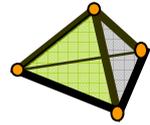


Fig C.7. – Ambient temperatures in an office, “inductor” probably not working.

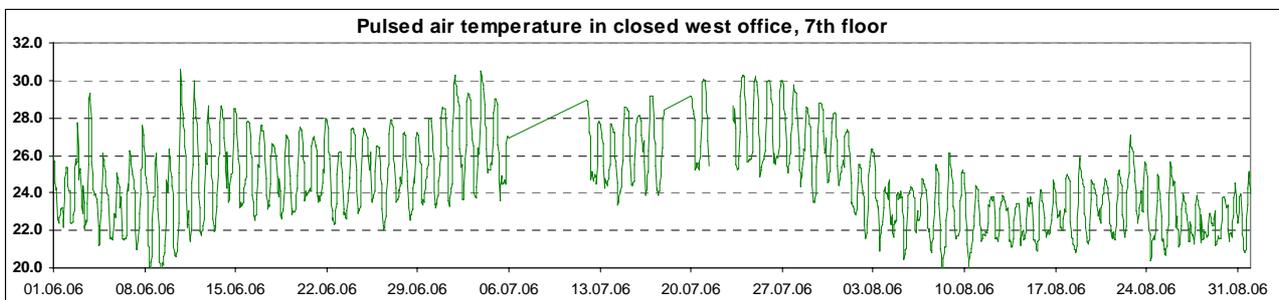


Fig C.8. – Corresponding Pulsed air temperature in the inductor

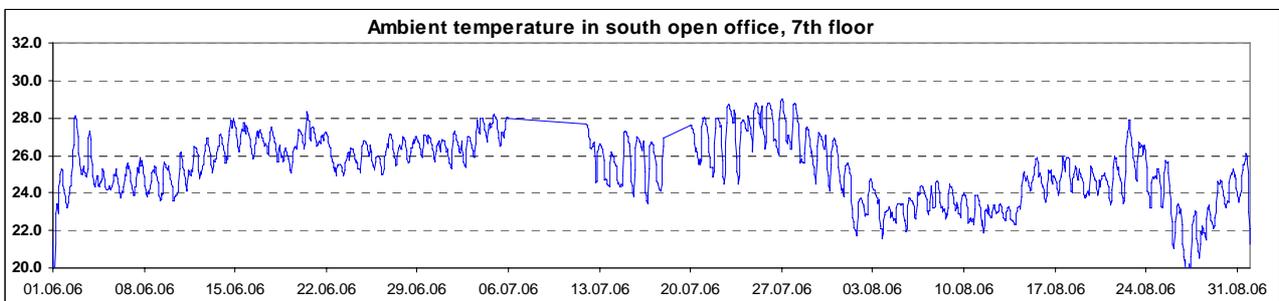


Fig C.9. – Ambient temperatures in an office, “inductor” operating properly.

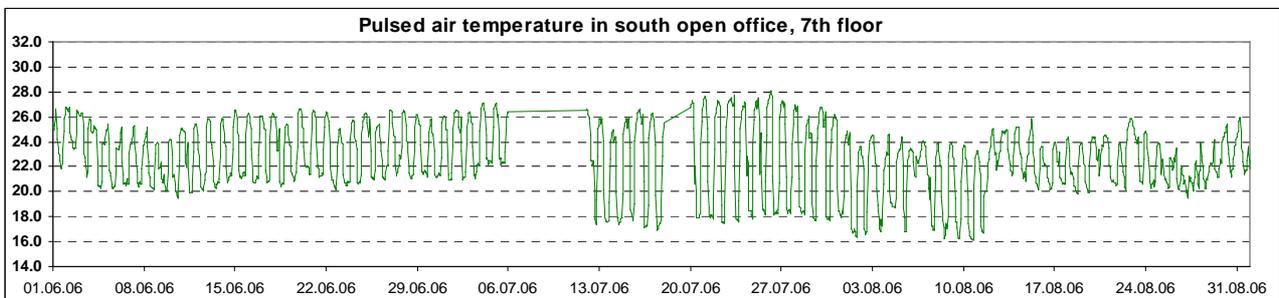
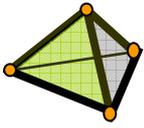


Fig C.10. - Pulsed air temperature in the inductor: activated and not activated



Annex D. - Dialogs and results of the Strategy tool

We give here as an example a complete panel of the different tables in the strategy tool. Please refer to the text for detailed explanations.

Energy calculation over one year (or period)

Project name	HCR Building Measurements and Audit
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This tool calculates the cold energy required over one reference period (year or other). It also gives graphs of the Power distribution over this period.

Calculations are based on:

- A design reference year giving temperatures in hourly values
- The "Signature" parameters of the air conditioning installation

Green cells: parameter to be defined

The basic "Signature" equation:

$$P = P_{cold_const} + (Text - Text_Thresh) * PCold_Slope$$

Parameters to be defined (from data or supposed)

PCold_const	40 kW	Constant consumption of some appliances (for example Info room)
TextThresh	18 °C	Threshold on external temperature for starting cooling installations
PCold_Slope	40 kW / °C	Slope of the Power needs as function of the external temperature

Main results

Qcold_year	794.3 MWh	Cold energy from the whole year sum
Nb running hours	2342 hours	(excluding Qconst Yield)
Max. temperature	35.7 °C	maximum temperature in the data sample
Max. power	708 kW	maximum power demand (for this max. temperature)

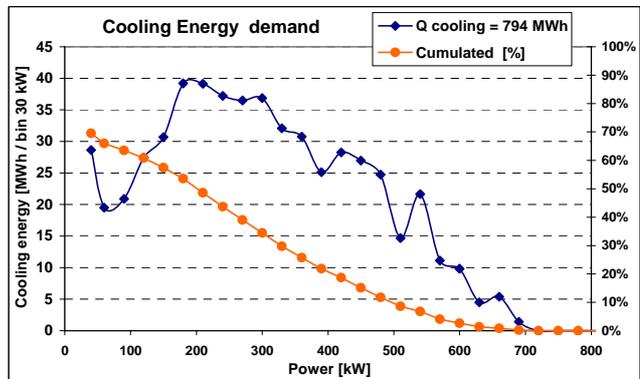
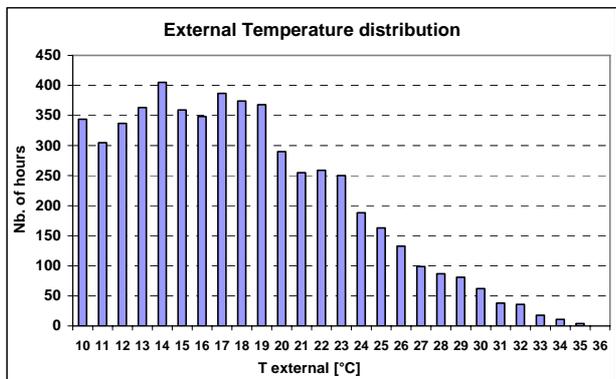
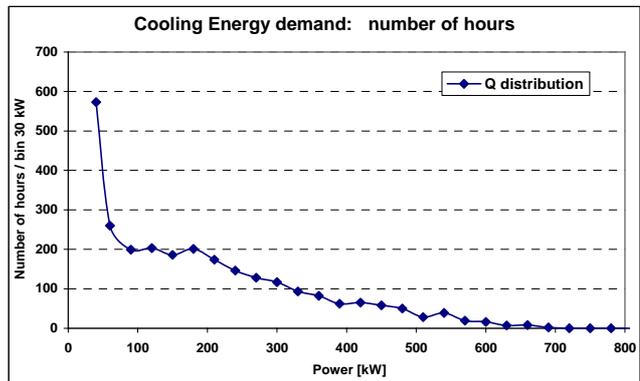
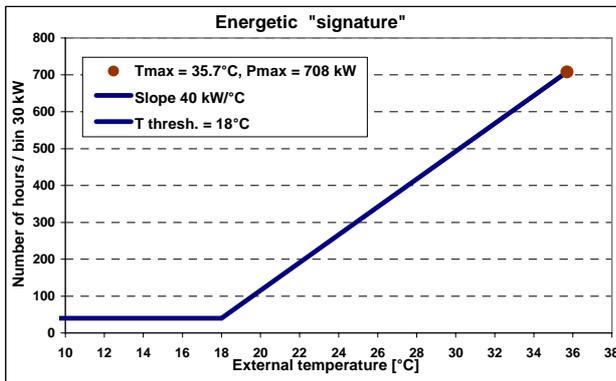
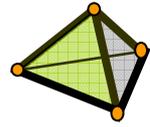


Figure D.1. – Excel tool "Tetraener_Audit_StrategyTool.xls - "Year Energy" sheet



Measured chilled loop behaviour

Project name	HCR Building Measurements and Audit
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This sheet aims to establish **parametrized models** for the **measured** present operating behavior of the chilled loop. It also asks for **hypothesis** about the possible Tdistrib, taking **over-sizing** and **partial load** into account.

First define a "Nominal Power" corresponding to the maximum external temperature foreseen

Linear models for

Distribution temperature:

$$TDistrib = TDnom + TDSlope * (PCold_Nom - PCold)$$

Loop flowrate

$$FRLoop = FRNom - FRslope * (PCold_Nom - PCold)$$

Calculations based on the previously defined "signature"

PCold_const	40 kW	Constant consumption of some appliances (for example Info room)
TextThresh	18 °C	Threshold on external temperature for starting cooling installations
PCold_Slope	40 kW / °C	Slope of the Power needs as function of the external temperature
Max. temperature	35.7 °C	maximum temperature observed in the data sample
Max. power	708 kW	maximum power demand (for this max. temperature)

Nominal conditions operating point :

Define a **Nominal Power**

PCold_Nom.	750 kW	Nominal power for meeting the worst external conditions
Text_Nom	36.8 °C	Corresponding external temperature
TDmeas_Nom.	6.0 °C	T Distribution loop at nominal conditions (measurements)
TRmeas_Nom.	11.0 °C	T Return loop at nominal conditions (measurements)
Loop Heat Cap.	1.05 kWh/m³k	If water, cpw = 1.16, otherwise acc. to antifreeze concentration
FlowR meas_Nom	129 m3/h	Resulting flow rate at nominal conditions

Define **circuit temperatures acc. to measurements at nominal conditions**

Linear model according to PCold

Define **circuit temperatures acc. to measurements at null power**

TDMeas (0kW)	6.0 °C	T Distrib. loop at the limit Power = 0
=> TDSlope_Meas	0.00 m°C / kW	
FlowR_Meas_0kW	0 m3/h	Flowrate at the limit Power = 0
FlowR_Meas_Sl	0.17 m3/h / kW	

Define **FlowR at null power**

Hypothesis: possible distribution temperatures

Taking oversizing and partial loads into account

TDPoss_Nom	7.0 °C	Tdistrib nominal maxi allowing requirements of all consumers
TDPoss_0kW	14.0 °C	Tdistrib at 0 kW allowing requirements of all consumers at partial loads
TDSlope_Poss	9.33 m°C / kW	

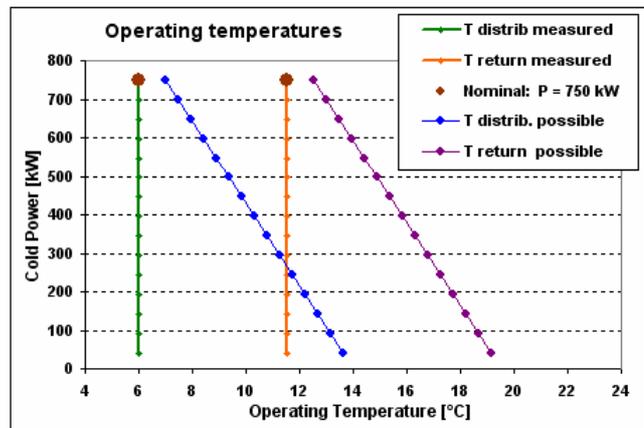
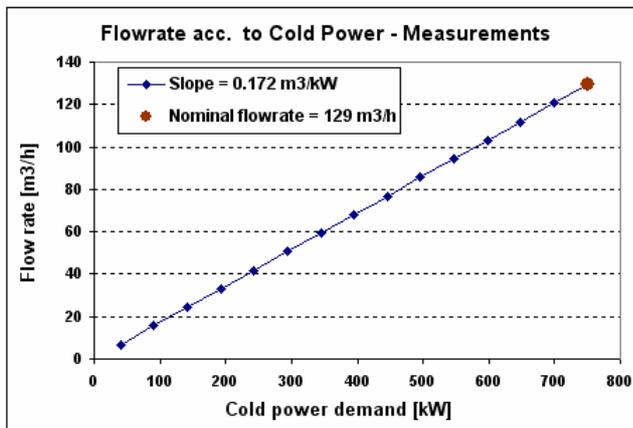
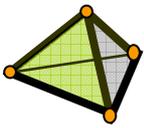


Figure D.2. – Excel tool "Meas. Distrib" sheet



Control strategy

Project name HCR Building Measurements and Audit

This tool shows the system distribution behaviour according to the chosen strategy
 The main parameters to be chosen here are the **FR Slope** and the **FR Thresh** from which slope is proportional

Temp. Output exchanger	$T_{Out\ Exch.} = T_{Lake} + (T_{Return} - T_{Lake}) \cdot (1 - Effic_Xchg)$	
Distribution temperature	$T_{Distrib} = \text{Minimum} (T_{OutExch}, T_{DPossible})$	
Loop flowrate	$FR_{loop} = FR_{Nom} - FR_{Slope} \cdot (P_{Cold_Nom} - P_{Cold})$	$FR_{loop} > FR_{thresh}$
	$= FR_{Slope2} \cdot P_{cold}$	$FR_{loop} < FR_{thresh}$

Calculations based on the previously defined : Signature Nominal power Possible distrib. temp.	PCold_const 40 kW	Constant consumption of some appliances (for example Info room)
	TextThresh 18 °C	Threshold on external temperature for starting cooling installations
	PCold_Slope 40 kW / °C	Slope of the Power needs as function of the external temperature
	PCold_Nom. 750 kW	Nominal power for meeting the worst external conditions
	TDPoss_Nom 7.0 °C	Tdistrib nominal maxi allowing requirements of all consumers
	TDPoss_0kW 14.0 °C	Tdistrib at 0 kW allowing requirements of all consumers at partial loads

Define circuit temperatures at nominal conditions	TOutExch_Nom 9.43 °C	T output exchanger Lake feeding: $T_{lake} + \Delta T_{exch}$ 9.43 °C
	TDistrib_Nom 7.0 °C	T Distribution loop at nominal conditions
	TReturn_Nom 13.0 °C	T Return loop at nominal conditions
	FlowR_Nom 108 m3/h	Resulting flow rate at nominal conditions

Define derating values of the Flowrate according to PCold power	Tdistrib (0kW) 9.0 °C	T Distrib. loop at the limit Power = 0
	=> TSlope_Xchg 0.58 m°C / kW	Lake feeding: $TD(0kW) = T_{lake} = 9.0$ °C
	FR slope 0.170 m3/h / kW	Flowrate decrease when power increases
	FR thresh [%] 20% % of FlowR nom	Minimum from which Flow decreases linearly to 0 = slope change of Flowrate
	FR threshold 22 m3/h	
	P (FR thresh) 243 kW	Corresponding Power from which FlowR prop. to power

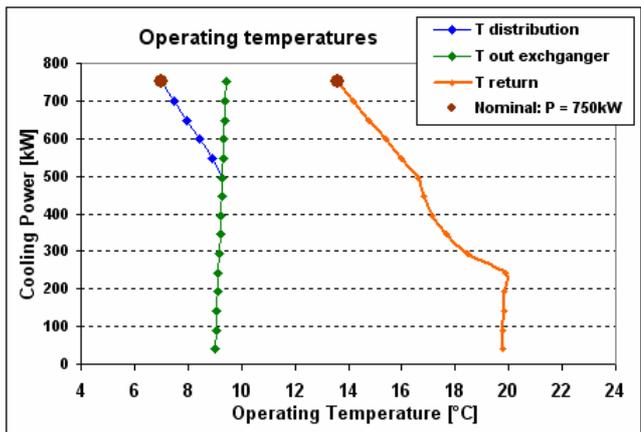
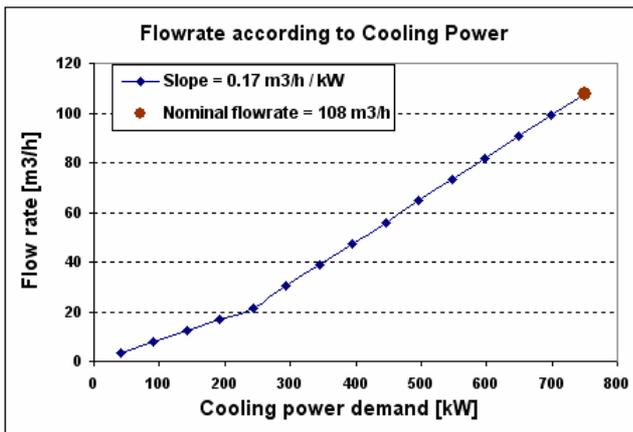
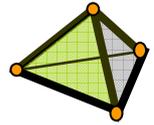


Figure D.3. – Excel tool "Control Strategy" sheet



Connection to the Lake: Energy, Water needs, Costs

Project name	HCR Building Measurements and Audit
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Based on the previous parameters, this tool determines the **Transferable Power and Energy from the lake**

Lake temperature	T_Lake 9 °C	Lake temperature (present state: constant over the refresh period)
Network constraints	FR Lake_Max 86 m3/h Xchg_KS 500 kW/K	Flowrate corresponding to the subscribed power Characteristic size of the exchanger
Contractual conditions	Subscr Power 600 kW Abonnt price 15.8 € / kW Energy basic price 6.5 ct€/kWh Derating price -0.33 cte/kWh Derating thresh 14 °C	Power subscribed by the user Price of the subscribed power Basic price of the cold energy delivered Derating acc. to Treturn Temperature limit for the basic tariff
Conventional energy	Electricity cost 10 ct€/kWh Average COP 2.5	Electricity for auxiliary cooling machines
Yearly results	Energy needs 790 MWh Operating time 2342 hours Oper. Time Nom 1053 hours Energy from lake 784 MWh Lake yield 99% Lake water needs 83 m3 * 1000 Relative 40.9%	Total building demand of cold energy Operating time without PCold_Const contributions Equivalent operating time at PCold_Nom Energy drawn from the Lake network Corresponding Flow in the lake circuit Relative to permanent subscribed flowrate
Financial balance	Abonnement cost 9'483 € Lake energy cost 38'314 € Aux. energy cost 251 € Total cost 48'048 € Average cost 6.1 ct€/kWh	Tax on the subscribed maximum Flowrate Energy cost with degressive tariff Electricity for Auxiliary cold energy Total cost of the cold service Specific cost

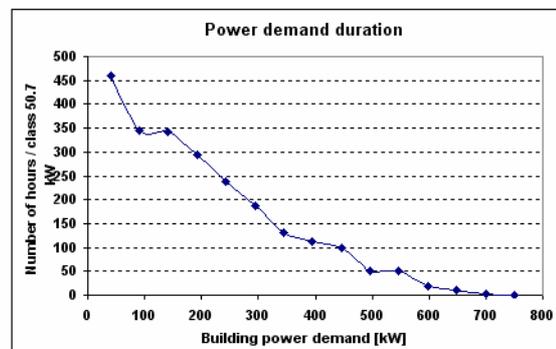
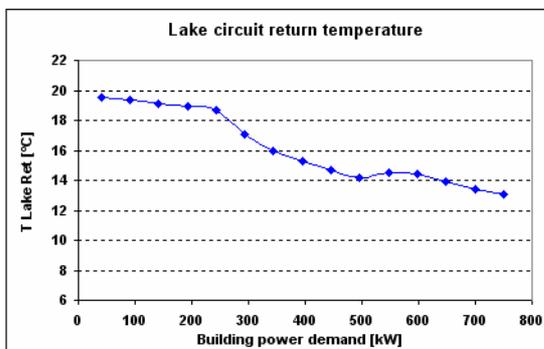
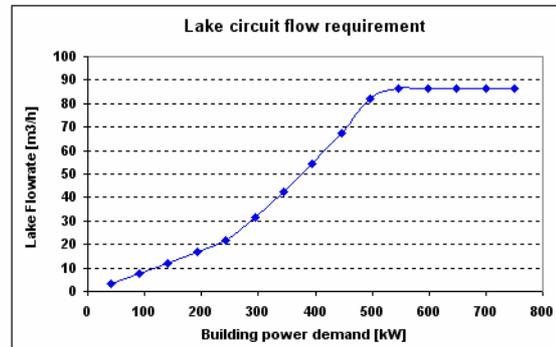
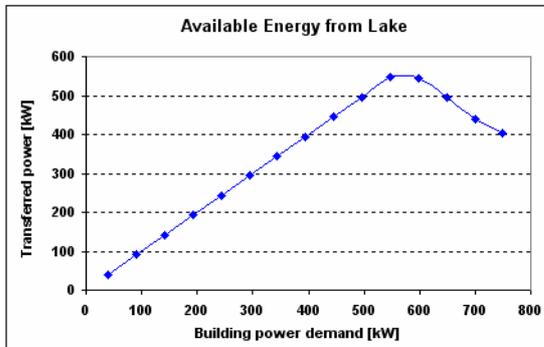
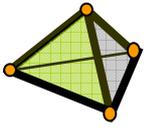


Figure D.4. – Excel tool "Lake Balance" sheet



Scenarios

Project name	HCR Building Measurements and Audit
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This sheet gathers results of several scenarios (from Signature to Balances and Costs) for comparisons of Control Strategies

Scenario	descriptions
#1	Basic case: possible Tdistr nom = 7/13°C, FR slope optimized, subscribed power = 600 kW
#2	Basic case + Increase subscribed power to 750 kW
#3	Basic case + Decrease exchanger size to 300 kW/k
#4	Basic case + FR slope kept purely proportional
#5	Basic case + Possible Tdistrib = 7/13°C whatever the Power

Current values

			#1	#2	#3	#4	#5
"Signature" of the Cold Power demand							
Constant consumption (e.g. information technology appliances)	PCold_const	kW	40	40	40	40	40
Threshold on external temperature for starting cooling installations	TextThresh	°C	18	18	18	18	18
Slope of the Power needs as function of the external temperature	PCold_Slope	kW/k	40	40	40	40	40
Derived:							
Maximum temperature in the meteo data sample	Max. Ext. temp.	°C	35.7	35.7	35.7	35.7	35.7
Maximum power demand (for this max. temperature)	Max. power	kW	708	708	708	708	708

			#1	#2	#3	#4	#5
Present Control Strategy (measurements)							
Nominal power for meeting the worst external conditions	PCold_Nom.	kW	750	750	750	750	750
Corresponding external temperature	Text_Nom	°C	36.8	36.8	36.8	36.8	36.8
T distribution temperature at nominal power	Tdmeas_Nom	°C	6.0	6.0	6.0	6.0	6.0
T return temperature at nominal power	TRmeas_Nom	°C	11.0	11.0	11.0	11.0	11.0
Loop heat capacity (if water: 1.16 kWh/m ³ k)	Loop Heat Cap	kWh/m ³ k	1.05	1.05	1.05	1.05	1.05
Flowrate at nominal power	FlowR_Meas_Nom	m ³ /h	129.3	129.3	129.3	129.3	129.3

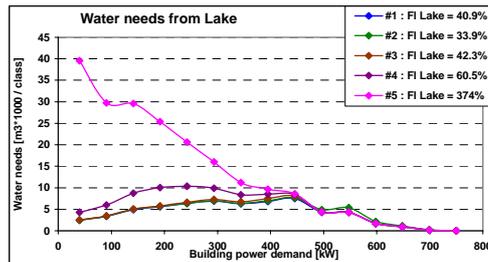
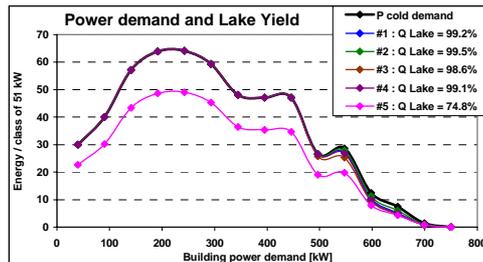
			#1	#2	#3	#4	#5
New Control strategy with Lake feeding							
T distribution possible at nominal power (for meeting requirements)	TDPoss_Nom	°C	7	7	7	7	7
T distribution possible at null power (for meeting requirements)	TDPoss_0kW	°C	14	14	14	14	7
Effective chilled loop temperatures							
T distribution at nominal conditions	Tdistrib_Nom.	°C	7.0	7.0	7.0	7.0	7.0
T output exchanger at nominal conditions	TOutExch_Nom	°C	9.4	9.4	10.0	9.4	9.4
T return at nominal conditions	Treturn_Nom	°C	13.0	13.0	13.0	13.0	13.0
T distribution at P = 0 kW (normally = TLake)	Tdistrib_0 kW	°C	9.0	9.0	9.0	9.0	9.0
T slope at exchanger output	=> TSlope_Xchg	m°C / kW	0.58	0.53	1.32	0.58	0.58
Effective Loop Flowrate							
Flow rate at nominal conditions	Flow Rate Nom	m ³ /h	108	108	108	108	108
Flowrate decrease when power decreases	FR slope	m ³ /h/kW	0.170	0.170	0.170	0.142	0.142
Minimum from which Flow decreases linearly to 0 (elbow)	FR threshold	m ³ /h	22	22	22	22	22
Corresponding Power from which FlowR prop. to power	P (FR thresh)	kW	243	243	243	143	143

			#1	#2	#3	#4	#5
Lake temperature							
Maximum Flowrate subscribed	FR Lake_Max	m ³ /h	86	108	86	86	86
Exchanger size	Xchg_KS	kW/K	500	500	300	500	500

			#1	#2	#3	#4	#5
Contractual conditions							
Power subscribed by the user	Subscr Power	kW	600	750	600	600	600
Price of the subscribed flowrate	Abonnt price	€/ kW	15.8	15.8	15.8	15.8	15.8
Basic price of the cold energy delivered	Energy basic price	ct€/kWh	6.5	6.5	6.5	6.5	6.5
Derating according to Return temperature	Derating price	ct€/kWh	-0.33	-0.33	-0.33	-0.33	-0.33
Temperature limit for the basic tariff	Derating thresh	°C	14	14	14	14	14
Electricity for auxiliary cooling machines	Electricity cost	ct/kWhe	10	10	10	10	10
	Average COP		2.5	2.5	2.5	2.5	2.5

			#1	#2	#3	#4	#5
Yearly results according to temperature distribution							
Total building demand of cold energy	Energy needs	MWh	790	790	790	790	790
Operating time (excluding PCold_Const contributions)	Operating time	hours	2342	2342	2342	2342	2342
Equivalent operating time at nominal power	Oper. Time Nom	hours	1053	1053	1053	1053	1053
Energy drawn from the Lake network	Energy from lake	MWh	784	786	779	783	591
	Lake energy yield	%	99.2%	99.5%	98.6%	99.1%	74.8%
Corresponding Flow in the lake circuit	Lake water needs	m ³ *1000	82.7	85.7	85.5	122	755
Water needs relative to permanent subscribed Flowrate	relative	%	40.9%	33.9%	42.3%	60.5%	374.0%

			#1	#2	#3	#4	#5
Financial balance							
Tax on the subscribed maximum Flowrate	Abonnement cost	€	9 483	11 853	9 483	9 483	9 483
Energy cost with degressive tariff	Lake energy cost	€	38 314	38 486	37 737	46 994	38 426
Electricity for Auxiliary cold energy	Aux. energy cost	€	251	153	430	298	7 957
Total cost of the cold service	Total annual cost	€	48 048	50 492	47 650	56 774	55 866
Specific cost	Average cost	ct€/kWh	6.1	6.4	6.0	7.2	7.1



Annex E. - Tool for the evaluation of cooling options in a single office

This part gives an evaluation of the cooling loads for a typical west oriented office of the HCR building, following the method of SIA 2021 [Zürich 2002]



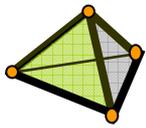
Fig E.1. - Plan and façade of an office

The evaluation of the total summer heating of one typical office during a day with external temperature between 20° and 30°C, gives the following results:

Solar heating contribution parameters :	88 [Wh/m ² .day]	39% of total insulating double glazing with external blind g factor of window combined with blind: 0,15
Internal heating contribution parameters :	137 [Wh/m ² .day]	61% of total
	2 persons + equipment:	18 W/m ²
	lighting intensity	10 W/m ²
Occupation conditions (persons+equipment)		7 hour/day

Therefore the total heating contribution is 225 [Wh/m².day] , which means that it should be possible to manage the summer gains by a simple ventilation system (see board in Annex E).

Constructed in 1989, this building has not too much glazed parts, and a good external blind system on the façades.



This quick evaluation tool is part of the "**Cahier Technique SIA 2021**" [Zürich, 2001].

		somme journalière moyenne de l'apport de chaleur total (apports de chaleur solaire et interne) Qtotal en Wh/m2.d			
		150	250	350	450
système pour ventilation et refroidissement		Evaluation des risques relatifs au confort thermique et appréciation du système choisi			
0	seulement ventilation par fenêtres	évent. suffisant	insuffisant	insupportable	insupportable
	confort avec ventilation fenêtre de jour				
	choix de l'équipement technique	évent. suffisant	insuffisant	insuffisant	insuffisant
1	ventilation méca. + ventilation de nuit	28°C à 29°C	29°C à 31°C	30°C à 32°C	31°C à 34°C
	taux renouvellement de l'air 2.0 h ⁻¹	évent. suffisant	insuffisant	insupportable	insupportable
	confort sans ventilation fenêtre de jour				
	confort avec ventilation fenêtre de jour				
	choix de l'équipement technique	suffisant	évent. suffisant	insuffisant	insupportable
		convenable	évent. suffisant	insuffisant	insuffisant
2	comme 1 + refroidissement air primaire	26°C à 27°C	27°C à 29°C	28°C à 31°C	29°C à 33°C
	confort sans ventilation fenêtre de jour	bon	suffisant	insuffisant	insupportable
	confort avec ventilation fenêtre de jour	très bon	bon	évent. suffisant	insuffisant
	choix de l'équipement technique	optimal	convenable	évent. suffisant	insuffisant
3	comme 2 + refroidissement complémentaire de jour avec 20 W/m2	<< 26°C	< 26°C	26°C à 27°C	27°C à 28°C
	confort sans ventilation fenêtre de jour	bon	bon	suffisant	insuffisant
	confort avec ventilation fenêtre de jour	bon	très bon	bon	évent. suffisant
	choix de l'équipement technique	surdimensionné	optimal	convenable	évent. suffisant

Table E.1. – Evaluation grid, according to Cahier Technique SIA 2021 method