2nd GLOBAL DISTRICT ENERGY CLIMATE AWARDS 2011

Climespace - City of Paris:

A District Cooling System to control impact of air-conditioning in Paris

From:		To:
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Motivational letter:

Paris, 31st of march 2011

Since 1991, Climespace operates and develops the Paris district cooling system under a public service concession held with the City of Paris. As a capital city with a dense urban fabric and some 60 million square metres of tertiary sector premises, Paris represents a favourable environment for the development of a district cooling system.

The District Cooling System operated by Climespace is a municipal scheme with millions of users each year. Climespace has 500 clients in Paris, including the greatest buildings, hotel and department stores of Paris and their millions of visitors per year.

In light of these accomplishments, the City of Paris and Climespace wish to participate in the International District Energy Climate Awards in the category District Cooling.

City of Paris and Climespace have now been working together for more than 20 years. Development of the largest District Cooling System in Europe, innovations in the facilities operation and management, selection of the most efficient technologies have contributed to major savings in energy consumption.

Damien TEROUANNE

Abstract:

Given the current context of global warming and the emergence of questions relative to urban heat island effect, the creation of a district cooling system can help limit drastically the impact of mass utilization of air conditioning.

As a capital city with a dense urban fabric and some 60 million square metres of tertiary sector premises, Paris represents a favourable environment for the development of a district cooling system. It is for this reason that Climespace operates and develops the Paris district cooling system under a public service concession held with the City of Paris since 1991.

Through its Climate Plan, the City of Paris is making energy control one of the key issues of its environmental policy. It has undertaken with its partners to reduce greenhouse gas emissions and energy consumption in its area by 25% between now and 2020. The Climate Plan also aims to increase the share of renewable energy in the city's energy consumption to 25%.

The District Cooling System of Climespace is the largest in Europe, with a network of more than 140 km in length and 325 MW of installed cooling capacity serving nearly 500 customers. The cooling energy produced is used, for example, for the air conditioning of the Louvre Museum, preserving the works of art and ensuring the comfort of the millions of people who visit the museum each year.

Since the end of the 1990's, Climespace has deployed a strategy based on energy efficiency. The construction of power plants cooled by the water from the River Seine, the use of renewable cold sources and fundamental changes in both the management and the operation of the facilities have enabled Climespace to substantially improve its performance between 2002 and 2010.

The development of the Paris district cooling system has limited the installation of stand-alone air-conditioning systems in the city. For an equivalent installed cooling capacity, the district cooling system and the strategy deployed by Climespace have brought truly impressive savings:

- Annual reduction in electricity consumption of 42%
- Annual reduction in CO_2 emissions of 48%

Climespace serves the interests of the Paris community through its commitment to continuously improve energy efficiency and reducing the environmental impact of its activity. An environmental assessment is communicated to the City of Paris each year.

CONTENTS

1. The City of Paris district cooling network

1.1. Background

Climespace has been producing and distributing cooling energy in the centre of Paris through a district cooling system since 1978. This system satisfies the air-conditioning requirements of many buildings in Paris (large stores, museums, offices, hotels).

Under the concession concluded with the City of Paris in 1991, the district chilled water system has undergone sustained development, with about 20 MW additional cooling energy installed per year.

Climespace is a subsidiary of the group GDF Suez, and is frequently called upon as a centre of expertise to assist the group's projects in the area of district cooling systems, in France and internationally.

1.2. Description of the system production means

The production means consist of 7 chilled water production plants and 3 cold storage units (1 chilled water storage unit and 2 ice storage units) with a **total installed cooling capacity of 280 MW** with distribution temperatures of between 0.5°C and 4°C.

The technical solutions adopted for the cooling of the refrigeration units differ between the plants:

- The Opéra, Etoile, Auber and Les Halles plants are equipped with air cooling towers. The cooling circuit water is in direct contact with the condensers.
- The Bercy, Canada and Tokyo plants use an open circuit cooling system that pumps water from the river Seine. This system is equipped with intermediate heat exchangers that create a physical separation between the Seine water and the condensing circuit.

These 7 production plants supply a 140-km chilled water distribution network to which nearly 500 customers are connected. This network and the location of the production plants that supply it are shown on map of the network below.

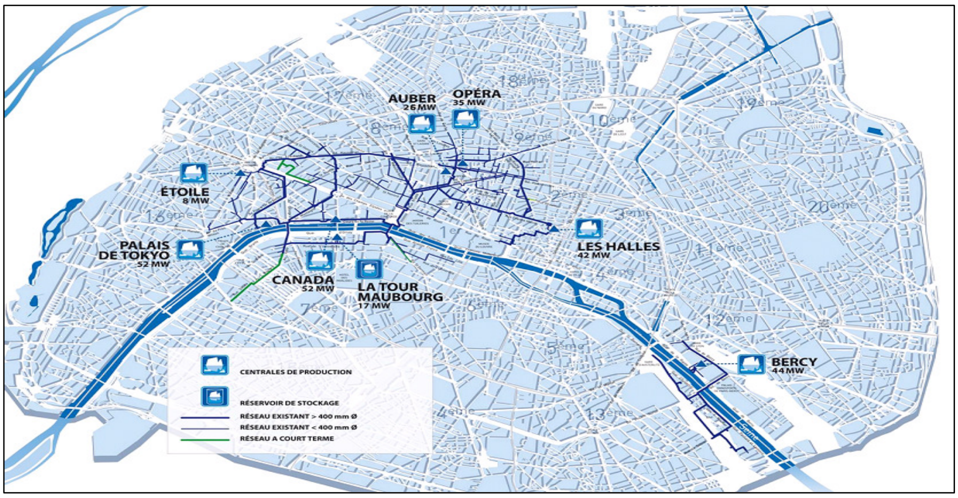

Figure 1: Map of Climespace networks

2. Context for the deployment of an environmental impact reduction strategy

Boosted by urban planning and global warming, the increasing need for air-conditioning in built-up areas has encouraged the development of air-conditioning systems, such as stand-alone air-conditioning systems and district cooling systems.

However, a joint study by Climespace and the ADEME[1] shows that the performance levels of stand-alone air-conditioning systems are poorly known, and often far below those stated by the manufacturers and highly dependent on their method of management. Furthermore, encouraged by regulations favouring the use of dry cooling systems, stand-alone conditioning systems contribute significantly to the urban heat island effect (UHIE). Simulations performed by Climespace, Météo France and the CNAM engineering school predict a local increase in nocturnal temperatures of 3°C (and which can reach 8°C in heat wave periods).

The widespread use of such systems that consume large amounts of energy is therefore not energetically sustainable.

District cooling systems on the other hand provide a sustainable response to the energy and environmental challenge that the development of air conditioning in towns represents. Combining high energy and ecological efficiency, district cooling systems have many advantages:

- **Centralized:** they allow better control of the energy efficiency of the cooling process as a whole, bringing a substantial reduction in electricity consumption and the associated CO2 emissions, greater control over refrigerant leakage and a large reduction in water consumption.
- **Integrated in the environment:** they enable the architectural heritage to be preserved, which is vital for a city like Paris.
- **Controlled:** they ensure good control of the health risk (Legionella bacteria).

Thus, the district cooling system helps achieve the ambitious targets the City of Paris has set in the framework of its Climate Plan. It has effectively committed itself to reducing energy consumption and carbon dioxide (CO_2) emissions by 25% while at the same time increasing to 25% the proportion of renewable energy sources in the energy consumed by the city.

This is why the City of Paris and Climespace intend to limit the impact of air-conditioning through the sustainable development of the Paris district cooling system.

In addition, it is necessary to assess and reduce the environmental impact of the system by reflecting upon a large-scale network management and control strategy that is not oriented solely towards the cooling demands of the customers.

Global management of a district cooling system (DCS) with a view to reducing its environmental impact must therefore integrate the following notions:

- Improving energy performance by integrating the following three aspects: choice of equipment technology, sufficient cooling demand from the customers, and facility management strategy
- Controlling the discharges associated with cold generation activity (chemical products, refrigerant, etc.).

As part of the monitoring process, Climespace gives the City of Paris an annual assessment of its activity and environmental performance.

Both, development of the Paris District Cooling System and its global management by Climespace, allowed for important energy savings in regards to general development of stand-alone systems in Paris.

3. Means used

To ensure effective tracking of the DCS performance, and above all to validate the performance improvements obtained, the indicators and all the factors that can influence them must be known and mastered. The most representative indicators appear to be Coefficients Of Performance (COP).

[1] ADEME: Agence de l'Environnement et de la Maîtrise d'Energie (French Environment and Energy Management Agency)

These COPs represent the quantity of electrical energy required to meet the cooling power demands of the system. Various COPs can be measured:

- **Machine COP**, which describes the performance of the refrigerating unit
- **Plant COP**, which describes the energy performance of the plant
- **Production COP**, which describes the overall performance of the DCS

Climespace's Production COP in 2002 was 3.06.

Tracking these indicators necessitates instrumenting the network and production plants. As a result, some 27,000 measuring points are linked to a supervision platform that centralizes, records and processes the measured data.

Deployment of these indicators within Climespace departments has allowed **a true strategy of management by COPs** to be put in place. Consequently, Climespace has oriented its development chiefly towards the control of electricity consumption by improving the production COP by the following means:

- Construction of basic production sites cooled by water from the river Seine
- Use of renewable energy by means of Free-Cooling
- Improvement of system performance by division of the network
- Installation of Variable Frequency Drives on the refrigerating unit compressors

Controlling refrigerant leaks further improves the environmental results achieved by Climespace. Lastly, again with a view to better assessing the impact of its activity, Climespace is also looking into the phenomenon of the urban heat island effect.

3.1. Construction of basic production sites cooled by water from the river Seine

Before 2002, Climespace's centre network consisted of 3 chilled water production plants equipped with air cooling towers (Etoile, Les Halles and Opéra). The total production capacity at the time was about 100 MW of refrigeration energy. The Bercy network has been using a 34 MW refrigeration plant cooled by water from the river Seine since 1995.

The main difference between these two types of cooling lies in their heat exchange capacity. In addition, the mean annual temperature of the Seine is lower than the mean of the outside air temperatures, therefore the water from the Seine is a better cooling source.

At the beginning of the years 2000, Climespace had to install new production plants on its centre network to meet the needs of the increasing number of connected customers. With the benefit of hindsight over several years operating the Bercy plant, improved performance could be achieved if the Seine water was more widely used for cooling:

- Reduction in electricity consumption (improvement in the COP) and improvement of CO_2 balance
- Reduction in the consumption of drinking water and chemical products necessary for the process
- Elimination of health risks
- Reduction in noise pollution (production plants located below the ground)
- Reduction in visual architectural pollution (town planning constraints in Paris)
- Elimination of steam plumes risks associated with cooling towers
- Reduction of urban heat island effect.

Perceiving the possibility of making substantial energy savings, the strategic decision was taken to develop the production capacity with sites using River Seine water. Two new production plants were thus built on the centre network (see figure 1):

- The **Canada Plant** in 2003 (52 MW cold)
- The **Palais de Tokyo Plant** in 2007 (52 MW cold)

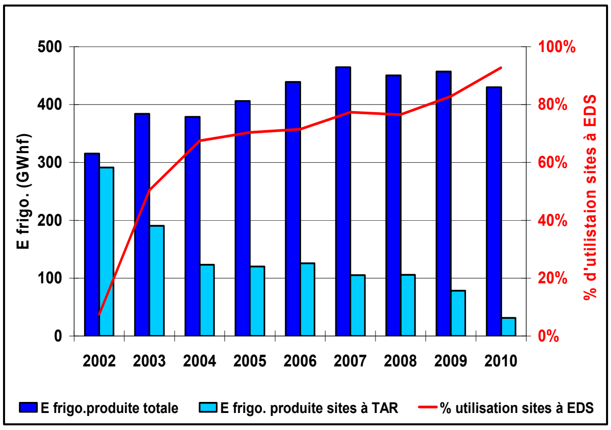

Figure 2: Percentage use of Seine water cooling plants

The majority of production was then gradually transferred to these sites representing about 50% of the production capacity of the centre network. Their share of production increased from 5% in 2002 to reach almost 90% in 2010 (figure 2 opposite).

A comparison of the plant COPs for these two types of cooling is shown in graphs 3 and 4 (for years 2009 and 2010):

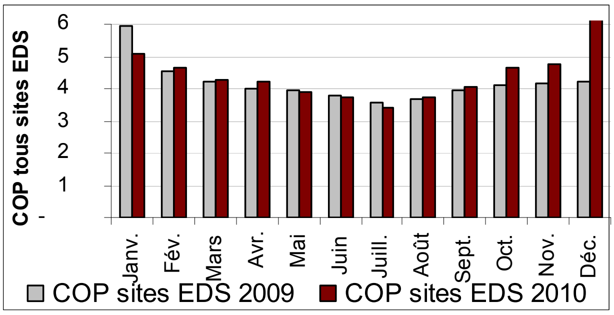

Figure 3 : COP for Seine water cooling plants

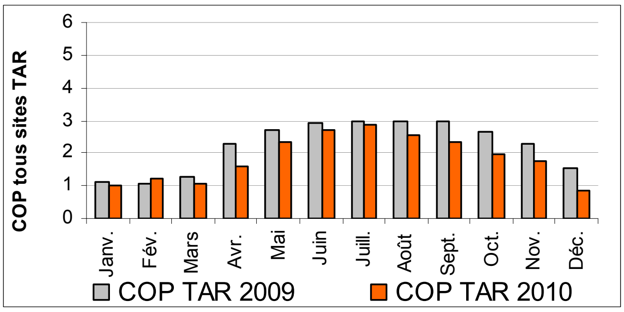

Figure 4 : COP for air-cooling tower plants

Although the performance of the plants with air cooling towers depends on their rate of use, it remains well below that of the plants using Seine water cooling. The plant COP remains below 3 all year round for the cooling tower sites, whereas it is above 3.5 all year round for the sites cooled using River Seine water.

Beside the commissioning and intensive use of the Canada and Palais de Tokyo plants, a spectacular improvement in performance was observed between 2002 and 2010. From 2003 to 2007, the Canada plant alone supplied the centre network. After 2007, the Tokyo plant's entry into service sped up the improvement in these energy performance levels (see figure 6).

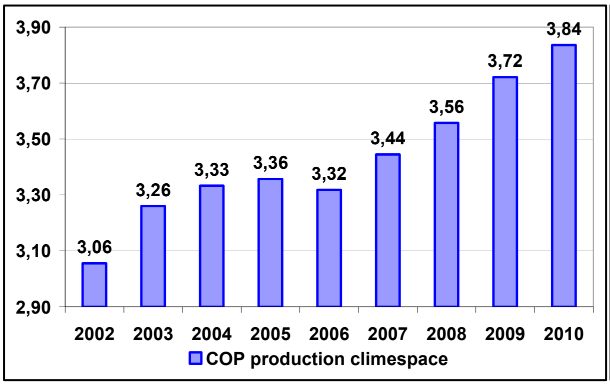

Figure 5 : Evolution of global COPs

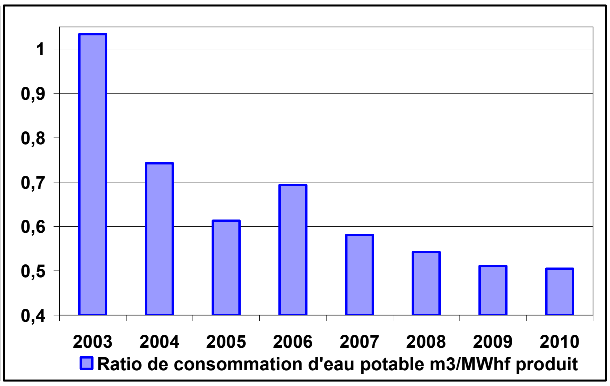

Figure 6: Evolution of water consumption

In 2010, the Production COP for Climespace was 3.84.

At the same time the consumption of drinking water and treatment products dropped. This is illustrated in figure 6 by the ratio of water volume consumed per MWh of refrigeration energy produced.

These improvements in performance were obtained in spite of the extremely strict environmental constraints imposed by the public authorities (regulations, Prefecture and City of Paris) aiming at limiting the temperature of the water discharged into the Seine and the pumping flow rate.

3.2. Use of renewable cold generated by the River Seine

Making intensive use of its new plants cooled by water from the River Seine, Climespace saw a further opportunity to improve performance: the recovery of renewable cold from the River Seine, or "free cooling".

For a certain time during the year (approximately 1000 to 2000 hours) the Seine water temperature is lower than that of the chilled water delivered to the Paris DCS. This being the case, it made sense to use this cold recovered from the environment to supply buildings that have a refrigeration energy requirement during this period. This solution brings a considerable improvement in energy performance (reduction in electricity consumption for a same given production of cold energy, therefore improved COPs) and a large reduction in CO_2 emissions.

Derived from a North-American concept, Climespace has innovated by applying it to a river representing a limited renewable source of cold and a large-scale network delivering high cooling capacities even in winter. The challenge is therefore to use this free cooling source to the maximum of its potential.

The concept consists in using the river Seine water as the cold source to directly cool the water of the distribution network without operating refrigeration units and production auxiliaries. In this case, the only equipment remaining in operation are a Seine water pump and a distribution pump (see figure 7).

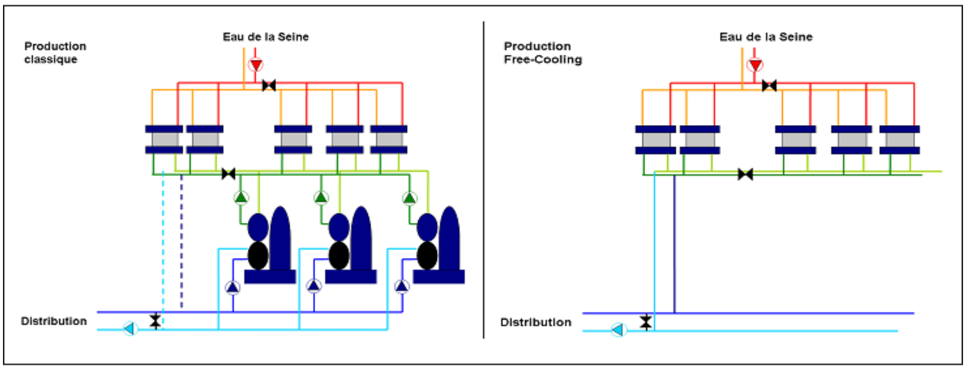

Figure 7: Principle of operation of free cooling

If not incorporated into the original design of the plant, free cooling involves a considerable amount of essential but tedious work, as the plant hydraulic circuits and automatic control systems have to be modified. The aim is to be able to switch from one production mode to the other as simply, rapidly and reliably as possible in order to optimize the use of this mode of production.

Free-cooling production was integrated in the Palais de Tokyo plant from the design stage and was thus implemented on the Paris DCS as of 2007. The Bercy plant was adapted for this mode of production in 2008. The investments required for the implementation of free cooling, all sites considered, were paid off in about three years of operation.

The graph in figure 8 presents the mean plant COPs achieved by the recovery of natural cold from the environment as a function of the river Seine temperature from December 2010 to January 2011.

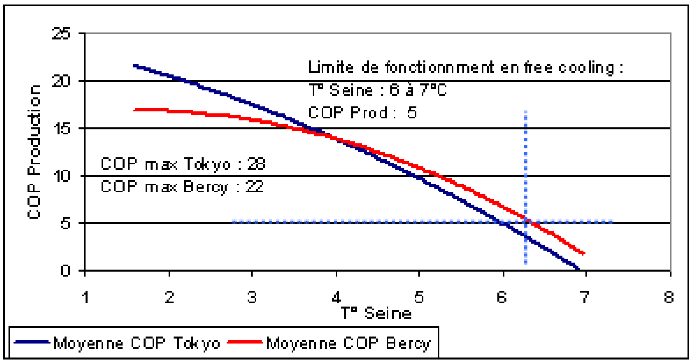

Figure 8: Mean COPs with free cooling

The performance levels achieved are three to four times higher than those obtained with conventional production.

3.3. Division of the distribution network

As from 2007, virtually all the production was ensured by two plants located close to one another on the Centre network, namely the Palais de Tokyo plant and the Canada plant: (see figure 9). But in spite of the performance improvement observed on the COPs, new problems arose. The distribution pumps of the two plants tend to work against each other. Consequently, the idea of physically separating the networks by means of sets of valves was proposed.

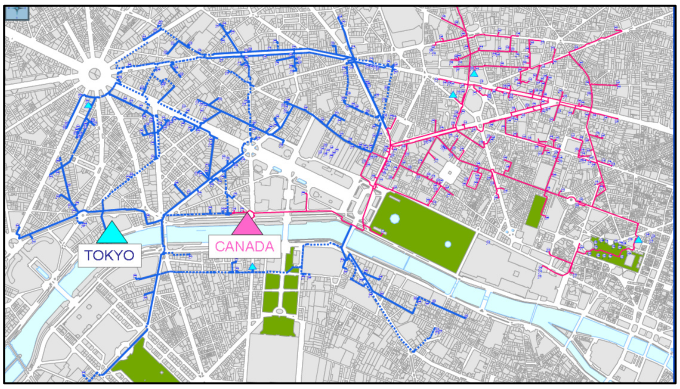

Figure 9: Plan of centre network in unmeshed configuration

This principle of network division had already been applied to small systems (where critical zones are rare). It consists in assigning one production plant to one distribution zone. For a network of the size of the Climespace DCS however, the project was completely new and ambitious, since once the network is divided performance is improved but the risks are also greatly increased (little back-up cold capacity available if there is a problem in a distribution zone).

On the technical side, dividing the network did not necessitate any construction work since the valves used to divide the network were already there. The chosen operating configuration is with two main grids on the centre network: the CANADA grid and the TOKYO grid (see figure 9). **Division became effective in September 2010 and allowed an improvement in the production COPs thanks to the reduction in the power levels used for pumping.**

To visualize the improvement in performance, the graph figure 10 compares the performance of the October and November for the years 2008, 2009 and 2010. After a transient entry into service phase, the performance improvement is about 11% with respect to a single-grid network.

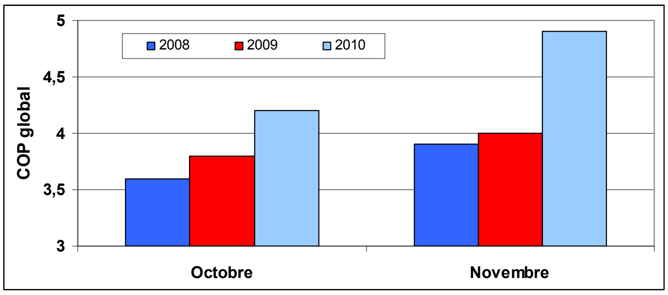

Figure 10 : Impact of grid division on the COP

The simplicity of the network division procedures allows rapid switching between a single-grid and divided-grid network configuration for maintenance operations necessitating plant shutdown, for example.

3.4. Implementation of Variable Frequency Drive on the refrigeration unit compressors

The two main energy consumers in a production plant are the liquid refrigeration unit compressors and the circulation pumps (which represent 50% and 20-30% respectively of the electrical energy consumed).

Though Climespace had widely installed variable speed drives on its circulation pumps so that circulation flow rates could be constantly adapted to the needs, this was not the case with the refrigeration unit compressors before 2009.

When designing the Auber production plant it was decided to install variable speed drives on the compressors. Varying the speed of the compressors of the liquid refrigeration units effectively enables good performance levels to be maintained at low load rates. For information, under the same given cooling and load conditions, the machine COP of a unit equipped with a variable speed drive can exceed 10 at a load rate of 50% compared with 7 without speed variation.

Entry into operation of the Auber plant at the end of 2009 has confirmed the performance improvement predictions. The monthly COP of the plant reached 4.90 in May compared with an average of 3 for the conventional sites with cooling towers.

These results are now prompting Climespace to think about installing this type of equipment in its other plants.

3.5. Reduction in refrigerant leaks

Since 2002 Climespace has implemented a whole series of measures to minimize its refrigerant losses:

- Installation of leak detection systems in all the plants and on each machine,
- Increasing the frequency of leak searches by qualified personnel,
- Installation of shutoff valves on the refrigerant circuits of liquid refrigeration units (LRU) in order to isolate the main elements of LRUs,
- Training of control teams to intervene on LRUs with refrigerant circuit leaks,
- Working in collaboration with manufacturers to limit the use of "screwed" or "bolted" connecting parts and favour welded joints.

These actions have resulted in the progressive reduction in refrigerant leaks, which have fallen from 10% in 2002 to less than 1% in 2010. And alongside this the machine pool has been enlarged (from 50 to over 100 tonnes of refrigerant) and its average age has been reduced.

3.6. Reduction of the urban heat island effect

Cooling systems installed in built-up areas generate heat island effects to which district cooling systems can provide a solution.

De Monck et Al in 2010 produced a scenario simulating the air-conditioning needs in the city of Paris and the heat island phenomena. It presents the results of three scenarios:

- The current real needs (REAL)
- The current phenomenon if the air-conditioning needs are covered exclusively by dry air-conditioning systems(DRY AC)
- The heat island created by a doubling of the needs with the use of dry systems (DRY ACx2)

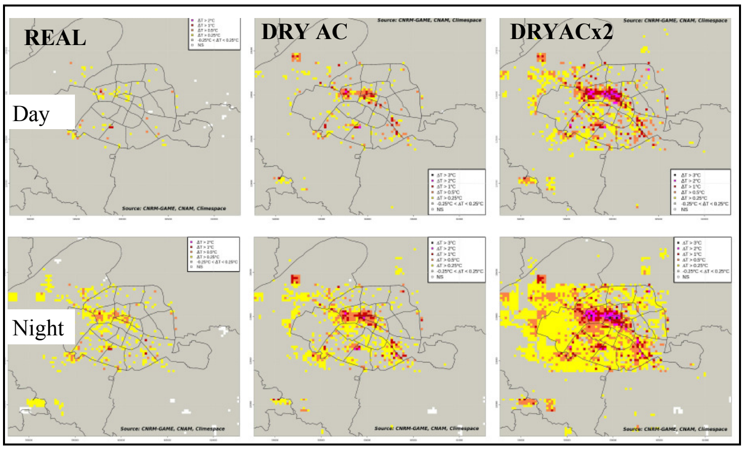

Figure 17: Mean temperature variations in the city of Paris with the three requirements simulation scenarioes (Munck et Al. 2010)

The results for the least favourable scenario (DRY Acx2) predict local night temperature increases of up to 3°C. In heat wave periods this heat island effect could reach much higher values, with temperature increases of up to 8°C!

By centralizing the production and associated cooling systems, and by opting for varied cooling systems (wet cooling towers and river Seine water), use of the Climespace DCS can limit these effects. The ongoing study conducted by Climespace, Météo France and the CNAM engineering school aims at quantifying the impact of the district cooling system in limiting the urban heat island phenomenon.

4. Observed reductions

Substantial reductions in electricity and water consumption and CO_2 emissions have been obtained thanks to the solutions implemented by Climespace.

4.1. Reduction in electricity consumption

As a result of its ambitious strategy and associated innovations, Climespace has considerably increased its energy performance between 2002 and 2010. The energy savings achieved thanks to performance-oriented management are high, since the **production COP has increased by more than 25%** (see figure 5).

Rigorous monitoring of performance by continuous data recording enables the impact of each technical improvement to be quantified.

Figure 11 shows the impact of network division on the performance of the Canada grid. Comparing 2009 with 2010, the plant COP of the Canada plant increased by 10% as from October 2010; grid division was carried out on 20 September 2010. Figure 12 shows the impact of grid division combined with free cooling on the performance of the Tokyo plant. In October and November 2010, the plant COP of the Tokyo plant increased by 26%. In December the increase in the plant COP is even greater thanks to the intensive use of free cooling.

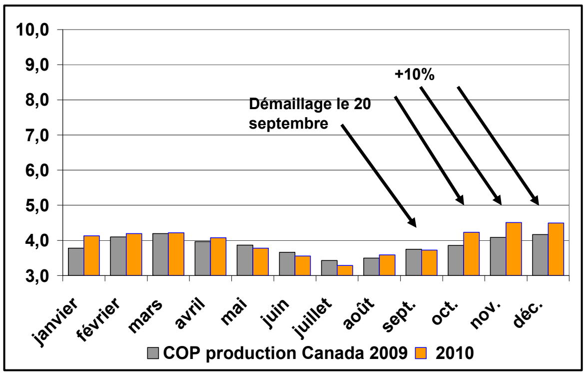

Figure 11: Canada plant performance 2009-2010

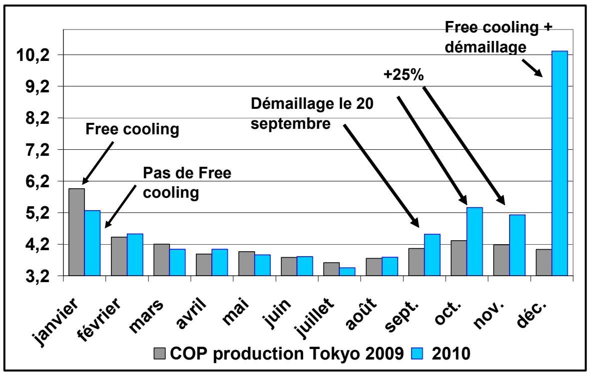

Figure 12: Tokyo plant performances 2009-2010

Network division brings a gain in the production COP of between 10 and 25% depending on the grid considered, and about 11% in the overall performance. **Free cooling** improves the monthly mean plant COP of the Tokyo plant by more than 150% (and well above this if instantaneous performance figures are considered).

Lastly, figure 13 shows the evolution of the general performance of Climespace with the two solutions combined. The production COP reached in December is 5.48 for a refrigeration energy production of almost 21 GWh.

In 3 months, dividing the network saved approximately 2000 MWh of electricity.

In 3 years, the use of renewable cold energy with production in free cooling mode saved 3500 MWh of electricity.

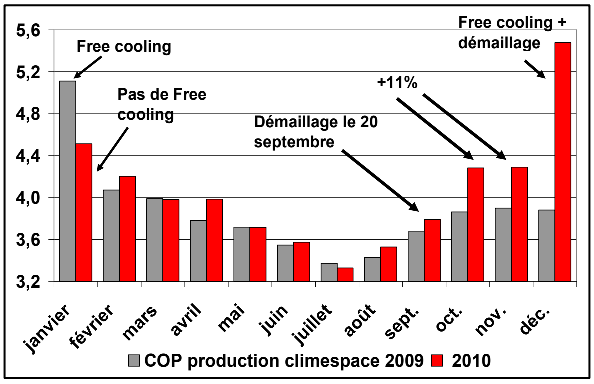

Figure 13: Production COP 2009-2010

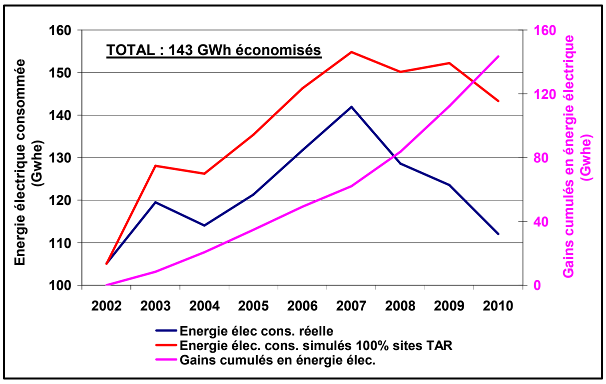

Figure 14: Evolution of electricity consumption

The objective of reducing the environmental impact of the activity of Climespace has, through the improvement in the production COP, enabled the electricity consumption of the Climespace production plants to be reduced very substantially. In 8 years of operation, **nearly 141 GWh of electrical energy have been saved**, that is to say the equivalent of the annual electricity consumption of Climespace.

4.2. Reduction in consumption of water and associated chemical products

Refrigeration energy production facilities that use cooling towers consume large quantities of water. The water used comes from the drinking water network and is treated to minimize health risks. Consuming water implies strong environmental impacts associated with the management of the resource and the energy consumed in making the resource available. Controlling water consumption and the use of the products necessary for its treatment is therefore an essential factor in reducing the environmental impact.

By switching the majority of its production to plants cooled by the Seine water, Climespace has avoided the consumption of very large quantities of water. **The resulting volume of water saved in 8 years is estimated at 3.5 million cubic metres; water consumption has dropped by 56%.** Using less water has also led to a reduction of about 80% in the input of treatment products.

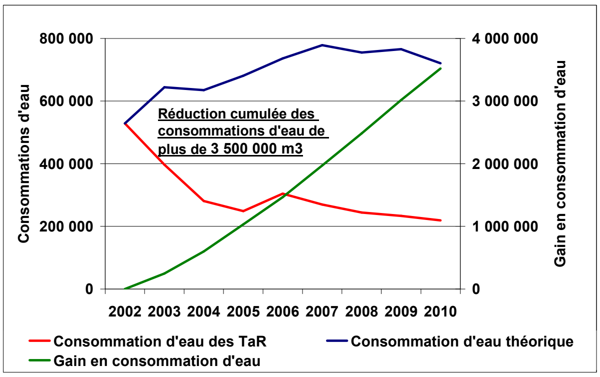

Figure 15 : Evolution of water consumption

Furthermore, until 2002 the strategy for managing the Legionella risk was to use biocide shock treatment. After 2002, the continuous treatment of the cooling tower circuits enabled the quantity of biocide treatment product injected to be reduced by around 90%. At the same time, the rate of positive bacteria detections fell by a factor of 7, from 70% to 11%.

4.3. Reduction in greenhouse gas emissions

The various measures taken by Climespace to reduce its environmental impact (generalization of Seine water sites, grid division, free cooling) have brought a reduction in the indirect TEWI (Total Equivalent Warming Impact) of about 71,732 tonnes of CO_2 in 8 years. The low winter electricity consumptions resulting from the use of free cooling since 2007 equate with large reductions in CO_2 emissions. This is because electricity production in winter creates a very large carbon footprint.

Controlling refrigerant leaks also helps reduce CO_2 emissions. Reducing leaks from 10% to below 1% between 2002 and 2010 has prevented the emission of some 14,000 tonnes of CO_2.

Taking the cumulated total, **almost 86,000 tonnes of CO_2 emissions have been avoided since 2002.**

5. Environmental impact of the district cooling system in the city of Paris and conclusion

The energy performance of the Parisian district cooling system has considerably improved between 2002 and 2010. The production COP has increased by 25%, water consumption has fallen by 56% and refrigerant leakage rates have been reduced from 10% to 1%.

But to quantify the general beneficial impact of the district cooling system associated with Climespace's strategy of management by COPs, its performance can also be compared with a production scenario based solely on stand-alone cooling systems.

The mean overall COP of instrumented stand-alone systems determined in a study conducted by Climespace, ARMINES and the ADEME is 1.97. The production COP for Climespace in 2010 was 3.87. To compare stand-alone installations and DCS, it is at last important to introduce the Overall COP which is the ratio between the frigorifical energy that is delivered to the client and the electrical energy that is used to produce this frigorifical energy. **In 2010, the Overall COP for Climespace was 3.40.**

Thus, for a constant annual energy production level, the district cooling systems allows annual electricity consumption to be reduced by 42%.

The electrical energy savings associated with the control of refrigerant leaks enable large reductions in CO_2 emissions to be achieved. The mean leakage rate observed on stand-alone systems is 12.6%, whereas that observed on the Climespace district cooling system is 1%.

Thus, for equivalent annual energy production and installed power, the district cooling system allows annual CO_2 emissions to be reduced by 48% in all.

The gains in energy efficiency are progressing in line with the City of Paris climate plan, which seeks to reduce its CO_2 emissions and its energy consumption by 25% while at the same time increasing the contribution of renewable energies in its energy mix to 25%.

To further improve the energy and environmental performance of its activity, Climespace is today studying the following solutions:

- Installation of new production plants cooled by the Seine water in the centre of Paris; these plants will allow the use of free cooling.
- Construction of combined Heat and Cold production plants using geothermal energy.

Over and beyond the economic aspect of the savings generated by this strategy, free cooling fits perfectly into the energy savings policy of the ISO 14001 certification obtained by Climespace in 2008. Moreover, the modifications introduced also lie fully within the framework of the energy savings certificates that Climespace is putting in place in partnership with the ADEME.

Lastly, with hindsight on the improvements made and Climespace's communication on the results of its strategy, chilled water network operators now have access to precise data if they wish to initiate projects of this type.

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