DISTRICT COOLING SYSTEM : THE MOST EFFICIENT SYSTEM FOR URBAN APPLICATIONS

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ABSTRACT

The District Cooling System (DCS) has many advantages in energy efficiency, resources preservation, environmental impact reduction, urban architecture. Under the framework of the public service since 1991, the Parisian DCS has been developed and represents today 305MW cooling requirements. The diminution of energy consumption is one of the major concerns for the operator. In the last ten years, the operator undertook changes to its production management in order to reduce electricity consumption and environmental impact. The results are significant with a reduction of 20 per cent of the specific consumption ratio. The competition with stand alone chilled water plants pushed to compare the energy performances with the DCS of Paris. An efficiency measurement campaign for independent plants done during one year shows that stand alone plants performances are different and lower from the theoretical ones considered for the design and gives significant advantages to the Parisian district cooling system with -47% decrease in electrical consumption and -51% for CO_2 emissions.

1. INTRODUCTION

The public service concession concluded by the City of Paris in 1991 enabled the district chilled water network to undertake major development. The District Cooling System (DCS) is developing at a rate of approximately 20MW worth of new customers per year.In 2009 the district network consisted of:

- 7 chilled water production plants, for a total cooling power of 290MW
    - 4 production plants cooled by air cooling towers
    - 3 production plants cooled by the Seine
- 3 cold storage units with a capacity of 140 MWh (2 ice storage units, 1 chilled water storage unit)
- 70 km of meshed district transport network running along sewers or galleries, and buried pipes
- 1 central control unit for equipment, that runs using 68,000 information fed back from sensors.

The manuscripts should report on original research or on technological developments and their applications.

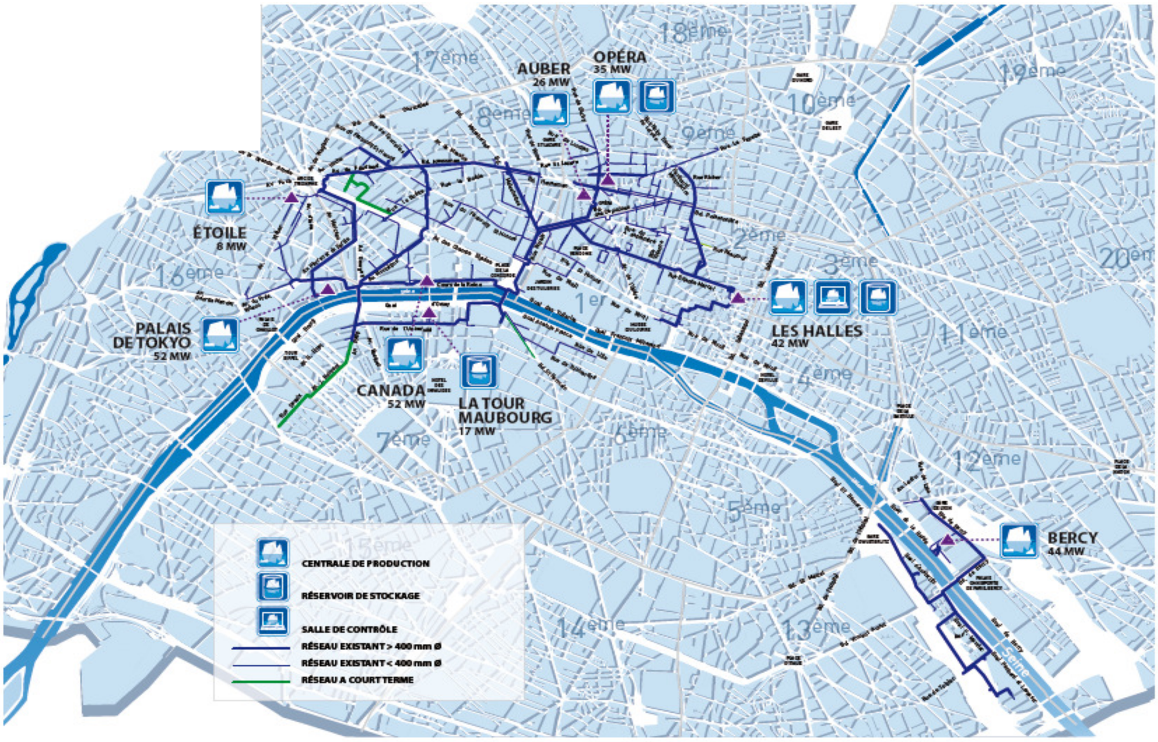

Figure 1.1. Paris DCS map view

2. CUSTOMER PROFILE

The total subscribed cooling capacity on the DCS represents 305 MW. The demand increases about 20MW each year. A total of 7 customers category are connected on the district cooling through 460 delivery station and spread as shown on figure 2.1. and 2.2.

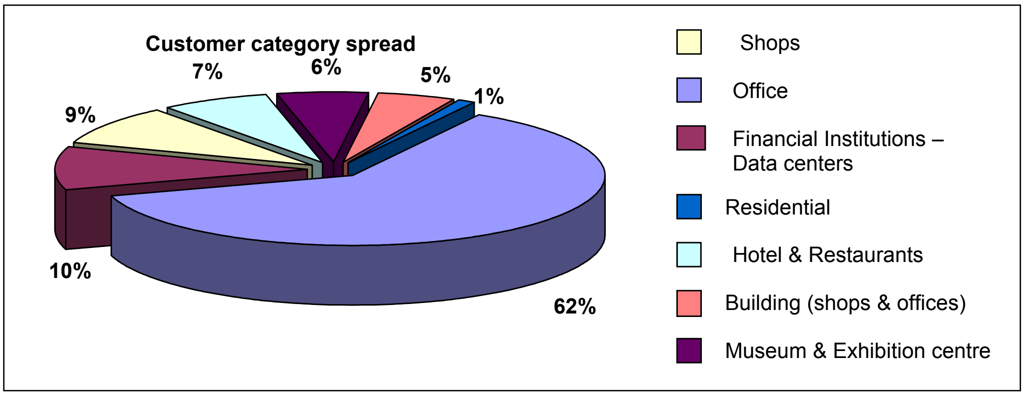

Figure 2.1. Customer spread by category

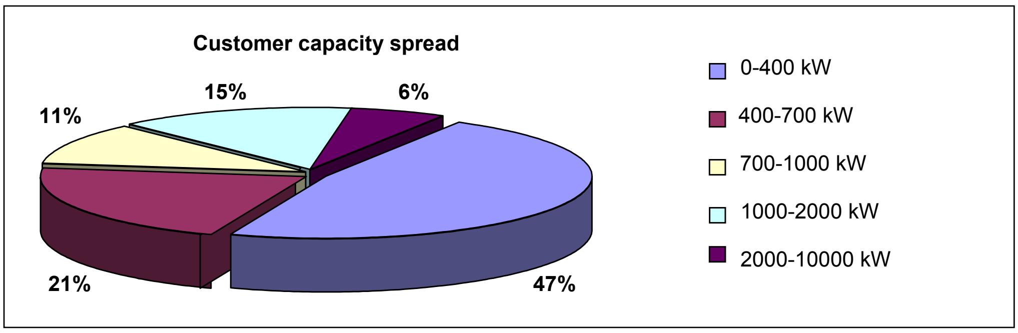

Figure 2.2. Customer spread by capacity

2. DEVELOPMENT OF THE OPERATION AND MANAGEMENT STRATEGY

3.1. Gradual migration of production capacity to sites cooled by Seine River

The energy share of sites cooled using water from the Seine went from **8%** in 2002 to **83%** in 2009. Over the same period, the cooling energy volume produced increased from 315 to 460 GWh cooling. The gradual shift from production capacity using cooling towers to plants cooled by the Seine resulted in a different breakdown for the various types of electrical energy consumption .Figure 3.1.1. and 3.1.2. illustrates these ongoing developments.

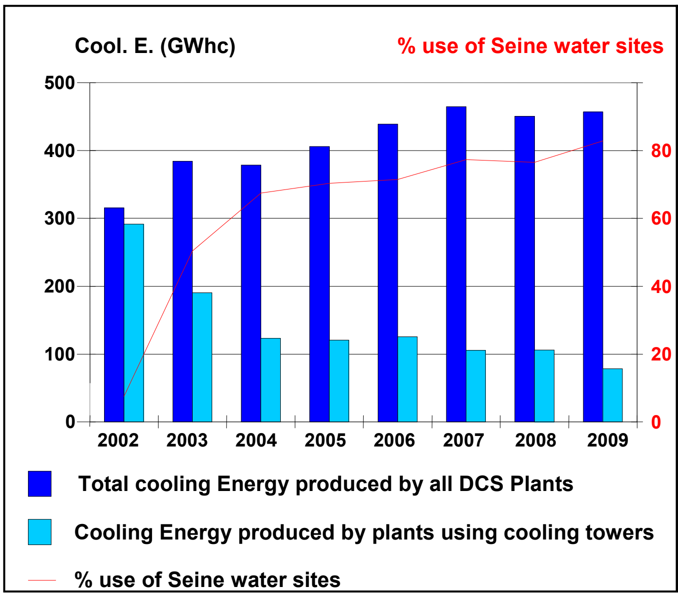

Figure 3.1.1. Cooling energy production

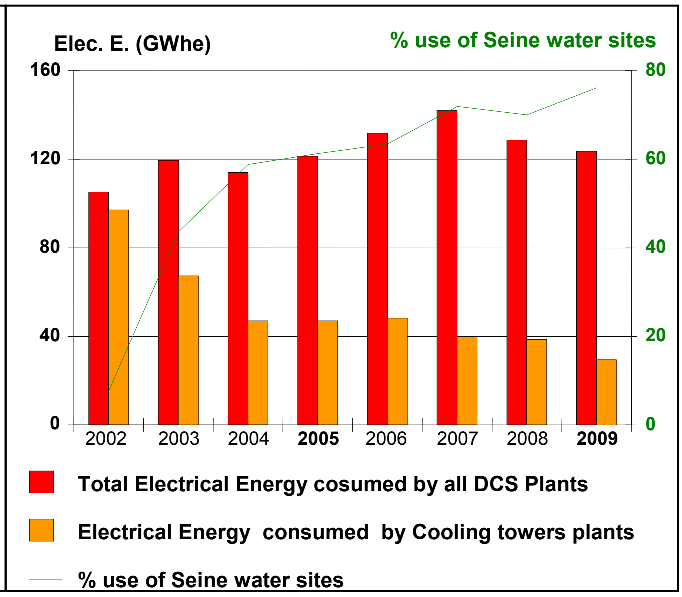

Figure 3.1.2. Electrical consumption

3.2. Use of Renewable Energy

Direct use of renewable cooling available when the Seine's water temperature is below 8°C enables a reduction in the electrical energy consumed in winter period. During the winter of 2008/2009, the electrical energy thus saved for the Tokyo and Bercy sites was 2.8 GWh. This renewable energy volume is moderate compared to the customers' annual needs. There is a major environmental impact because the electrical peak demand occurs in winter, when the peak electrical production method is highly polluting (coal/fuel oil/gas).

3.3. Reduction of electrical consumption

The specific consumption ratio relates to the electrical energy required to produce one kiloWatt hour of cooling. This is the reference energy performance indicator which is considered. Figure 8 illustrates the development of a specific annual consumption ratio for DCS production plants from 2002 to 2009.

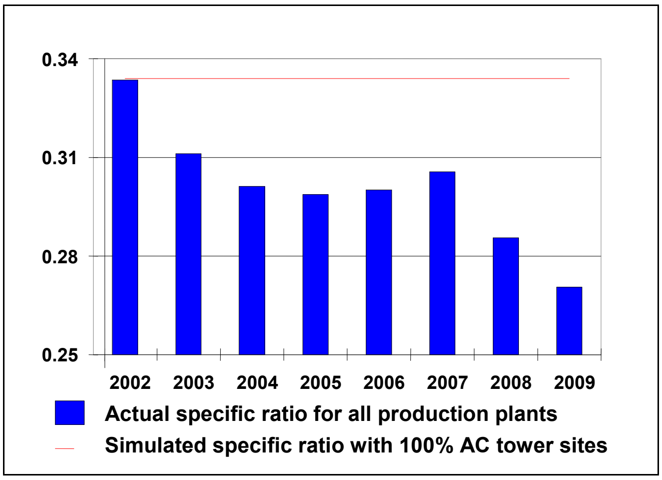

Figure 3.3.1. Annual specific consumption ratio

The specific electrical consumption ratio integrates the consumption of chilled water production units and their related auxiliaries as well as the consumption of cooling distribution pumps across the district chilled water network. 2008 showed a catching up in terms of energy performance characteristics

The total electrical savings relating to the placement in operation of sites cooled using water from the Seine is 112 GWh$_e$ over 7 years

3.4. Reduction of indirect CO_2 emissions

Electricity consumption causes indirect impacts on the environment. There are various types of discharges relating to electricity production:

- Air pollution due to the emission of CO_2, SO_2, NOx, radioactive waste, thermal discharges, and the visual pollution caused by plumes of steam (CO_2 only considered here)
- Water pollution due to thermal and chemical discharges

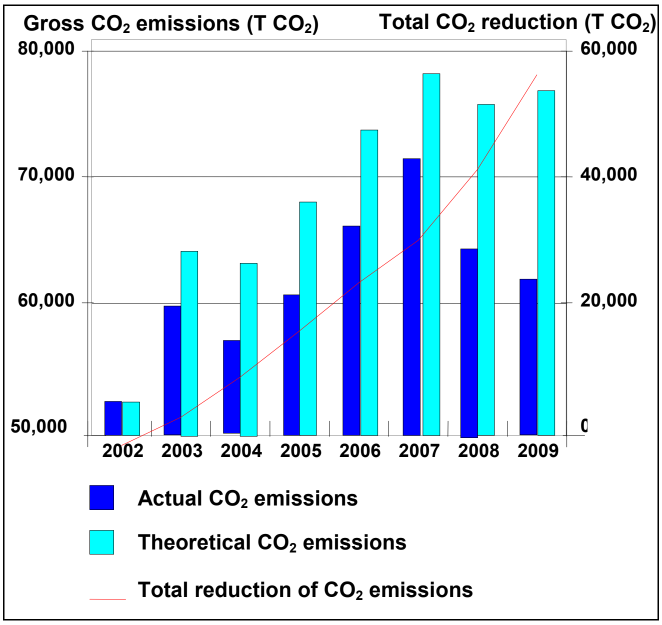

Figure 3.4.1. Annual CO2 emissions avoided

The CO_2 cost for the electricity consumed is assessed in accordance with the memorandum dated 8 October 2007 completed by the ADEME and the RTE. The value adopted in this document is the (27-member) European marginal CO_2 content relating to electricity consumption for refrigeration use : **500g/kWh$_e$**

The total reduction in CO2 emissions relating to the technological choice of cooling using water from the Seine is evaluated as being 56,153 tonnes of CO2 over 7 years.

3.5. Reduction in tap drinking water consumption

By their very nature, chilled water production installations using air cooling towers entail major water consumption levels. Under the framework of a development scenario 100% oriented towards sites cooled by air cooling towers, drinking water consumption levels are simulated using the water consumption ratio recorded in 2002. The ratio adopted was 1.68m^3/MWh$_c$.

The volume of drinking water saved by the placement into operation of sites cooled with water from the Seine is 3,000,000 m^3.

4. STAND ALONE PLANTS EFFICIENCY MEASUREMENTS

The operational energy performance characteristics of independent chilled water production installations are often different from the performance characteristics initially expected. The absence of an energy breakdown and operational analysis assessment conceals problems that independent installations have with excessive consumption levels, and the difference in relation to theoretical performance characteristics. Performance measuring campaign were done for independent installations in order to quantify the actual annual average performance difference.

4.1. Methodology and choice of installations

The Energy Efficiency Ratio for a chilled water production system is measured for the global electrical consumption of the following equipement:

- the chillers and primary pumping system,
- the cooling system used (air coolers or dry-coolers) and all others accessories required for a normal operation of the plant as water treatment, maintaining pressure, automated control systems, ventilation and lighting.

Choice was based on recent installations that runs throughout the year.

Installation	Building type
A	Hospital including the surgical unit, waiting room and room
B	Hospital including surgical units and examination areas
C	Bank including computer rooms, an office UPS room, reception rooms, refectory.
D	Commercial buildings

Table 4.1.1. Type of building involved in the study

Building	Date of starting	Chillers number	Compressor type	Refrigerant	Cooling capacity
A hospital	2000	3	screw	R134A	1260 kW
B hospital	1996	2	screw	R22	940 kW
C bank	1990	1	piston	R22	484 kW
D stores	2008	4	piston	R407C	776 kW

Table 4.1.2. Main characteristics of stand alone plants

4.2. Results and conclusions

The energy efficiency ratio was calculated using the measurements logged during 24 months. The average EERs calculated using measurements carried out continuously are relatively low. Neither the designer nor the manufacturer suggested calculating EER and ESEER during the design stage. The manufacturer EER is the only available parameter that the operator can use at present and he considers as the installation's overall efficiency whereas measurements have demonstrated that these actual performance levels are 32 to 78% lower. As forecast by a number of parameters, energy consumption on the sites is a sensitive issue. What is quite clear is that none of the installations was using chillers at maximum loading and this has an impact on efficiency. Chillers runs at 35 % loading on site A, at 40 % on site B, at 25 % on site C and at 30% on site D.

Installation	Measurement period	Average EER measured	Manufacturer's EER	$EER/EER_{manufacturer}$
A	24 months	2 .02	4.26	53 %
B	24 months	2.87	4.78	40 %
C	12 months	2.14	3.15	32 %
D	12 months	0.84	3.87	78 %
Average EER A/B/C/D		**1.97**		

Table 4.2.1. EER average measurements

In general, for all the sites equipped with instrumentation, it is possible to immediately detect conditions that significantly affect the true EER. Some, covered by recommendations found in a number of publications, can, however, be detected during the site design phase or may be linked to the gradual drift that affects the installation through its service life. In any event, lack of knowledge on consequences in terms of energy efficiency undoubtedly explains some investment choices.

Thus, for instance, evaporator and condenser pumps run for most of the time at a fixed output without any speed controller. This generates energy over consumption during the periods when the equipment is running under part loading.Condenser cooling remains fixed throughout the year, regardless of weather conditions and of the chiller's loading level and this adversely affects the EER in winter. If cooling were governed by the real demand, this would reduce electricity consumption accordingly.

The effective EER measured, depends on the condenser cooling technology used. Thus, a wet air-cooling tower will improve the installation's efficiency. The cooling tower represents 5 to 24% of the installation's total electricity consumption; this figure is 28% for the dry cooler and 6% for the air condenser. On the other hand, only the true measurement of the EER can be used to accurately assess chiller consumption which is directly affected by the way in which they are routinely managed. Similarly, accessories often only require low power levels but they consume high amounts of energy over the year given the demand made on them, reflecting the behaviour of the individuals working on the site or the latter's configuration.

5. COMPARISON BETWEEN PARIS DCS AND EQUIVALENT STAND-ALONE PLANTS

5.1. Energetical benefits

The comparison between DCS and stand-alone plants efficiency is based on results and measurement presented previously. It consists on comparing what could the electrical consumption, the electrical peak demand and the environmental impact if the DCS customers total capacity were covered by stand-alone plants. Without the DCS and the increase of its consumption ratio (kWe/kWc) the electrical consumption should be almost twice. The advantage in energy efficiency procured by the DCS correspond to + 47%.

	District Cooling System		Equivalent std-alone plants	
Total subscribed cooling capacity	305	MW	305	MW
Installed cooling capacity DCS	236	MW	-	-
Installed cooling capacity including + 20% cap	-	-	366	MW
Annual cooling energy supplied	398 000	MWh	398 000	MWh
Average COP measured	3,70	-	1,97	-
Consumption ratio	0,27	kWe/kWc	0,51	kWe/kWc
Electrical energy absorbed	107 460	MWh	202 030	MWh
Annual elect. consumption avoided	**94 570**	**MWh**		
Decrease in consumption	**-47**	**%**		

Table 5.1.1. Electrical consumption comparison

One chiller at full load on the DCS plant replaces several chillers running at part loads and low efficiency on stand alone plants.

The mutualisation of the cooling requirement and the use of high efficiency centrifugal chiller running permanently close to their maximum capacity and cooled by the river water reduces the electrical peak demand on the electrical network of the area. Without district cooling system, the electrical peak demand in summer would be 2.1 times higher than today one.

Summer peak demand	District Cooling System		Equivalent std-alone plants	
Summer cooling peak demand	174	MW	174	MW
COP summer period	3,10	-	1,48	-
Average summer electrical peak demand	56,13	MW	118	MW
Summer elect. Peak avoided	**62**	**MW**		
Decrease in peak	**- 53**	**%**		

Table 5.1.2. Electrical peak demand comparison

5.2. CO2 emissions benefits

When the chillers of a DCS are operated according industrial standards, the amount of refrigerant released in the atmosphere is reduced compared to stand alone plants. Impact on the greenhouse effect avoided is about 58 000 tons of equivalent CO_2. (Calculation is based on European CO_2 factor: 500 gCO_2/kWhe).

	District Cooling System		Equivalent std-alone plants	
DCS refrigerant charge measured	102 554	kg ref	-	
Refrigerant charge ratio	0,42	kg ref/kW	0,23	kg ref/kW
Std-alone refrigerant charge estimated	-	-	86 145	kg ref
Annual refrigerant leakage ratio	2,0%	-	12,6%	-
Annual qty of refrigerant released	2 051	kg ref	10 854	kg ref
Annual equiv. CO_2 emission avoided	**58 729**	**tons CO_2**		
- Direct effect	11 444	tons CO_2		
- Undirect effect	47 285	tons CO_2		

Table 5.2.1. Electrical peak demand comparison

6. CONCLUSIONS AND BENEFITS FOR DCS

The District Cooling System contributes seriously to reduce the environmental and the energetic impact due to the development of cities and dense urban areas. The projection done on DCS customer, representing 305 MW of cooling requirements, shows a large advantage in favour of the DCS on the limitation of electrical consumption and greenhouse effect contribution:

DCS VERSUS STAND ALONE PLANTS

ANNUAL ELECTRICAL CONSUMPTION AVOIDED	**94,6 GWH / YEAR**
DIFFERENCE VS STAND ALONE PLANTS	**- 47 %**
SUMMER ELECTRICAL PEAK AVOIDED	**62 MW / MONTH**
DIFFERENCE VS STAND ALONE PLANTS	**- 53 %**
CO_2 EMISSIONS AVOIDED	**58 729 TONS CO_2/YEAR**
DIFFERENCE VS STAND ALONE PLANTS	**- 51 %**

The DCS remains as an opportunity to rationalize the production and distribution of cooling energy to building with various applications and customer with changing activities.

Renewable and natural resources must be privileged in the design and development of the district cooling. The mutualisation of cooling requirement on the DCS allows doing investment to integrate those resources. An adapted management and operation strategy leads to significant savings.

In addition to these significant reduction and savings, the DCS offers some other advantages:

- Adjustment of the cooling capacity: the delivery station is permanently adaptable to the cooling requirements of the building due to the change of application of it or temporary non occupation.

- Valorisation of building additional space: The minimum size of the chilled water delivery station room offers to the building developer more valuable space compare to stand-alone plant. The absence of chillers and/or cooling tower on the roof let opportunity to install solar panel.

- Free cooling operation: The low temperature of the Seine River allows the system to produce and to distribute chilled water and avoid the start of the compressor during several weeks.

- Reduction of the public health risk relating to legionnaire's disease: By producing 80% of the cooling energy with the plant cooled by the river the risk of legionella contamination is significantly reduced. The use of chilled water plants with the cooling tower corresponds only to the cooling peak demand during short periods.

- Reduction of potable water consumption: Cooling chilled water plant with the seine river avoid potable water consumption on cooling tower plants and discharge into sewers. The use and rejection of chemicals products is proportionally reduced.

- Elimination of noise pollution: The chilled water production is centralized through industrial plant that takes into account noise constraints of the area. It contributes to eliminate an important number of stand-alone air-cooled chilled water plants.

- In addition to the strong reduction in CO_2 emissions, operation of the DCS according to industrial standard permit to divide by 6 the quantity of refrigerant released into the atmosphere.

7. PROSPECTS

The approach undertaken for reducing primary energy consumption is oriented towards the following complementary orientations:

NEW PRODUCTION PLANT COOLED BY THE SEINE

In order to respond to the increase in demand for connections to the district chilled water network, the operator is seeking a new site near the Seine so that it can establish a production plant. This production plant will be equipped with installations enabling free-cooling in winter and, if there is sufficient volume available, a high-capacity cool water storage unit. A study concerning the environmental impact of the heat on the Seine is currently being carried out Paris-wide in order to limit disruption to the aquatic environment.

COMBINED HEATING/COOLING PRODUCTION

Opportunities for executing small combined heating/cooling production plants using heat pump installations are being studied. For a long time, the major additional cost in terms of production and the district heating network posed an obstacle to the development of this type of installation. Consequently, making this type of installation financially profitable greatly depends on the cost of primary energy sources and on financial assistance from public bodies.

USE OF BY-PRODUCT HEAT IN SUMMER – STEAM FROM HOUSEHOLD WASTE INCINERATION PLANTS

The Parisian heating network is basically supplied by steam produced by household waste incineration plants. During summer, the excess steam is not used by the heating network. Recovering this heat for the purpose of chilled water production by means of absorption units would enable this by-product waste to be reused. However, the required increase in the cooling power and the low cooling temperature for absorption units limits the creation of this type of production plant.

8. REFERENCES

Merchat M, Senejean B, Benassis F, Faurel C, Thibault S, 2009, Refrigeration system overall energy efficiency, *6th International Conference on Energy Efficiency in Motor Driven System, Nantes,France*

Merchat M, Senejean B, Benassis F, Doucouré A, Thibault S, 2009, Mesure de la performance énergétique des systèmes de refroidissement, *CVC La revue des Climaticiens N° 859*

Martin B, 2009, Environmental performance: building-bound vs. collective solutions, *34th Euroheat and Power Congress, Venice, Italy*