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PERFORMANCE AND PROFITABILITY PERSPECTIVES OF A CO_2 BASED DISTRICT ENERGY NETWORK IN GENEVA'S CITY CENTER

S. Henchoz[1], D. Favrat[1] and C. Weber[2]

[1] LENI - EPFL, Lausanne, Switzerland

[2] Amstein & Walthert Genève SA, Geneva, Switzerland

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ABSTRACT

A new type of district energy network capable of providing simultaneously heating and cooling is being investigated. It is based on the use of CO_2 as a heat transfer fluid by taking advantage of the latent heat of vaporization, to store and transfer heat across the network. The goal of the present study is to determine the performance of a CO_2 network when applied to a real urban area. It focuses first on determining the requirements for the various thermal energy services for a part of Geneva's city centre. The energy consumption is first computed for the energy conversion technologies now in place in this area - namely fuel boilers and vapour compression chillers. Then the new energy consumption is computed if a CO_2 network were used instead of the existing technology. Finally a profitability analysis of the CO_2 network variant is done accounting for investment, energy purchasing, equipments replacement, operation, and maintenance costs.

For an interest rate of 6% and a price of the delivered heating/cooling energy at 0.13 CHF per kWh, a net present value of 82.8 million CHF after 40 years is achieved, while the break-even is reached after 5 years of operation.

INTRODUCTION

District heating and cooling networks have been used to deliver energy in urban areas for many decades. Generally, these networks rely on centralized and efficient energy conversion technologies supplying heating and/or cooling to the users through a water loop. In most of the cases, the supply temperature of such a network is selected according to the most demanding consumer connected. Thus all the other users are supplied at a temperature beyond their need – often far beyond their need. Furthermore, when heating and cooling have to be supplied, two independent water loops are needed. Finally, most of the time, heat discharged by the cooling users in the district cooling network is not transferred to the district heating network, and thus not recovered.

A new type of district energy network is being investigated. It is based on the use of CO_2 as a heat transfer fluid. It uses the latent heat of vaporization, instead of sensible heat, to store and transfer heat. The pressure of the network is selected such that evaporation/condensation takes place at around 12 to 14 °C. This level of temperature allows free cooling to be used for most of the cooling applications, while decentralized heat pumps transfer heat, from the network to each heating user, at the required temperature level. Furthermore only two pipes are required by the network, thus allowing the recovery of waste heat from the cooling users to be recovered by the heating users. Obviously, the heat required by the heating users may, most of the time, not be strictly equal to the waste heat discharged by the cooling users. Hence, a central plant is needed such that the required amount of heat can be taken from/released into the environment.

Fig 1 provides a schematic view of a CO_2 network. A more detailed description of the concept is done by Weber and Favrat in [2]. A presentation of a list of possible energy services and associated conversion technologies that can be included in a CO_2 network was done by Henchoz et al. in [4].

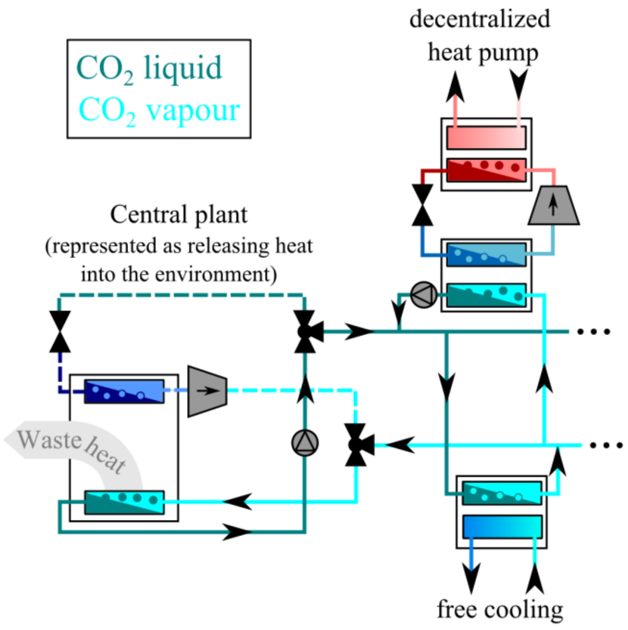

Fig. 1 Schematic representation of a CO_2 based district energy network.

AREA STUDIED

It was chosen to study the area of “Rues Basses” in Geneva. Data such as the energy reference area (ERA) and buildings affectation was made available to the authors by Geneva’s cantonal office for energy [12]. Fig 2 shows a map of the area studied. The area was divided in 32 groups of buildings for which the 3 possible affectations were considered:

- Commercial buildings
- Office buildings
- Residential buildings

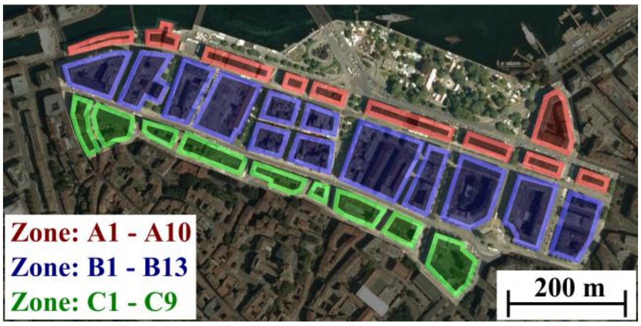

Fig. 2 Map of the area considered, depicting the subdivision in 32 zones [12].

Table 1 shows the ERA for the groups of buildings depicted in Fig 2. For readability reasons, the detailed data for each group is not presented. However, all the computations were done with this subdivision in 32 zones, such as to keep as much information as possible on the spatial distribution of the various physical quantities.

Table 1

	ERA = Energy Reference Area [m^2]		
Zone	Commercial	Offices	Residential
A1 –A10	20’700	89’200	17’700
B1 – B13	97’000	260’700	51’500
C1 – C9	40’400	62’600	48’100
A1 – C9	158’100	412’400	117’300
Total: 687’800			

According to the the scanE the ERA of the above mentioned categories can be subdivided in two subcategories as presented in Table 2.

Table 2

	Subcategories	
Commercial	Shopping mall	Restaurant
	90%	10%
Offices	Individual office	Open space
	50%	50%
Residential	Post1990 residential	Pre1990 residential
	20%	80%

THERMAL ENERGY NEEDS

The various energy services considered in this study are the following:

- Space heating
- Air conditioning
- Hot water preparation
- Refrigeration
- Server cooling

For the six subcategories of Table 2, the yearly energy required for the various services was taken from [5] and [6]. Notice that since the buildings in the area considered are old, the SIA document of 1988 [5] seemed to be reasonable. For each subcategory it was chosen to account at maximum for two energy services in heating, respectively cooling, one being a function of the outside air temperature and the other being constant throughout the year. The services considered as well as the corresponding yearly energy per m^2 of ERA are shown in Table 3.

In order to be able to evaluate the energy quantities on a monthly basis, especially the effects of the seasonal variations on space heating and air conditioning the following approach was used:

$$Q_{ERA} = \frac{UA}{ERA} \cdot \int (T_{room} - T_{atmospheric})dt \qquad (1)$$

Where Q_{ERA} is the yearly energy per m^2 of ERA, *UA* the heat transfer coefficient through the building envelope. The integral can be replaced by the yearly heating, respectively cooling degree days. Hence the coefficient of loss becomes:

$$\frac{UA}{ERA} = \frac{1000}{24} \cdot \frac{Q_{ERA}}{YDD} \qquad (2)$$

The annual values for Geneva are 2300 °C days in heating and 600 °C days for cooling. The degree days where obtained from monthly data for the atmospheric temperature available at [7]. The values for the various loss coefficients are shown in Table 3.

Table 3

Category	**Services**	**Yearly energy** [kWh/m^{2}yr]	**Loss coef.** [W/m^2°C]
Shopping mall	Space heating	124.1	2.26
	Hot water prep.	7.9	
	Air conditioning	70.0	4.84
	Refrigeration	30.0	
Restaurant	Space heating	66.0	1.20
	Hot water prep.	66.0	
	Refrigeration	10.0	
Individual office	Space heating	55.0	1.00
	Air conditioning	72.0	4.97
	Server cooling	8.0	
Open space	Space heating	55.0	1.00
	Air conditioning	45.0	3.11
	Server cooling	45.0	
Post1990 residential	Space heating	37.5	0.68
	Hot water prep.	12.5	
Pre1990 residential	Space heating	70.8	2.17
	Hot water prep.	21.2	

The total thermal energy required annually is 107’494 MWh. 54% of which are for heating and 46% for cooling. Fig 3 shows the energy required for each service along the year on a monthly basis. The heating peak occurs in January for an average load of 15.5 MW, the max over min heating requirement is 31.6. The cooling peak occurs in August with an average load of 16.1 MW and the max over min ratio is 9.4.

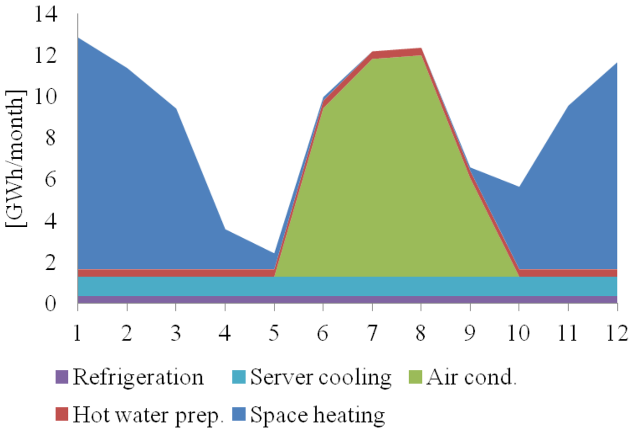

Fig. 3 Monthly energy required for the various services considered.

CURRENT ENERGY CONVERSION TECHNOLOGY

The current supply of energy in the studied area is considered to be exclusively relying on fuel boilers for space heating and hot water preparation, while air cooled vapour compression chillers provide the cooling service . The boilers are considered to operate following a pulse width modulation by alternating between full load and idle periods of variable duration. The design atmospheric temperature was set to -6°C [5]. The part load energy effectiveness of the boilers is then computed as follow:

$$\varepsilon = \left(\frac{1}{\varepsilon_n} + \frac{\lambda_0}{\tau} - \lambda_0 \right)^{-1} \tag{3}$$

Where ε_n is the effectiveness [1] at nominal load and λ_0 the residual consumption at idling condition, as a percentage of the delivered nominal load.

The vapour compression chillers performance is approached by considering ideal Carnot heat-pump cycles, with constant exergy efficiency. Because air-cooled condensers are considered, the parasitic power consumption of the fans was accounted for. Hence, the electric power required is computed as follow:

$$\dot{E} = \dot{E}_{cycle} + \dot{E}_{fans} \tag{4}$$

With

$$\dot{E}_{cycle} = \frac{\dot{Q}_{evap}}{\eta} \frac{T_{cond}}{T_{evap}} \left(1 - \frac{T_{evap}}{T_{cond}} \right) \tag{5}$$

Where Q_{evap} is the heat load, η the exergy efficiency, T_{cond} the condenser temperature and T_{evap} the evaporator temperature. The two temperatures are given by:

$$T_{cond} = T_{atmospheric} + \Delta T_{air} + \Delta T_{\min} \tag{6}$$

$$T_{evap} = T_{service} - \Delta T_{\min} \tag{7}$$

The parasitic power consumed by the fans at the condenser is given by equation (8), according to [3]:

$$\dot{E}_{fans} = \frac{0.605 \cdot \left(\dot{Q}_{evap} + \dot{E}_{cycle}\right)}{\left(\Delta T_{air} + \Delta T_{\min}\right)^{0.9937}} \qquad (8)$$

In the expressions (6),(7) and (8), ΔT_{air} is the temperature increase when the cooling air passes through the condenser and ΔT_{min} is the minimum approach of temperature.

The various parameters used for computing the consumption of the current energy conversion technology are listed in Table 4.

Table 4

Parameters		Value
Boilers	ε_n	0.90
	λ_0	0.02
Chillers	η	0.35
	ΔT_{air}	12°C
	ΔT_{min}	2.5°C
$T_{service}$	Air conditioning	18°C
	Refrigeration	5°C
	Server cooling	21°C

The monthly energy consumption was computed for the 32 groups of building. The annual total amount is 77'576 MWh, 84.6% of which is fuel oil and 15.4% electricity. The maximum monthly averaged load occurs in January for the boilers at 17.43 MW, the max over min ratio being 31.9. For the chillers, the maximum monthly averaged electric load occurs in August at 4.38 MW. As for air cooled compression chillers, a decrease in the atmospheric temperature has a strong positive effect on the power consumption; the max over min ratio is 30.7, which is much higher than the min-max cooling load factor. The monthly consumption for the different services is shown at Fig. 4. Notice that the type of energy consumed is mentioned for each service.

The yearly effectiveness in heating, for the considered area and the current energy conversion technology is 0.88. The yearly effectiveness in cooling is 4.15.

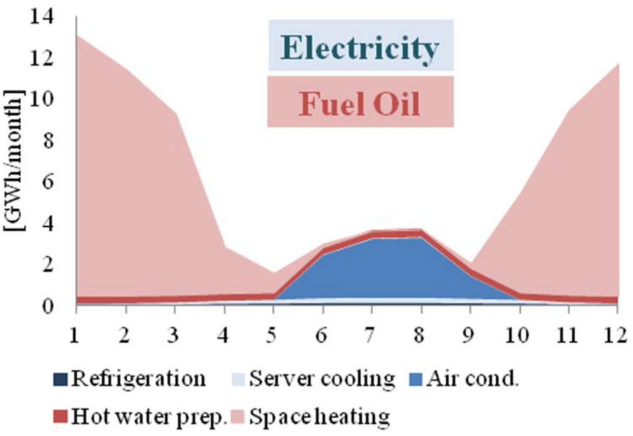

Fig. 4 Monthly energy consumption of the boilers and air-cooled vapour compression chillers by energy service.

CO$_2$ NETWORK

In order to evaluate the performance of the CO$_2$ network, in a realistic test case, such a network is imagined such as a replacing technology for the area of "Rues Basses". All the services considered previously have to be supplied by the network. Fig. 5 shows the configuration of the two main lines, as well as the location of the central plant. Each line is constituted of two pipes, one containing CO$_2$ in a liquid state and the other containing CO$_2$ in a vapour state. Both are very close to the saturation, which is set at 12°C (47.3 bar). As the area considered is located very close to the lake, the central plant is assumed to be taking heat from, respectively releasing heat in it. The lines are respectively 903 m and 940 m long. The total length of the network is 3'686 m.

Fig. 5 Configuration of the CO$_2$ imagined for the current study.

The decentralized conversion technologies chosen to supply the various services at the user end are the following:

- Intermediate heat pumps for space heating and hot water preparation. (Heat from the CO$_2$ condensation is transferred to the refrigerant through an evaporator-condenser.)
- Free cooling for air conditioning and server cooling. A pressure differential of 1 bar is

maintained between liquid and vapour lines such that the CO_2 flows freely in the evaporator.

- CO_2 vapour compression chillers for refrigeration. Liquid CO_2 is expanded to the required saturation temperature and evaporated; the vapour produced is then recompressed to the network.

The electric energy required for the decentralized heat-pumps is evaluated with the same method than in the previous section for the vapour compression chillers. Obviously in this case there are no parasitic power consumption caused by the air cooling. The required temperatures for the services are the same except for space heating. Since the effectivness of heat-pumps depends strongly on the level at which heat is delivered, the following heating curve was supposed (the buildings are assumed to have a renovated envelope) [6].

$$T_{service} = 55 - 1.47 \cdot (T_{atmospheric} + 6) \qquad \forall T_{atmospheric} \leq 16.4°C \tag{9}$$

The temperature at condenser and evaporator becomes respectively:

$$T_{cond} = T_{service} + \Delta T_{\min} \tag{10}$$

$$T_{evap} = T_{network} - \Delta T_{\min} \tag{11}$$

In the equation above $T_{network}$ is the saturation temperature of CO_2.

The electric energy required for the central plant when operated as a heat pump is evaluated similarly, the temperature T_{cond} and T_{evap} are defined by:

$$T_{cond} = T_{network} \tag{12}$$

$$T_{evap} = T_{lake} - \Delta T_{water} - \Delta T_{\min} \tag{13}$$

In (13) ΔT_{water} is the temperature decrease of the water flowing through the evaporator, and T_{lake} the temperature of the water at evaporator's inlet.

Knowing the energy required for each service, the latent heat of vaporization Δh_{vap} of the CO_2 at $T_{network}$ and with the conversion technologies defined above, it was possible to evaluate the massflow of CO_2 liquid, consumed by each of the 32 groups of buildings:

$$\begin{aligned} \dot{m}_{liquid} &= \frac{\dot{Q}_{evap} - \dot{Q}_{cond}}{\Delta h_{vap}} \\ \dot{Q}_{evap} &= \dot{Q}_{AirCond} + \dot{Q}_{Server} + \dot{Q}_{refrig.} + \dot{E}_{refrig.} \\ \dot{Q}_{cond} &= \dot{Q}_{heating} - \dot{E}_{heating} + \dot{Q}_{HotWater} - \dot{E}_{HotWater} \end{aligned} \tag{14}$$

The massflow of vapour is simply the opposite of the massflow computed with equation (14).

By mass balance, the massflow along the liquid and vapour lines could be computed. The pressure drop was computed for each segment with Churchill's correlation.

The electric energy required for the circulation pumps at the central plant was evaluated as follow:

$$\dot{E}_{PumpCentrd} = \frac{1}{\eta_{pump}} \left(\sum_{i=1}^{n} \dot{m}_i \frac{\Delta P_i}{\rho_{liq}} + \sum_{k=1}^{n} \dot{m}_k \frac{\Delta P_k}{\rho_{vap}} \right) \tag{15}$$

Where the two terms on the right hand side are the sum of the pumping losses on each segment for the liquid and vapour lines respectively. Obviously η_{pump} is the efficiency of the circulation pumps. There were 18 segments considered; their length corresponding to the distance from one group of buildings to another. Notice that some of the closest groups were lumped together such as to reduce the number of segments and that the massflows coming from the groups B1 to B13 were splitted equally between the two branches of the network.

As mentioned earlier the liquid line is at a higher pressure than the vapour line thus enabling free cooling but implying an additional pumping power consumption for all the heating users. The expression is the following:

$$\dot{E}_{PumpUsers} = \frac{1}{\eta_{pump}} \frac{\Delta P_{vap-liq}}{\rho_{liq}} \sum_{i=1}^{n} \dot{m}_i \tag{16}$$

Where the sum denotes the total massflow of CO_2 pumped from the vapour line to the liquid line by the heating users.

The total pumping power for the network is the sum of equations (15) and (16).

The values for the various parameters used for computing the CO_2 network's energy consumption are listed in Table 5 while Table 6 shows the value of the various parameters used for the computation of the pressure drop in the network's piping.

Table 5

Parameter		**Value**
$\eta_{central}$	Central efficiency	0.55
η_{HP}	Users heat pumps efficiency	0.45
η_{pump}	Circulation pumps efficiency	0.8
ΔT_{min}	Minimum approach of temperature	1°C
ΔT_{water}	Temperature decrease of the water	4°C
T_{lake}	Inlet temperature of the water	7.5°C
$T_{network}$	Network's temperature	12°C
Δh_{vap}	Latent heat of vaporization at $T_{network}$	189.3 kJ kg^{-1}
$\Delta P_{vap-liq}$	Pressure differential vapour - liquid	1 bar

Table 6

Parameter		Value
φ_{liq}	Diameter of the liquid lines	100 mm
φ_{vap}	Diameter of the vapour lines	200 mm
ρ_{liq}	Density of the liquid	846 kg m^{-3}
ρ_{vap}	Density of the vapour	144.7 kg m^{-3}
μ_{liq}	Dynamic viscosity of the liquid	79.3 μN s m^{-2}
μ_{vap}	Dynamic viscosity of the vapour	16.4 μN s m^{-2}
$T_{network}$	Network's temperature	12°C
k_{pipe}	Roughness of the pipes	0.3 mm

The CO_2 network studied shows an annual energy (electricity) consumption of 16'765 MWh. The monthly averaged electric power peaks in January at 4.77 MW. The maximum over minimum ratio is 24.8. The share represented by the network utility – namely the central plant consumption and the pumping energy – amounts to 25.7% annually. Fig. 6 shows the energy consumed on a monthly basis for the energy services provided as well as for the central plant and for the circulation pumps. Note that air conditioning and server cooling do not appear, this is explained by the fact that free cooling causes no direct energy consumption. However, air conditioning is the main reason why the pumping energy has its peak in the summer period. During the months of July and August the share of pumping energy represents more than 50% of the total network's consumption.

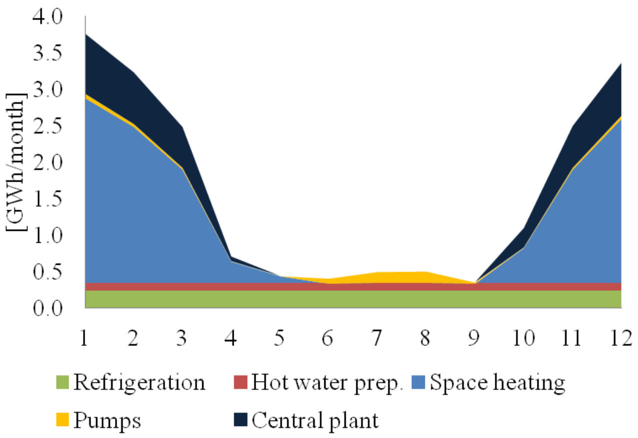

Fig. 6 Monthly energy (electricity) consumption of the CO_2 network studied.

The yearly effectiveness in heating, for the considered area and with the CO_2 network as energy conversion technology is 3.61. The yearly effectiveness in cooling is 124. The share of the pumping energy due to cooling and heating is 68.1 % and 31.2% respectively.

Compared to the current technology in place, the CO_2 network allows for a reduction of 78.4% in energy consumption. Such a reduction is achieved by order of importance through:

- A more efficient heating due to the use of a combination of centralized and decentralized heat-pumps.
- The replacement of all the vapour compression chillers by free cooling systems for the services of air conditioning and server cooling.
- The waste heat recovery from the cooling users allowing for the central plant not to consume electricity for heat pumping from May to September.

Finally, the greenhouse gases emission reduction is at the minimum 52% and can go up to almost 100% depending on the type of electricity bought from the grid.

EVALUATION OF THE INVESTMENT REQUIRED

In order to study the profitability of the CO_2 network presented, it is necessary to evaluate the investment required. It was chosen to divide the system into two main cost categories – the piping and the equipments.

The cost of the piping has been considered as the sum of the pipes cost and the excavation cost. A 2.5 multiplication factor is used to account for the extra cost for excavation in urban area.

The different elements considered for the investment cost related to the equipments are:

- The decentralized heat pumps
- The central plant, with the heat-exchanger and the compressor.
- The network regulations, including circulation pumps, control valves and programmable logic controllers (PLC).
- The plate heat exchangers at the cooling users.

The various cost functions used are presented in Table 7. The source for the cost function of the pipes is [2].

The decentralized heat-pumps cost function was fitted from data of two different manufacturers totalling 52 water-water heat-pumps. For the heat pumps used for hot water preparation, the function was fitted from 12 heat pumps of the same two manufacturers. In the latter case the cost of a hot water buffer tank was taken into account. For this study, it was decided that the biggest heat pump available would correspond to the biggest of the 52, respectively 12 heat pumps of the survey.

The cost function for the central plant heat exchanger and compressor are both from [3]. It is assumed that the heat exchanger of the central plant can operate indistinctly as an evaporator or a condenser, the area chosen to compute the cost is the biggest one. The overall heat transfer coefficient assumed is 1000 W m^{-2} K^{-1}. In the present case the maximum load in condensation is around 16 MW under a log mean temperature difference (LMTD) of 2.33°C, while in evaporation it is only 9.3 MW under a LMTD of 2.49°C. Hence, the size needed is constraint by the condensation and the required heat transfer area is 6'900 m^2.

The cost function for the main circulation pump (central) is from [3]. A fixed cost per unit purchased is assumed for the decentralized circulation pumps, the regulation valves and the PLCs.

The plate heat exchangers cost correlation was fitted from data coming from a call for 4 different CO_2 evaporators and condensers. Based on the maximum volume flowrate in commercially available CO_2 plate heat exchangers, it was found that the maximum heat load per exchanger is around 67 kW under the temperature differences they are operated in the CO_2 network presently studied.

A multiplication factor of 2.65 was applied to the purchasing cost in order to obtain the installed cost.

The detail of the investment required for the network is presented in Table 8

Table 7

Cost function	**X [unit]**	**Unit** Max size
$C_{Pipe} = 7.33\ X + 767$	φ [mm]	CHF m^{-1}
$C_{Excav} = 1.66\ X + 237$	φ [mm]	CHF m^{-1}
$C_{HeatPump} = 1'488\ X + 6'813$	$\dot{E}$ [kW]	CHF 25.8 kW
$C_{HotWatHeatPump} = 1'853\ X + 9'391$	$\dot{E}$ [kW]	CHF 15.5 kW
$C_{CentralHEX} = 513\ X^{0.82} + 5'700$	A [m^2]	CHF 10^4 m^2
$C_{CentralComp} = 10'260\ X^{0.6} + 22'800$	$\dot{E}$ [kW]	CHF
$C_{CentralPump} = 50'160\ X^{0.9} + 35'340$	$\dot{V}$ [m^{3}s^{-1}]	CHF
$C_{UserPump} = 2'000$	-	CHF
$C_{Valve} = 600$	-	CHF
$C_{PLC} = 1'000$	-	CHF
$C_{CoolingHEX} = 627\ X^{0.57}$	A [m^2]	CHF 67 kW$_{th}$

Table 8

Piping	Pipes	6'881 kCHF
	Excavation	4'476 kCHF
	Total piping	**11'356 kCHF**
Decentralized heat pumps		**6'296 kCHF**
Central plant	Compressor	718 kCHF
	Heat exchanger	727 kCHF
	Total central plant	**1'445 kCHF**
Network regulation	Central plant circulation pump	39 kCHF
	Decentralized circulation pumps	376 kCHF
	Control valves	182 kCHF
	PLCs	284 kCHF
	Total regulation	**880 kCHF**
Cooling users heat exchangers		**340 kCHF**
Total purchasing cost		**20'318 kCHF**
Bare module factor (not applied on the piping cost)		**2.65**
Total installed cost		**35'104 kCHF**

PROFITABILITY OF THE CO_2 NETWORK STUDIED

In this section, the profitability of the network studied is assessed. The performance indicator chosen is the Net Present Value (NPV). It consists in transferring the different future cash flows with a fixed interest rate so as to be able to compare these future amounts of money with today's investment.

In this study the NPV for every year of operation year is computed taking into account:

- The initial investment
- The revenues from heat and cold sales
- The cost of buying electricity from the grid
- The cost of replacing the equipments
- The cost of operation
- The cost of maintenance

Purchasing cost and installed cost are discussed in the previous section. The cost of engineering is considered to be 18% of the total installed cost. Hence the total initial investment for the network is 41.422 Mio. CHF.

The price of the kWh of heating respectively cooling supplied to the users is set at 0.13 CHF kWh^{-1}. The price of electricity from the grid is 0.22 CHF kWh^{-1}. According to [8, 9] the electricity price rose in average of 1.2% per year, between 1980 and 2010. A similar rate of increase was taken into account in the present study for both the electricity bought from the grid and the thermal energy billed to the customers.

For the current analysis, it was decided to consider an overall lifetime of 40 years. It corresponds to the lifetime of pipes. Nevertheless the lifetime considered for the rest of the equipments was only 15 years: Thus, two replacements of the equipments were taken into account in the NPV computation. The engineering overhead of 18% was also included in the equipments replacement cost. A 3.5% annual increase of the equipment cost is considered, corresponding roughly to the rate of increase of the *Chemical Engineering Plant Cost Index* between 1950 and 2010.

The cost of operation is assumed to be constituted mainly by manpower. It has been assumed that three equivalent full time jobs are required for operating the network. The manpower rate is 65.2 CHF h^{-1} and increases of 1.2% per year which, according to [10], corresponds to the value for the industries of production and distribution of energy. Every full time job is considered equal to 1927 h yr^{-1} [11].

The annual maintenance cost considered was 4% of the installed cost for the decentralized heat pumps and 1.5% for the piping. A 1.2% annual increase of the maintenance cost was considered, assuming that the maintenance cost is mostly driven by the cost of related manpower.

Finally the interest rate used for the NPV computation was 6%.

The evolution of the NPV over the lifetime of 40 years is shown at Fig. 7.

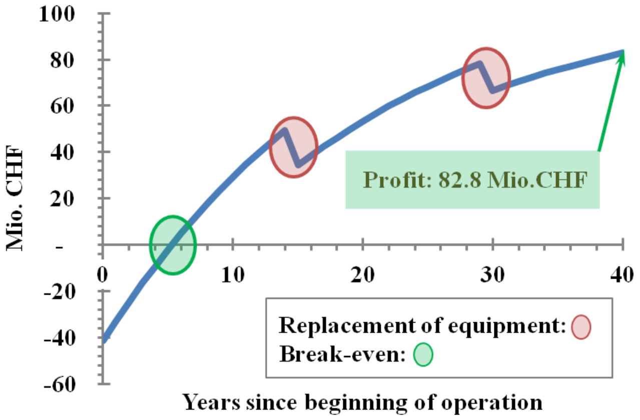

Fig. 7 Evolution of the net present value of the CO_2 network studied along its lifetime. (40 years, 6% interest, price of heat/cold: 0.13 CHF kWh^{-1})

The main results of the profitability analysis are the following:

- The break-even point is reached short after 5 years of operation.
- The profit generated amounts to 82.8 Mio. CHF present value.
- The cost of production of a kWh of service delivered (price for NPV = 0 after 40 years) is 0.087 CHF kWh^{-1}.
- The contribution to the total cost is distributed as follow:

1.	Electricity from the grid:	39.6%
2.	Total initial investment:	25.0%
3.	Replacement of equipment:	20.0%
4.	Maintenance:	11.3%
5.	Operation:	4.10%

CONCLUSION

Based on the energy reference area and the affection of the buildings in the area of “Rues Basses” in Geneva, the required monthly energy was evaluated for space heating, hot water preparation, air conditioning, refrigeration and server cooling. It led to an annual demand of 107’494 MWH, 54% of which is heating and 46% cooling.

The energy consumed was evaluated considering decentralized fuel boilers and vapour compression chillers as energy conversion technologies. It showed an annual consumption of 77’576 MWh of energy, 84.6% of which is fuel oil and 15.4% electricity.

A CO_2 network was then considered to replace the former technology. The resulting network represents a total of 3’686 m of piping; its annual electric energy consumption is 16’765 MWh representing 78% less than for the conversion system based on boilers and vapour compression chillers. Moreover the greenhouse gases emissions reduction is at least 52% and can reach almost 100%, depending on the type of electricity bought from the grid.

An evaluation of the investment required for the network led to a cost for the piping of 11.3 Mio. CHF and 8.9 Mio. CHF for the rest of the equipment. The total initial investment including installation cost and engineering is 41.4 Mio. CHF.

A profitability analysis based on the net present value of the system was carried out. It accounted for investment, energy sale and purchase, equipment replacement, operation and maintenance. The interest rate considered was 6% and the price of heating/cooling service 0.13 CHF kWh^{-1}. The profitability analysis showed that the break-even point would be reached after 5 years of operation and the profit generated would reach 82.8 Mio. CHF present value, for a lifetime of 40 years.

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