Venerdì 18 aprile 2008 ore 9.00
Sala convegni ARSSA

Gases from the vineyard to the cellar

Thermal and financial solvency of the refrigeration of the crushed grapes with CO2

Ing. Tommaso Bucci

CO_2 chemical and physical parameters

- Molecular weight: **44**
- Relative density of the gas : **1,52**
- Density of the liquid **(-37°C)**: **1,10**
- Fusion point **(-56,6°C)**: **5,2bar**
- Transport and storage conditions: **20bar -20°C**
- Sublimation: **-78,5°C**
- Yield frigorie Liq.-gas passage: **82—84 Fr/Kg**

Particularity**:**

The CO_2 expanding at pressures below 6 bar, instead of evaporating solidifies.

Entropic diagram

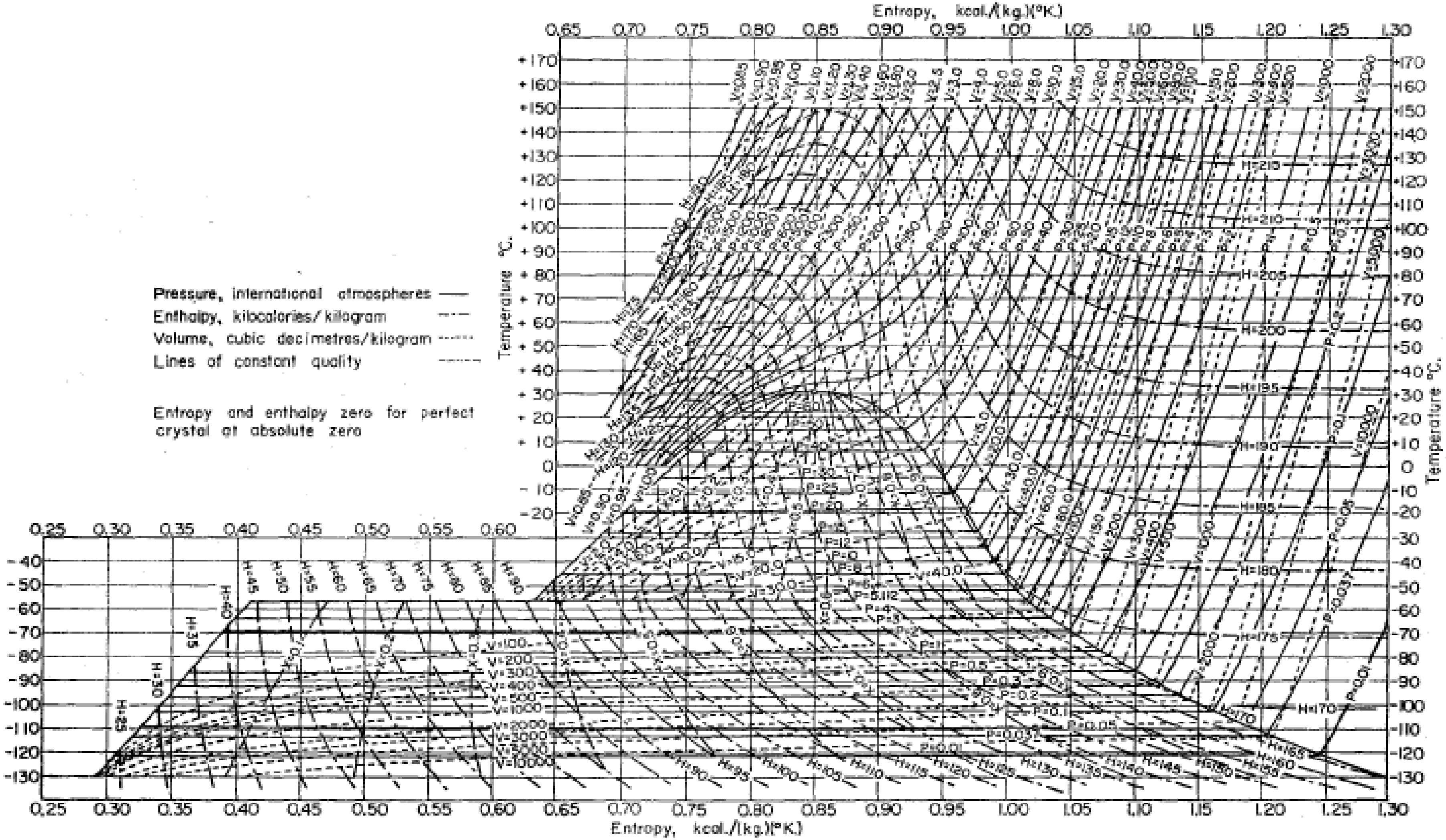


Fig. 3-19. **Temperature-entropy diagram for carbon dioxide.** [*From "Thermodynamic Functions of Gases," vol. 1, Butterworth, London, 1956. Copyright material. Reprinted by permission of the authors and publishers. A wall-sized reproduction of this diagram is obtainable from Butterworth & Co. (Canada), Ltd.*]

Enthalpy diagram

THERMODYNAMIC PROPERTIES

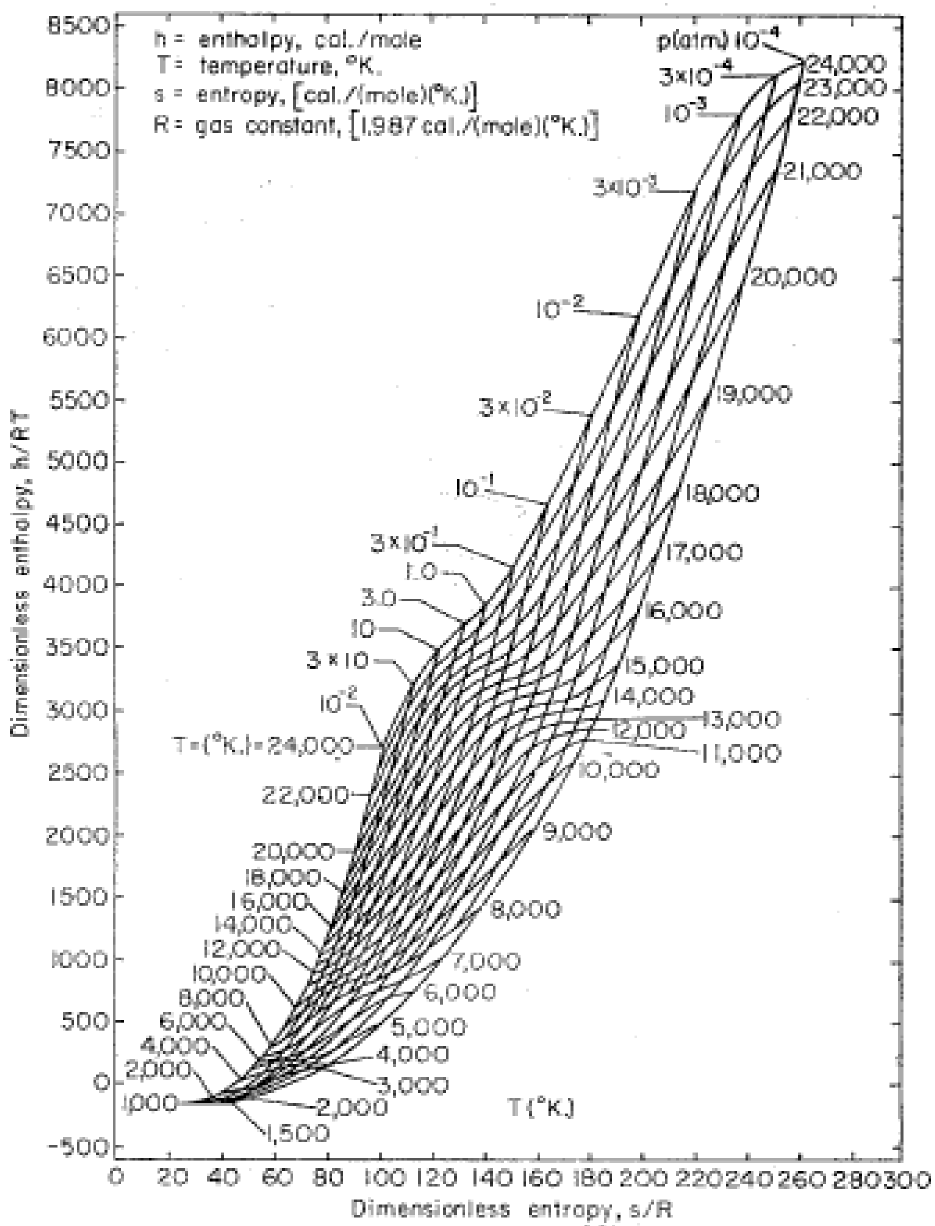


Fig. 3-20. Mollier diagram for carbon dioxide to 24000°K. *(From Raymond, Rand Rept. RM 2292, November, 1958. Reproduced by permission of the author and of the Rand Corporation.)*

Table 3-218. Saturated Carbon Dioxide†‡

Temp., °F.	Abs. pressure, lb./sq. in.	Volume, cu. ft./lb.		Enthalpy, B.t.u./lb.		Entropy B.t.u./(lb.)(°R.)	
		Condensed phase*	Vapor	Condensed phase*	Vapor	Condensed phase*	Vapor
t	p	v_f	v_g	h_f	h_g	s_f	s_g
−140	3.18	0.01008	24.320	−121.5	129.2	0.6065	1.3908
−120	8.90	.01018	9.179	−116.0	132.0	.6332	1.3636
−100	22.22	.01032	3.804	−110.1	134.3	.6403	1.3199
−90	33.98	.01040	2.525	−106.7	135.1	.6499	1.3033
−80	50.85	.01048	1.700	−102.5	135.7	.6607	1.2881
−70	74.82	.01059	1.162	− 98.0	135.9	.6724	1.2726
−69.9	75.10	.01059	1.157	− 97.9	135.9	.6725	1.2724
−69.9	75.10	.01360	1.1570	− 13.7	135.7	.8885	1.2724
−60	94.7	.01384	0.9270	− 9.2	136.6	.8997	1.2647
−50	118.2	.01409	.7492	− 4.7	137.2	.9110	1.2572
−40	145.8	.01437	.6113	.00	137.8	.9218	1.2503
−30	177.8	.01466	.5029	4.5	138.2	.9325	1.2436

Temp., °F.	Abs. pressure, lb./sq. in.	Volume, cu. ft./lb.		Enthalpy, B.t.u./lb.		Entropy B.t.u./(lb.)(°R.)	
		Liquid phase	Vapor	Liquid phase	Vapor	Liquid phase	Vapor
t	p	v_f	v_g	h_f	h_g	s_f	s_g
−20	214.9	.01498	.4168	9.1	138.5	.9430	1.2372
−10	257.3	.01532	.3472	13.9	138.7	.9532	1.2303
0	305.5	0.1570	.2904	18.8	138.9	.9636	1.2247
10	360.2	.01614	.2437	24.0	138.7	.9744	1.2188
20	421.8	.01663	.2049	29.4	138.3	.9856	1.2127
30	490.8	.01719	.1722	35.4	137.8	.9976	1.2067
40	567.8	.01787	.1444	41.7	136.7	1.0092	1.1994
50	653.6	.01868	.1205	48.4	135.0	1.0218	1.1917
60	748.6	.01970	.0994	55.5	132.1	1.0353	1.1826
70	853.4	.02112	.08040	63.7	127.5	1.0500	1.1724
80	968.7	.02370	.06064	73.9	118.7	1.0694	1.1555
87.8	1069.4	.03454	.03454	97.0	97.0	1.1098	1.1098

*Above the solid line the condensed phase is solid; below the line it is liquid.

† "Refrigerating Data Book," 5th ed., American Society of Refrigerating Engineers, New York, 1942.

‡ s_f = 1.0 at 32°F.

h_f = 36.7 at 32°F.

For an extensive listing of work from 1935 to 1957 see Liley, *J. Chem. Eng. Data*, **4**, 238 (1959). In addition to the references listed there Cramer [*Chem.-Ing.-Tech.*, **27**, 484 (1955)] gives 44 references, a *T-S* diagram from −100° to 1000°C., to 12,000 atm., and a *H*-log *P* diagram from −50 to 175°C., to 3000 atm. Majumdar and [illegible] [*Geochim. et Cosmochim. Acta*, **10**, 311 (1956)] give fugacities and free energies to 1000°K and 1400 bars. For ideal-gas functions to 6000°K, see Huff, Gordon, et al., *N.A.C.A. Rept.* 1037, 1951. The data of Sweigert, Weber, and Allen appearing in the third edition of this handbook have been criticized by [illegible] and Kuss, *Petrol. Refiner*, **31** (11), 137 (1952).

Example:

Refrigeration of a mass of **20.000 Kg** of grapes not stemmed from **25° C** to **10° C**, **DT 15° C**.

The grapes after pressing of the grapes is reduced to a mass **M** of **19.000 Kg** around.

Specific heat of the crushed product **Cp = 0,2** x **0,3** + **0,8** x **1** = **0,86kcal/Kg**
The necessary frigories **F** = **Cp** x **DT** x **M**
Therefore **F** = **0,86** x **15** x **19.000** = **245.100Fr** (theoretical)

For a correct calculation we must consider the variables losses, according to the goodness of the insulation therefore, with an estimated increase of about **10%,** we will have **270.000Fr.**

Amount of liquid CO_2 = **270.000/82** equal to **3.292Kg**

Therefore **0,165 Kg CO_2/Kg of grapes** for **DT 15°C**

Or again **0,011 Kg CO_2 for Kg** of grapes for each degree of refrigeration

COSTS:

Assuming the price of CO_2 of **0,25€/Kg** and **60.000€** of **Boreal system**

The cost of CO_2 for the case under examination becomes:
0,165 x **0,25** = **0,04125€/Kg** therefore **4,125€/Quintal** for **DT 15°C** and **2,75€/Quintal** for **DT 10°C**
(for the example considered 825€ for 20.000Kg of grapes DT 15°C)
anyway (**0,25€/Kg)** / **(82Fr/Kg)** = **0,003€/Fr (1€ = 333Fr)**

In addition to these the **costs of system** or **fixed costs**:
a) **Decennial** quote depreciation COOLER (BOREAL) **6.000€** (twenty-year **3.000€)**
b) Annual rental fee of COLD STORAGE OF CO_2 **3.600€**
c) Maintenance **400€/year** (very modest, of only Boreal)

Total fixed quotes: **10.000€/year** (with ten-year depreciation)
(**7.000€/year** with twenty-year depreciation)

TRADITIONAL REFRIGERATION

In traditional refrigeration plant with compression,? The thermal performance of refrigeration systems are normally defined by the **COP** (**Coefficient of Performance or, coefficient of performance**)

This refers to the relationship between the electromechanical power supplied **E** and heat (thermal energy output) **Q**, therefore what the facility disposes to the CONDENSER.

COP = E/Q

This is typical parameter of so-called systems HEAT PUMP, where the heat **Q** is what matters.

In our case we are affecting refrigeration F supplied from the evaporator.

So we want to know the relationship **Ke = F/E** sometimes referred to as **“EFFECTIVE SPECIFIC COOLING POTENTIAL”**

From thermodynamics we know that:

Q = E + F

Therefore **COP = Q/F** becomes **(E+F)/E** therefore **COP = 1 + Ke**

and therefore **Ke = COP - 1**

Given the traditional system with intermediate fluid glycol water, This overall performance including the pumping of the glycol solution is reasonably estimable for simplicity:

2.000Fr/KWh

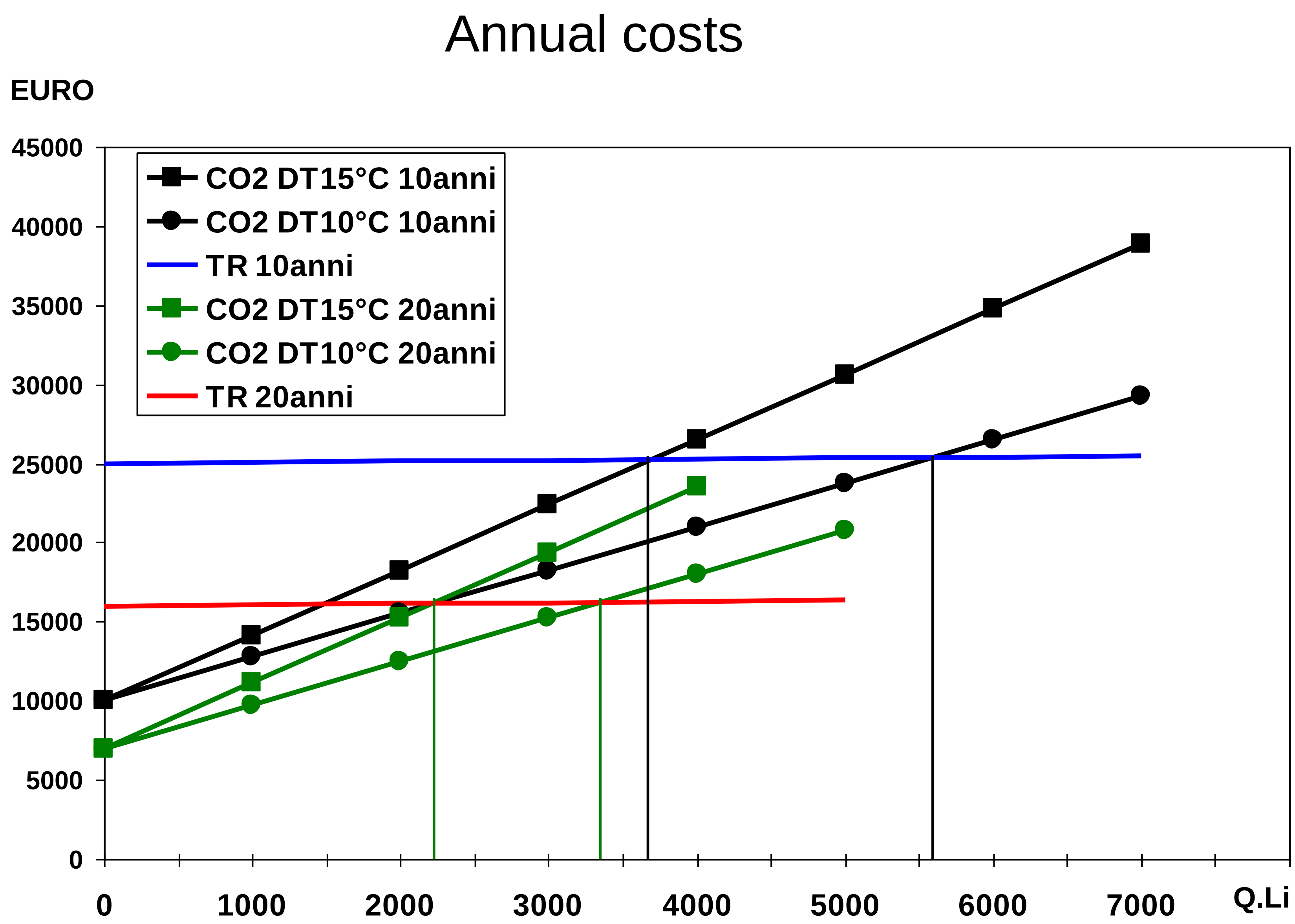
Variable costs arising:
considered the cost of the electrical energy alone of **0,1€/KWh**
We will have a cost of **0,00005€/Fr (1€ = 20.000Fr)**
that is, with the above considerations **675€/1000Q.ls** for **DT15°C**

Fixed costs:
centralized system + power supply + final exchanger (Spiraflow) + glycol solution deployment (for medium resolution of about 0,6€/Fr),
for a required capacity of **300.000Fr**, suitable for our case, we will have a cost of **180.000€**

a) Ten-year quote of depreciation: **18.000€ (twenty-year 9.000€)**
b) Fixed quote commitment power (ENEL) for powers below 500KW: **22,68 €KW/year**

Need **150 KW equal to 3.402€/year**

Maintenance of at least 2% immobilisation (complex plants) **3.600€/anno**
Total of fixed quotes **18.000+3400+3.600=25.000€/year (twenty-year 16.000€)**



Annual costs
EURO
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
CO2 DT15°C 10anni
CO2 DT10°C 10anni
TR 10anni
CO2 DT15°C 20anni
CO2 DT10°C 20anni
TR 20anni
0
1000
2000
3000
4000
5000
6000
7000
Q.Li

COMPARISON SYSTEMS

	CO_2	TRADITIONAL	RELATION CO_2 TRADIZIONAL
COST OF SYSTEM FOR 300.000Fr	60.000	180.000	0,33
ANNUAL FIXED COST	10.000	25.000	0,4
COST OF 1.000.000Fr	3.000	50	60