The urgent need for thermodynamically based indicators in policy and decision making

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Content

- Exergy performance index, in legal framework
- Life cycle exergy analyses
- Importance of coupling with environmental threats: Let decision makers get not one item but a complete menu

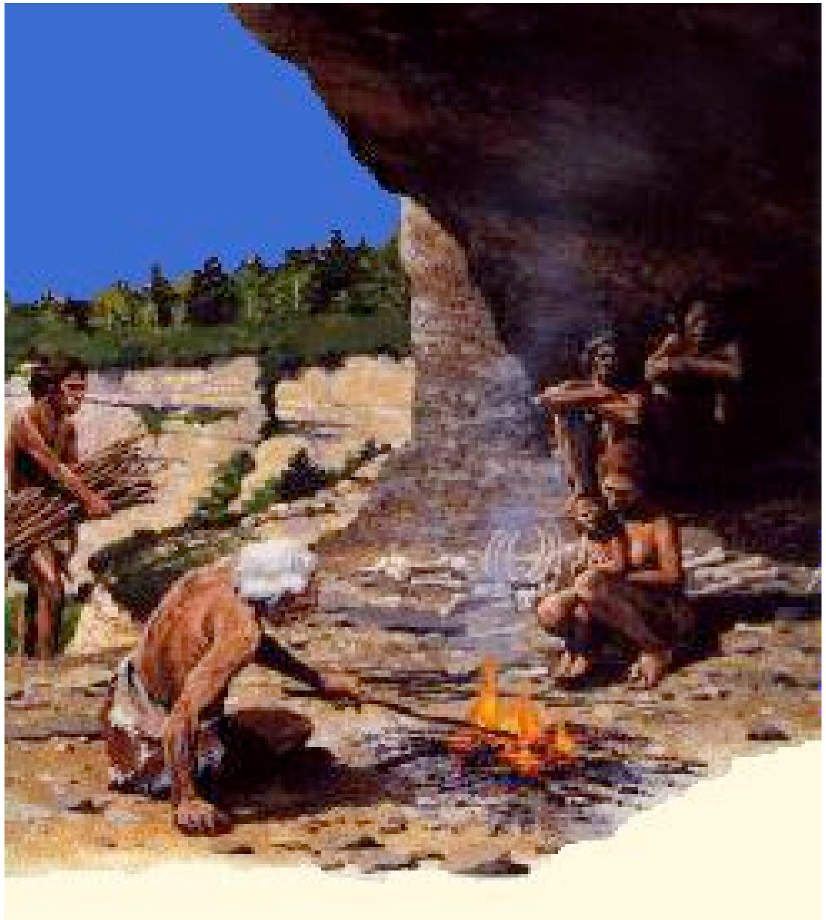
  --> environomic multi-objective optimisation

Historical 1: combustion and heating

Simple combustion for heating (since around 400000 years)

Today still the majority of the heating systems (simple oil or gas boilers)

Is it really a 21st century technology?



First Law efficiency of boilers = around 92% of the Lower Heating Value
Exergy efficiency (2nd Law) = around 16% (for an average supply temperature of 60°C)

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Exergy

The exergy associated with a transfer or a stock of energy is defined as the potential of maximum work which could ideally be obtained from each energy unit being transferred or stored (using reversible cycles with the atmosphere as one of the energy sources either hot or cold).

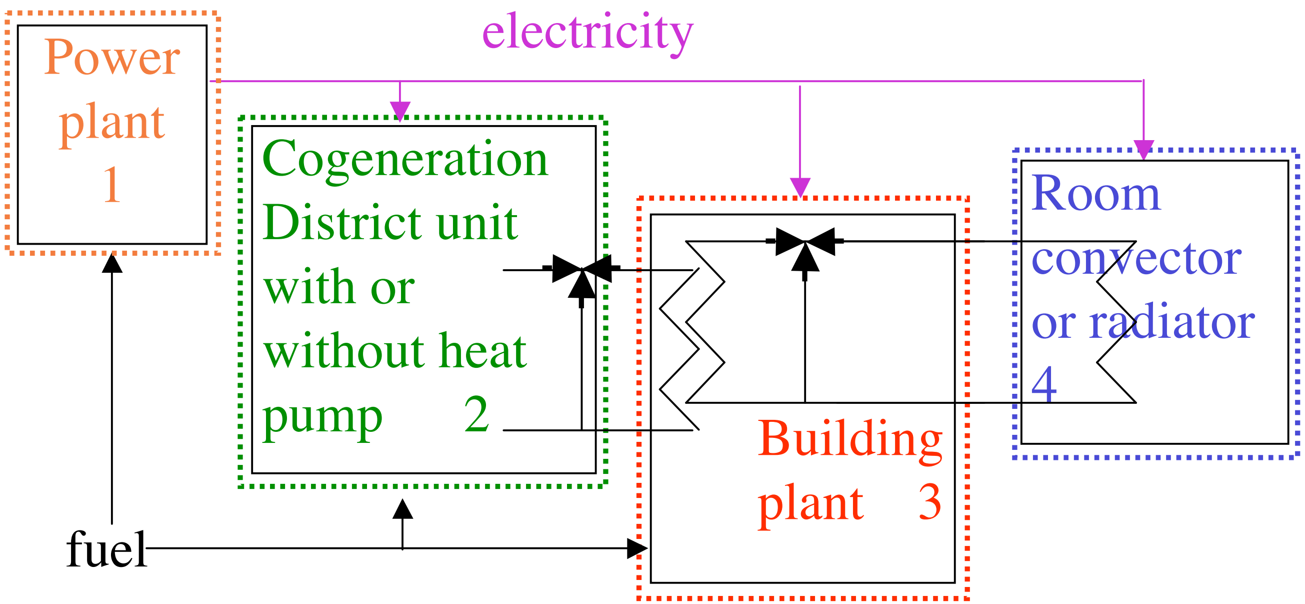
The exergy approach allows to quantify in a coherent way both the quantity and the quality of the various forms of energy considered.

The exergy presents the major advantage of defining efficiencies which can be adapted to every situation (cogeneration of heat , power, cold,fuel, etc.) and for all application domains. The efficiency which are, always lower than 100%, give an assessment of the relative quality of the different technical options.

Exergy efficiency

- **Is an indicator of the quality with which men convert resources**
- **Does not basically give information:**
  - **concerning the use of renewable versus non renewable resources,**
  - **on the relative conversion difficulties of a given primary energy. For example solar energy because of the weak irradiation density is more difficult to convert than oil or natural gas and solar conversion systems result in low efficiencies in spite of their inherent advantages,**
  - **on the local environmental impacts (pollutants affecting health) and only indirectly on global environment issues**

From local to global



$$\eta = \eta_1 \; \eta_2 \; \eta_3 \; \eta_4$$

Example: Combined cycle power plant without cogeneration (1)+District heating heat pump (2) + DH heat exchanger in the building (3) +convector (4)

$$\eta = \left(\frac{\dot{E}^-_{el,1}}{\dot{E}^+_{y,1}}\right)\left(\frac{\dot{E}^-_{y,2}}{\dot{E}^+_{el,2}}\right)\left(\frac{\dot{E}^-_{y,3}}{\dot{E}^+_{y,3}}\right)\left(\frac{\dot{E}^-_{q,4}}{\dot{E}^+_{y,4}}\right) = \frac{\dot{E}^-_{q,4}}{\dot{E}^+_{y,1}}$$

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Examples de technologies	Power plant	Dist. plant	Building plant			Room convector			Overall exergy efficiency [%]		
Supply/return temperatures			45°/35°	65°/55°	75°/65°	45°/35°	65°/55°	75°/65°	45°/35°	65°/55°	75°/65°
Direct electric heating (nuclear power)	0.32					0.07	0.07	0.07	2.2	2.2	2.2
Direct electric heating (combined cycle cogeneration)		0.55				0.07	0.07	0.07	3.7	3.7	3.7
Direct electric heating (hydro power)	0.88					0.07	0.07	0.07	6.0	6.0	6.0
District boiler		0.2	0.54	0.76	0.86	0.53	0.38	0.33	5.8	5.8	5.8
Building non-condensing boiler			0.11	0.16	0.18	0.53	0.38	0.33	6.1	6.1	6.1
Building condensing boiler			0.12			0.53			6.6		
District heat pump (nuclear power)	0.32	0.61	0.54	0.76	0.86	0.53	0.38	0.33	5.6	5.6	5.6
Domestic heat pump (nuclear power)	0.32		0.45	0.45	0.45	0.53	0.38	0.33	7.6	5.4	4.8
Domestic cogeneration engine and heat pump			0.22	0.25	0.26	0.53	0.38	0.33	11.8	9.4	8.7
District heat pump (combined cycle power)	0.54	0.61	0.54	0.76	0.86	0.53	0.38	0.33	9.4	9.4	9.4
Domestic heat pump (combined cycle power)	0.54		0.45	0.45	0.45	0.53	0.38	0.33	12.9	9.2	8.1
Domestic heat pump (cogeneration combined cycle power)		0.55	0.45	0.45	0.45	0.53	0.38	0.33	13.2	9.4	8.3
Cogeneration fuel cell and domestic heat pump			0.25	0.27	0.28	0.53	0.38	0.33	13.4	10.4	9.5
District heat pump (hydropower)	0.88	0.61	0.54	0.76	0.86	0.53	0.38	0.33	15.4	15.4	15.4
Domestic heat pump (hydropower)	0.88		0.45	0.45	0.45	0.53	0.38	0.33	21.2	15.1	13.3

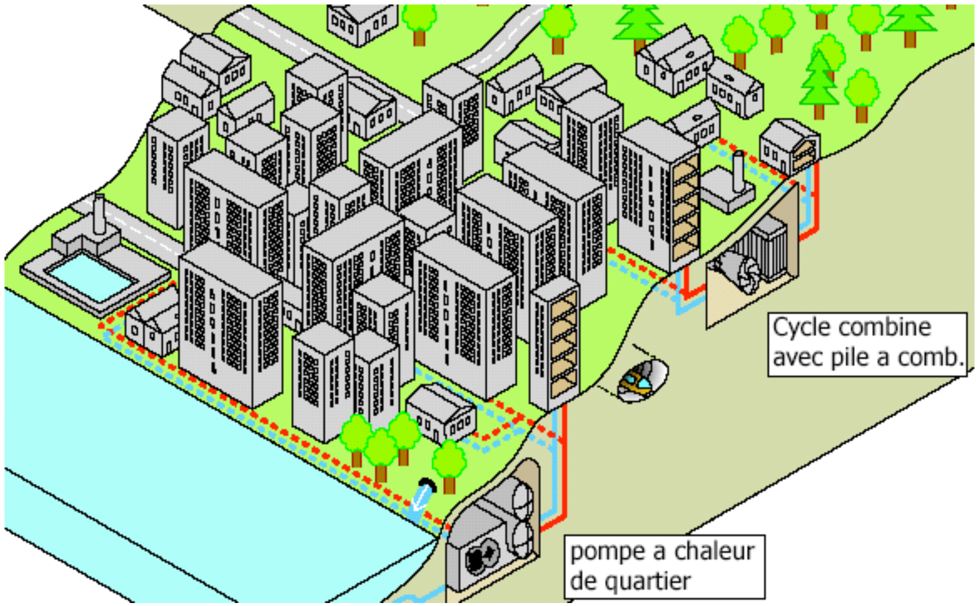
Overall exergy efficiency of Air conditioning / refrigeration

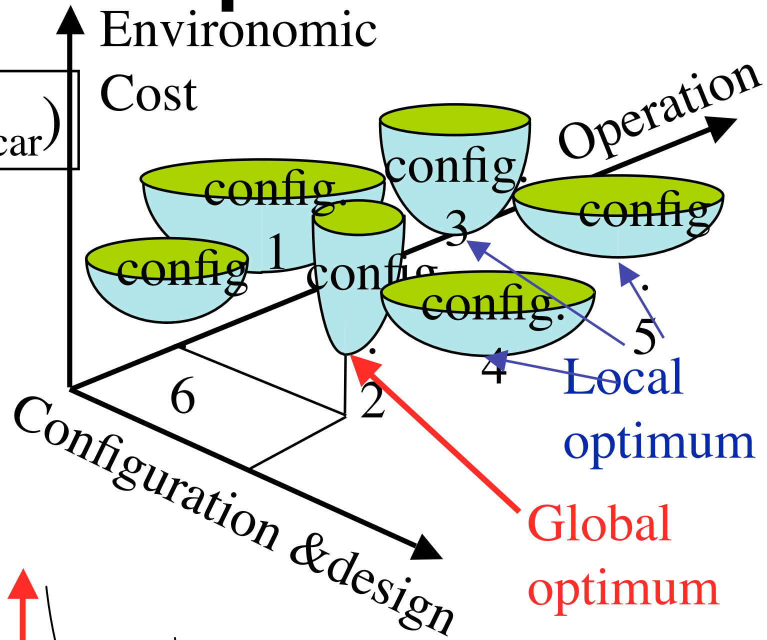
(hypothesis : compression refrigeration with 40% exergy efficiency)

Power plant technologies	Power plant	Dist. plant	Building plant			Room convector			Overall exergy efficiency [%]		
Supply/return temperatures			10°/15°	5°/10°	0°/5°	10°/15°	5°/10°	0°/5°	10°/15°	5°/10°	0°/5°
Nuclear power	0.32		0.4	0.4	0.4	0.56	0.43	0.34	7.1	5.4	4.3
Gas motors	0.36		0.4	0.4	0.4	0.56	0.43	0.34	8.1	6.2	4.9
Combined cycle power plant without cogeneration	0.54		0.4	0.4	0.4	0.07	0.07	0.07	12.1	9.3	7.3
hydropower	0.88		0.4	0.4	0.4	0.53	0.38	0.33	19.8	15.2	12.0

Environomic mono - objective optimisation

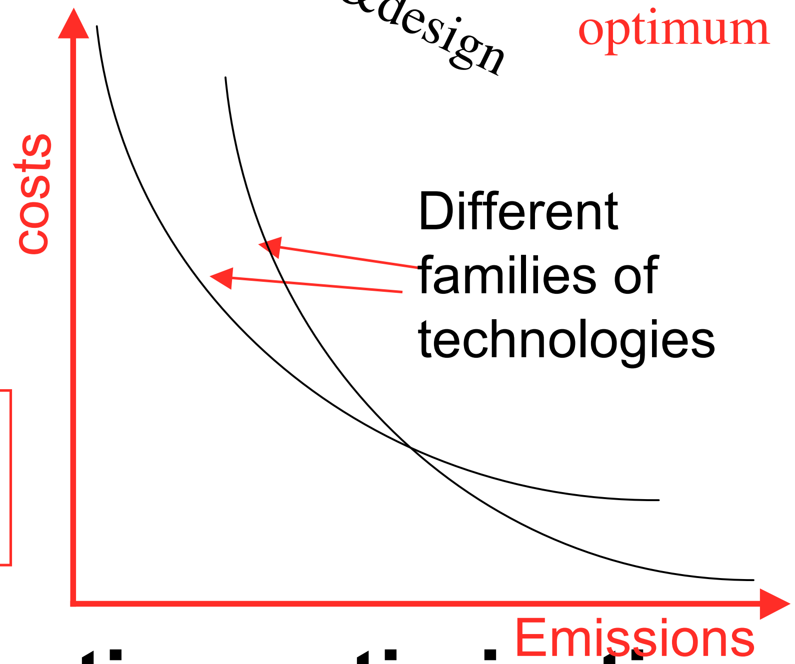
$$\text{min. } C_{\text{énergie}} = f(C_{fuel} + C_{capital} + C_{pollution} + C_{scar})$$





$$\text{min. } C_{\text{énergie.}} = f(C_{fuel} + C_{capital} + C_{scar})$$

min. Specific pollution

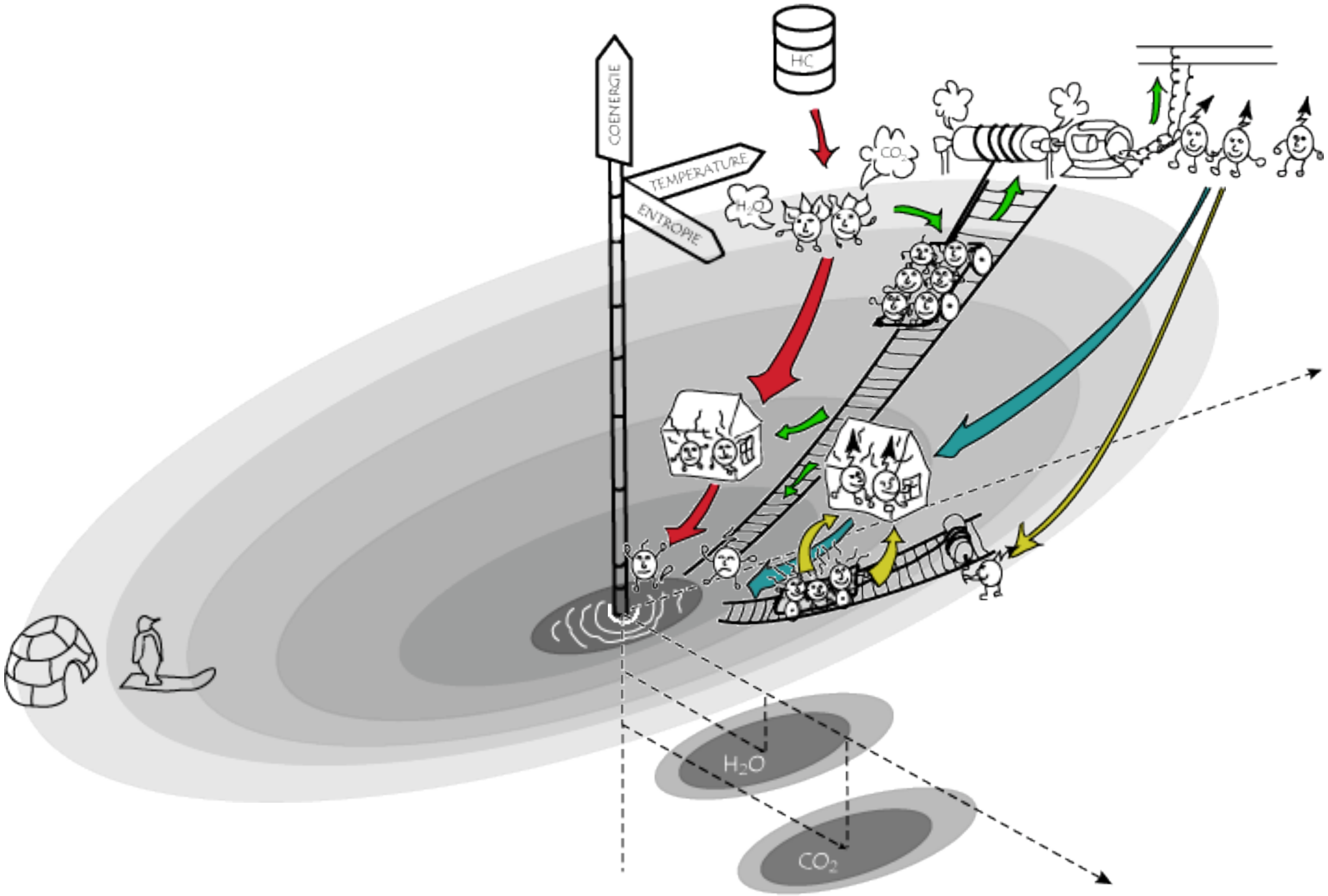


Environomic multi - objective optimisation

Conclusions

- The introduction of an exergy indicator in a law on energy allowed to convey:
  - The importance of low temperature heating or of high temperature cooling,
  - The weak efficiency of the present heating and cooling technologies and some of the improvement prospects
  - A coherent ranking of the alternatives in view of improving the planning of energy systems
  - Life Cycle Exergy is an interesting extension
- In spite of this step a major effort still needs to be made in education in order to ensure its proper implementation at all levels
- Environmental regulation should not be only based on inequalities but economic penalties based on emissions should be introduced (towards an ecological fiscal system)

Cartoon representation of the concepts of heating, cogeneration or heat pumping



Source (partial): Borel L, Favrat D Thermodynamique et énergétique. PPUR 2005