Low exergy systems for heating and cooling

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IEA ECBCS Annex 49
Low Exergy Systems for High-Performance Buildings and Communities

- Exergy is a measure of energy quality

Exergy/energy ratio (T_0=20°C)	
Mechanical energy	*1.00*
Electrical energy	*1.00*
Nuclear fuel	*1.00*
Solar radiation	*0.95*
Fossil fuels	*0.90*
Heat at 100°C	*0.21*
Heat at 40°C	*0.06*

- Although building heating and cooling require low valued energy, climatisation is usually provided with high exergy sources!

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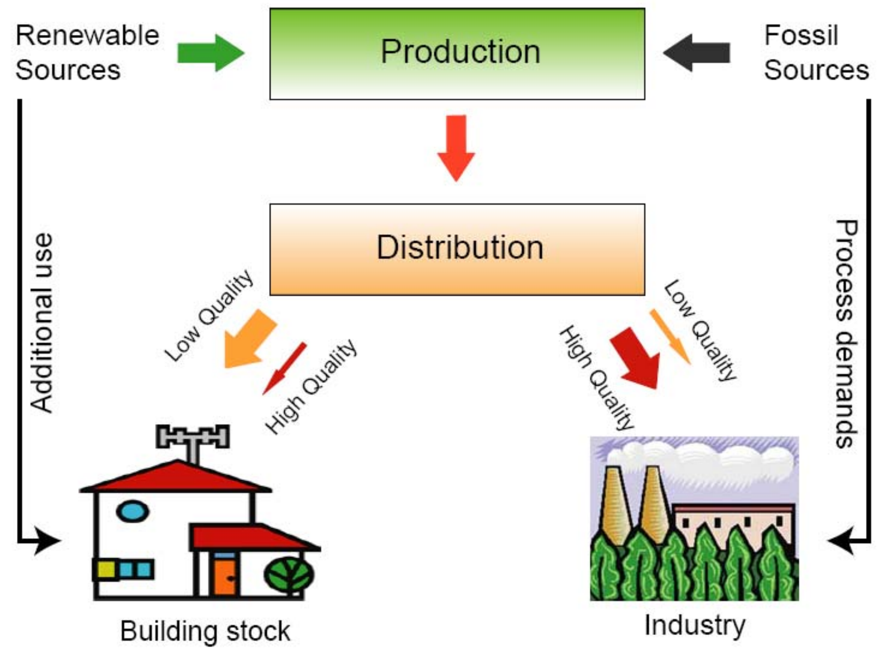
<u>The LowEx approach</u>:

- matching the quality levels of the energy supply and demand for the building stock
- minimising exergy consumption in the building systems

<u>The Annex 49 project</u>:

- developing exergy analysis methodologies and tools
- Pinpointing and promoting exergy efficient community supply systems and building technologies



Energy\exergy analysis of heating/cooling options in Italy

Comparison among different commercial climatisation options

Methodology:

- Steady state calculation of exergy efficiency with design temperatures seasonally and locally varying:
  - Heating T_U= 20°C T_0= -5°C (Mi), 5°C (Pa)
  - Cooling T_U= 26°C T_0= 32°C (Mi, Pa)
- Energy generation (plant) and heating/cooling supply (system) levels
- System size referring to a single residential unit

Energy\exergy analysis of heating/cooling options in Italy

Plant level:

- Electricity/heat generation: Italian electricity mix, CCGT, large and mini CHP, PV
- Performance:
  - Energy efficiency η_1
  - Exergy efficiency $\varepsilon_1 = \frac{Ex_U}{Ex_C}$

System level:

- Performance:
  - Energy efficiency η_2 (COP)
  - Exergy efficiency $\varepsilon_2 = Ex_U / Ex_C = $

$$= Q_U \left| 1 - \frac{T_0}{T_U} \right| \Big/ Ex_C$$

Entire energy chain performance:

- Overall energy efficiency

  $\eta = \eta_1 \eta_2$
- Overall exergy efficiency

  $\varepsilon = \varepsilon_1 \varepsilon_2$

Energy\exergy analysis of heating/cooling options in Italy

<u>System level</u>: example of analysis

- comparison among heat pumps (T_0= -5°C)

system	*COP*	ε	*COP/ COP$_0$*	$\varepsilon/\varepsilon_0$
Air-to-air heat pump	**2.82**	**0.24**	**100 %**	**100 %**
Air-to-water heat pump	**1.79**	**0.15**	**64 %**	**64 %**
Ground source heat pump	**4.50**	**0.32**	**160 %**	**132 %**

$$\frac{\varepsilon_{GSHP}}{\varepsilon_{ASHP}} = \frac{COP_{GSHP}}{COP_{ASHP}} \frac{1}{1+(COP_{GSHP}-1)\left(1-\frac{T_0}{T_G}\right)}$$

"thermal pollution" entropy production

- comparison between absorption chillers (T_0= 32°C)

system	*COP*	ε	*COP/COP$_0$*	$\varepsilon/\varepsilon_0$
Single stage	**0.7**	**0.103**	**100 %**	**100 %**
Double stage	**1.1**	**0.079**	**157 %**	**77 %**

different temperature levels in input!

Energy\exergy analysis of heating/cooling options in Italy

Entire energy chain analysis: heating

Heating options (Milano)

source	*generation*	η_1	ε_1	*system*	η_2	ε_2	η	ε
RE equivalent	waste heat recovery	1	1	district heating	0.9	0.319	**0.90**	**0.319**
RE equivalent	small size cogeneration	3.30	0.79	district heating	0.9	0.319	**2.97**	**0.253**
fossil+RE	combined cycle	0.55	0.55	ground source heat pump	4.5	0.318	**2.48**	**0.175**
fossil	combined cycle	0.55	0.55	air-to-air heat pump	2.82	0.240	**1.55**	**0.132**
fossil+RE	Italian electrical mix	0.36	0.36	ground source heat pump	4.5	0.318	**1.62**	**0.114**
RE equivalent	large size cogeneration	1.31	0.32	district heating	0.9	0.319	**1.18**	**0.100**
fossil	Italian electrical mix	0.36	0.36	air-to-air heat pump	2.82	0.240	**1.01**	**0.086**
fossil	√			condensing gas boiler + radiant panels	1.05	0.085	**1.05**	**0.085**
fossil	combined cycle	0.55	0.55	air-to-water heat pump	1.79	0.153	**0.98**	**0.084**
fossil	√			condensing gas boiler + radiator	0.98	0.075	**0.98**	**0.075**
fossil	√			gas boiler + radiator	0.86	0.067	**0.86**	**0.067**
fossil	Italian electrical mix	0.36	0.36	air-to-water heat pump	1.79	0.153	**0.64**	**0.055**
RE	photovoltaic	0.15	0.16	ground source heat pump	4.5	0.318	**0.68**	**0.050**
RE	photovoltaic	0.15	0.16	air-to-air heat pump	2.82	0.240	**0.42**	**0.038**
fossil+RE	√			solar collectors+condens. gas boiler+radiant panels	0.38	0.033	**0.38**	**0.033**
RE	photovoltaic	0.15	0.16	air-to-water heat pump	1.79	0.153	**0.27**	**0.024**

- **moving from Milano to Palermo affects slightly the order of the list**
- **most exergy efficient solutions: using waste or cogeneration heat, energy efficient heat pumps +CCGT**
- **fully renewable solutions (solar systems) are in general the less exergy efficient….but renewable!**

Energy\exergy analysis of heating/cooling options in Italy

Entire energy chain analysis: cooling

source	*generation*	η_1	ε_1	*system*	η_2	ε_2	η	ε
RE equivalent	waste heat recovery	1	1	single stage absorption chiller	0.7	0.103	**0.7**	**0.103**
RE equivalent	waste heat recovery	1	1	double stage absorption chiller	1.1	0.079	**1.1**	**0.079**
fossil+RE	combined cycle	0.55	0.55	direct ground cooling	10	0.123	**5.50**	**0.068**
RE equivalent	small size cogeneration	3.30	0.45	single stage absorption chiller	0.7	0.103	**2.31**	**0.046**
fossil+RE	Italian electrical mix	0.36	0.36	direct ground cooling	10	0.123	**3.60**	**0.044**
fossil+RE	combined cycle	0.55	0.55	ground source heat pump	4.5	0.072	**2.48**	**0.040**
fossil	combined cycle	0.55	0.55	air-to-air heat pump	3.46	0.069	**1.90**	**0.038**
fossil	combined cycle	0.55	0.55	air-to-water heat pump	3.25	0.065	**1.79**	**0.036**
fossil+RE	Italian electrical mix	0.36	0.36	ground source heat pump	4.5	0.072	**1.62**	**0.026**
fossil	Italian electrical mix	0.36	0.36	air-to-air heat pump	3.46	0.069	**1.25**	**0.025**
fossil	Italian electrical mix	0.36	0.36	air-to-water heat pump	3.25	0.065	**1.17**	**0.023**
RE	photovoltaic	0.15	0.16	direct ground cooling	10	0.123	**1.50**	**0.019**
fossil	large size cogeneration	1.31	0.18	single stage absorption chiller	0.7	0.103	**0.92**	**0.018**
RE	photovoltaic	0.15	0.16	ground source heat pump	4.5	0.072	**0.68**	**0.011**
RE	photovoltaic	0.15	0.16	air-to-air heat pump	3.46	0.069	**0.52**	**0.011**
RE	photovoltaic	0.15	0.16	air-to-water heat pump	3.25	0.065	**0.49**	**0.010**
RE	Solar collector	0.40	0.06	single stage absorption chiller	0.7	0.103	**0.28**	**0.006**

- **cooling exergy efficiency generally lower than heating!**
- **most exergy efficient solutions: waste heat + absorption chillers and CCGT+ direct ground cooling**

Dynamic vs steady state analysis

Preliminary comparison between steady state and dynamic evaluation of exergy efficiency for some heating/cooling systems

Dynamic simulation of the heating and cooling demand of a residential unit

	ε steady	ε dynamic
Air source reversible heat pump	$COP(T_0)\cdot\left(1-\frac{T_0}{T_U}\right)$	$\left\langle COP(T_0(t))\cdot\left(1-\frac{T_0(t)}{T_U}\right)\right\rangle$
Condensing boiler	$\eta\cdot\left(1-\frac{T_0}{T_U}\right)$	$\eta\left\langle\left(1-\frac{T_0(t)}{T_U}\right)\right\rangle$
Direct ground cooling system	$COP\cdot\frac{\left\lvert 1-\frac{T_0}{T_U}\right\rvert}{\left\lvert 1-\frac{T_0}{T_G}\right\rvert}$	$COP\cdot\left\langle\frac{\left\lvert 1-\frac{T_0(t)}{T_U}\right\rvert}{\left\lvert 1-\frac{T_0(t)}{T_G}\right\rvert}\right\rangle$

Dynamic vs steady state analysis

Milano	ε steady $T_0=T_{design}$	ε steady $T_0=< T_0(t)>$	ε dynamic
Air source reversible heat pump (heating)	0.184	0.157 *(-15 %)*	0.157 *(-15 %)*
Condensing boiler	0.079	0.061 *(-23 %)*	0.062 *(-22 %)*
Air source reversible heat pump (cooling)	0.052	√	0.036 *(-31 %)*
Direct ground cooling system	0.201	√	0.117 *(-42 %)*

- Significant difference between steady and dynamic values, but if T_0 is a monthly mean instead of a design value ....
- The difference depends on the system
- Further investigations are necessary...