

Exergy Method To Evaluate The Building Energy Performance

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Abstract: Design and management of healthy buildings are the result of an evaluation process. Several factors are involved during this process: comfort indoor temperature, technological and economical aspects. Every country has a different climate and therefore outdoors temperature, but a similar indoor temperature range. To warm buildings in different sites a different amount of energy is needed. How can be compared energy consumption in different climate contests?

Exergy analysis is a tool to evaluate the "quality of energy consumption". The exergy study of building/plant system could be used to heat a building with less energy consumption. In this paper we propose an exergy analysis tool instrument (simple and quick) to evaluate and to compare thermal energy and economic cost

Keywords: energy audits, exergy audits, energy efficiency

Topics 3: Design and operation of healthy building

1.Introduction

"Thermodynamic is an economic science".

During buildings design is necessary to evaluate and check the energetic performances of the system plant building. The upcoming European standard evaluates building consumption leaving aside the kind of plant design.

In every climate, outdoor temperature varies from place to place while indoor temperature are similar everywhere.

How can be compared the quality of energy used in relation with these different parameters?

1.1Aim of the paper

In this paper we study a simplified method to evaluate the quality of energy consumption in buildings.

The aim is to find a relation between energy consumption to heating building, included energy wrapped dispersion and plan system, and exergy consumed.

With the same amount of energy consumed the tariff paid is the same without any relation with a heat transmission modus, energy waste and exergy consumed.

Low temperature plants have lower exergy consumption then lower energy waste.

To spread the use of low temperature plants with low exergy consumption, we need to intervene within the tariff index.

A way to promote it could be an exergy analysis.

2.Exergy analysis

The study of energy consumption in winter regime evaluates the building and plant system losses in relation with the demand of energy needed to have an even temperature.

The method explained leaves aside the plant design as well as the unit temperature.

2.1 The exergy evaluation

The method proposed tries to find out which is the best system to assess qualitatively the consumption of energy, through the exergy evaluation of the different sub unit of the building.

The method re formulates the research of the group LowEX for the program IEA ECBCS Annex 37.

The exergy study of the system building, heating plant allows assessing the yield of energy at net of the entropy wasted to have an even temperature.

The exergy consumed is evaluated by sub systems of the building:

1. The insulation of building external layer: temperature inside/outside and temperature gap between internal and external wall
2. The distribution plant: temperature of the heating unit /°t indoor, and °t heat in/°t heat out of the distribution plant
3. The heat generator: ratio between °t heat out and the fuel power

The summation of the exergy indexes of the three subsystems gives the amount of exergy used for heating.

Taking account of these parameters allows comparing the costs of energy consumption with energy consumption.

The ratio between costs of the energy consumption and the exergy consumption gives the economical/energetic yield.

This method enables us to compare different systems and realize which one at the same level of energy waste less energy, therefore performs with energy efficiency.

3. Methods

Object of study is the heat exchange between building wrapped and outside temperature, building and heating plant, and plant elements.

This method could allow to parameter energy/exergy relation, with simple project parameters: environmental temperature, plant heating terminal temperature and boiler power.

The first step consists of calculating the dispersion of energy depending of geometrical and thermo and physical parameters of buildings.

These are volume, surface and the wrapper average transmittance.

In relation with energy dispersion (calculate with the method applied by Italian Law n.°10/91), *Boiler nominal utility power*, *boiler furnace power*, and plant performance are all determined in relation with energy dispersion.

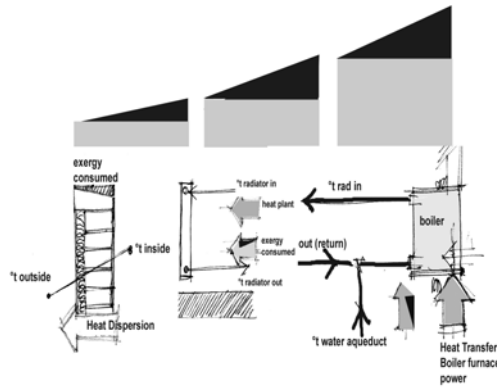


Fig.1. Flow energy/exergy scheme

The second step is an exergy calculation of each plant sub component of the building and of the plant.

Exergy calculated represents the exergy heat transfer formula:

$$Ex_{wrapped} = Ex_w = Q_w \left(1 - \frac{t_e}{t_i} \right) \quad [1]$$

$$Ex_{plant} = Ex_p = \frac{Q_p}{(t_i - t_e)} \left((t_m - t_i) - t_m \ln \frac{t_m}{t_i} \right) [2]$$

with:

Q_w = heating wrapped dispersion

Q_p = heating plant consumption

3.1 Building heating dispersion calculation

With reference to the fig. 2, the heating dispersions could be calculated in the following structure:

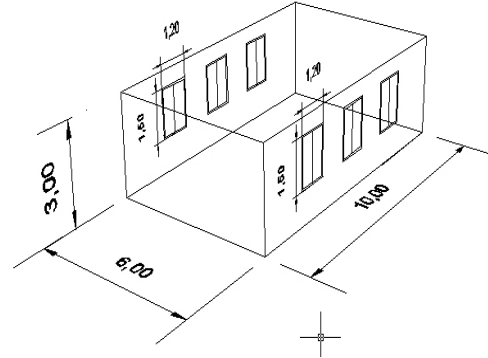


Fig.2. Building scheme

Building Geometry	
floor area:	60.00 [m ²]
wall area :	96.00 [m ²]
windows area:	3 x 1.80 = 5.40 [m ²]
Height	3.00 m
Thermo physic parameter	
U wall transmittance	0.46 [W/m ² K]
U window transmittance	2.10 [W/m ² K]
Project temperature	
(t_m) indoor temperature:	20°C
(t_{out}) outdoor environmental temperature:	-5°C
Heat dispersion	
3111.75 [W]	included ventilation heat dispersion
Year Heat dispersion:	
6389.79 [kWh/year]	Calculate with Italian law
Boiler	
Nominal utility Power: (Pn)	3660.88 [W]
Boiler furnace Power (Pf)	4206.92 [W]
η_b boiler performance	80%
η_p plant performance	$63 + 3 * \ln \frac{Q_{disp}}{100}$ [%]
η_{st} seasonal performance coefficient	$77 + 3 * \ln \frac{Q_{fornito}}{100}$ [%]

Tab.1. Thermal and geometrical parameters

with:

Supply heating

$$Q_{supply} = \frac{Q_{disp}}{\eta_{plant.}} \quad [3]$$

Boiler nominal Power:

$$Pn = \frac{Q_{fornito}}{\eta_{boiler}} \quad [4]$$

Boiler furnace Power:

$$Pf = \frac{Pn}{\eta_{boiler}} \quad [5]$$

3.1.1. Use of project of plant temperature

In this case the fixed parameters are: environmental temperature, boiler performance, indoor temperature. The project parameter is heating terminal temperature.

The reference parameters to calculate the exergy consumed are: radiator in and out temperature ($^{\circ}t_{r-out}$), wall surface temperature, boiler temperature.

These parameters enable to compare energy and exergy consumption.

The exergy consumed are calculated for different kinds of plant:

heating terminal temperature	$^{\circ}t$ radiator in ($^{\circ}t_{r-out}$)	t radiator out ($^{\circ}t_{r-out}$)
[HT] High Temperature	90 °C	70 °C
[MT] Medium Temperature	60 °C	40 °C
[LT] Low Temperature	45 °C	25 °C
[VLT] Very Low Temp.	35 °C	25 °C

Tab.2. Different working temperature considered

3.2 Exergy heat transfer (wrapped)

Exergy heat transfer is calculated with [1] in relation with indoor and outdoor temperature. We obtain: exergy heat transfer, $Ex_w = 321.16$ W

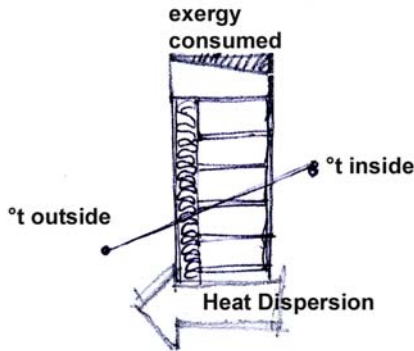


Fig.3. Representation of temperatures and dispersions

3.3 Exergy heat transfer wall-indoor temperature

To calculate exergy heat transfer between wall surface temperature and indoor temperature we need to calculate t_{wall} .

$$t_{wall} = t_{in} \left(\frac{(t_{in} - t_{out})U}{U_{wall}} \right) \quad [6]$$

therefore we obtain: $^{\circ}t_{wall} = 18.56$ °C

(where U wall transmittance wall except for the internal adduction coefficient)

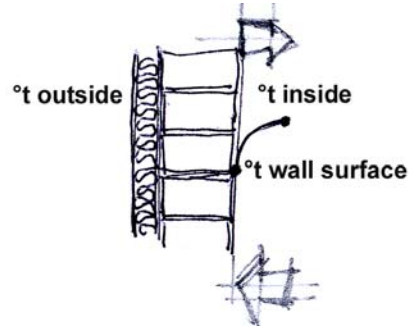


Fig.4. Healthy building wall temperature index

Afterwards, we obtain exergy heat transfer:

$$Ex_w = 18.51 \text{ W.}$$

The wall surface temperature (indoor) is an important parameter to evaluate the salubrity of buildings.

Wall surface temperature lower of + 2 °C with respect to indoor temperature is dangerous because it could cause air convection, heat loss exchange by irradiation (wall-body), air connectivity, dust shifting and general discomfort.

Exergy consumed could be an index to evaluate the building healthiness and the wall stratigraphy components.

3.4 Health building wall temperature index.

It represents the expression of exergy consumed between wall surface temperature and indoor temperature and exergy heat transfer of the wrapper in percent.

$$\frac{Ex_w (t_{wall} - t_{in})}{Ex_w (t_{out} - t_{in})} = \% \quad [7]$$

In this example the physical parameters are determined.

3.5 Exergy heat transfer between building and plant

Using formula [1], it calculates the exergy heat transfer between indoor temperature and heating plant terminal surface (e.g. radiator), for each kind of plant considered.

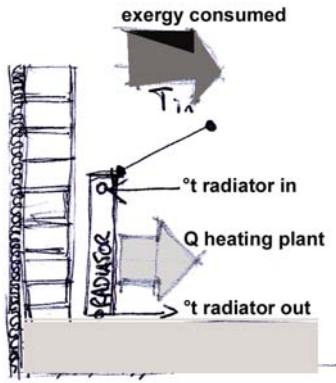


Fig.5. Representation of radiator in-and-out temperature

	HT	MT	LT	VLT
Exergy [W]	725.92	452.17	295.93	183.32

Tab.3. Exergy for the four plants analysed. Case 1

3.6 Exergy heat transfer between °t-radiator-in and °t- radiator-out plant

The exergy heat transfer of plant, related to radiator in and out temperature, is calculated with [2]. The amount reserved for heating plant terminal (e.g. radiator) is:

$$Q_{plant} = Pn * \eta_{stag} \quad [8]$$

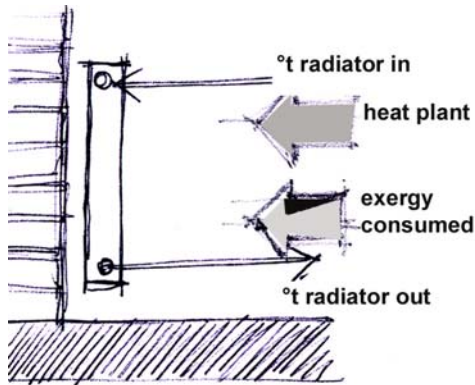


Fig. 6. Heat and exergy for the radiator

	HT	MT	LT	VLT
Exergy [W]	766.50	708.89	640.77	608.95

Tab.4. Exergy for the four plants analysed. Case 2

3.7 Exergy heat transfer boiler nominal utility power

Exergy heat transfer calculated with [1], referred to nominal utility power of boiler, necessary to heat

the water from waterworks, should be obtained from $t_{average}$, which is calculated from:

$$t_{average} = \frac{t_{waterworks} + (0.5 * t_{rad-out})}{2} \quad [9]$$

where t_{av} = average temperature

$t_{waterworks}$ (-5°C)

$t_{radiator-out}$

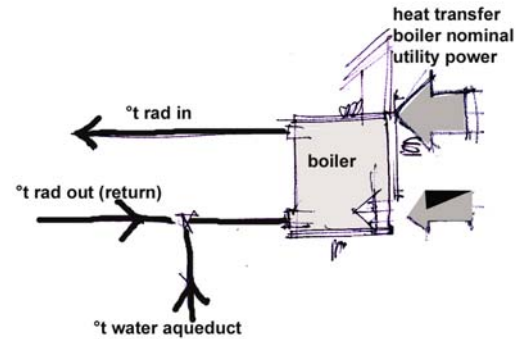


Fig.7. Representation of boiler in-and-out temperature

	HT	MT	LT	VLT
Exergy [W]	523.01	391.54	315.08	237.22

Tab.5. Exergy for the four plants analysed. Case 3

3.8 Exergy heat transfer boiler furnace power

Exergy heat transfer calculated with [1], referred to boiler furnace power, necessary to heat the water from waterworks, should be obtained from t_{boiler} , which is calculated from $t_{average}$, with [10]:

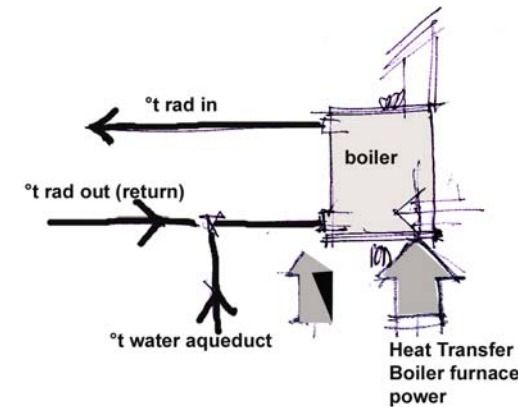


Fig.8. Representation of boiler in-and-out temperature and boiler furnace power

$$t_{boiler} = \left(\frac{(t_{rad-in} - t_{av}) Pf}{Pn} \right) + t_{average} \quad [10]$$

	HT	MT	LT	VLT
Exergy [W]	1278.53	1278.56	1278.58	1278.53

Tab.6. Exergy for the four plants analysed. Case 4

Total exergy consumed is the summa of each single exergy consumed, as represented in tab. 7

	HT	MT	LT	VLT
Energy [W]	6384.95	6384.95	6384.95	6384.95
Exergy [W]	3633.64	3170.84	2870.03	2647.64

Tab.7. Comparison between Energy and Exergy for the four plants analysed.

As a result of the analysis, exergy values decrease in low temperature plants.

4 Energy and exergy cost (economic valuation)

The second step is to analyse energy charges. Energy system charge links the energy consumed to heat building with the kind of combustible. In this paper energy costs refer to the price of natural gas in Italy. Superior calorific power is fixed in 37.68 MJ/m³. The heating bill is related to the energy consumed.

natural gas cost:	60.33	(cent of €/mc)
Q year:	16388.88 kWh	1565.82 m ³ natural gas consumed
energy bill:	974.66 €/year	include tax

Tab.8. energy prices and bill

The energy year consumption (Q_{year}) can be calculated in the following way:

$$Q_{year} = 0.024 * \frac{Pf}{(\theta_{t_{in}} - \theta_{t_{out}})} * GG \quad [11]$$

where: GG=day degree

In this valuation model, the kind of combustible used is included in energy/economic valuation in order to simplify the chemical exergy and physical exergy calculation.

In this paper we propose a coefficient to connect energy consumption, energy consumed and economic charge. It could be called exergy/economy coefficient, and it could be defined as “exergy charge efficiency” called ϕ :

$$\phi = 1 - \frac{Exergy_{consumed}}{Energy_{consumption}} \quad [12]$$

The exergy charge could be evaluated in relation with an exergy charge coefficient increase.

$$Ex. cost = \frac{En. cost}{\phi} - En. cost \quad [13]$$

in c€/natural gas m³.

Exergy charge could calculate the energy bill increasing due to the energy waste. The low exergy solutions are energetically and economically advantageous.

The relation between the different charges for the four plants considered in this work, are summarised in the following table and pictures:

	HT	MT	LT	VLT
natural gas consumption [m ³]	1565.82	1565.82	1565.82	1565.82
energy cost [c€/mc]	60.33	60.33	60.33	60.33
coef. ϕ	43.09%	50.34%	55.05%	58.63%
exergy cost [c€/mc]	79.68	59.53	49.26	42.74
energy cost bill [€]	974.65€	974.65€	974.65€	974.65€
exergy cost bill [€]	1277.60€	961.94€	801.34€	699.23€

Tab.9. Different charges for the four plants.

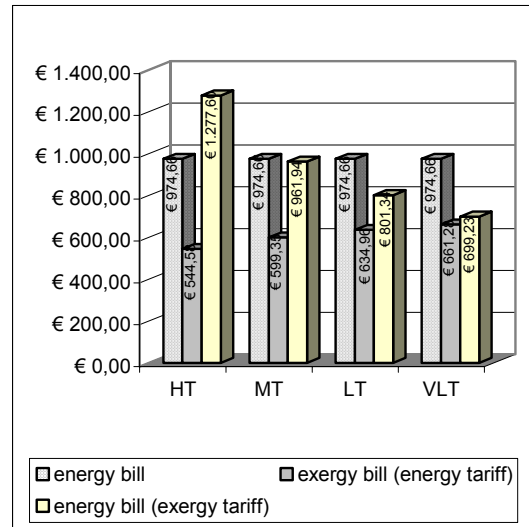


Fig.9. Energy and exergy bill

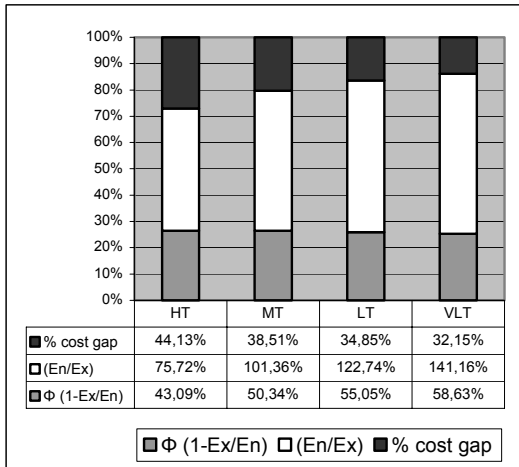


Fig.10. Energy/exergy coefficient

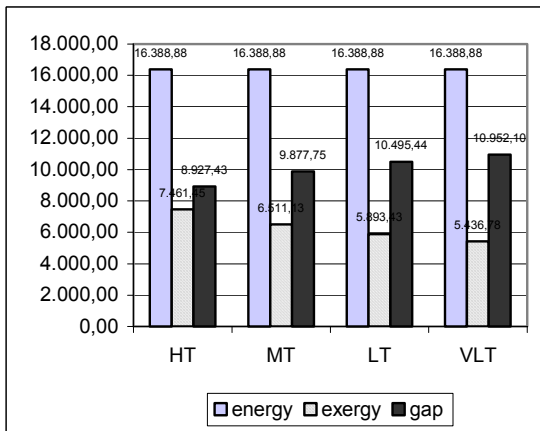


Fig.11. energy consumption exergy consumed comparison

As a confirmation of previous results, it could be observed that exergy charge increases in building with more energy dispersion.

This evaluation method could be used to compare building insulation, plant project, plant temperature, and other parameters, for the same exergy costs.

Conclusion

In this paper a simple and quick tool to compare qualitatively the energy consumption, even in sites with different climate has been presented and discussed.

This is not an exhaustive study but an input for a further discussion about how the exergy method could be applied to find different building design.

It could be applied to standardise and to evaluate a-dimensionally different solutions and to start politic actions for new buildings.

This method could be implemented through existing auditing, environmental index, such as CO₂ TOE, and others.

The same procedure could be applied for electricity consumption to find a unique exergetic index.

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