Approaching The Whole Quality Of Buildings: Methods For The Evaluation Of Economic, Energetic And Environmental Issues

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Summary: In this work the energy, economy and environment ("three E") requirements for buildings are approached in a joint view, by means of an application to an example building typical of the Italian building stock.

With this aim, the rate of involvement of renewable sources is here considered for linking energy and environmental characteristics. Economic and environmental features are joint by means of the evaluation of the cost of the saved CO_2. Economic and energy characteristics are linked by means of the cost of the saved energy. In turn, the environmental ambit is addressed by means of the ecoprofile methodology and of the environmental labelling of buildings.

This should lead toward a first approach for singling out an overall indicator of the environmental sustainability that, suitably related to other performances of the buildings (e.g., the durability of materials and the indoor performances), could be proposed as a tentative measure of the whole quality of buildings

Keywords: Building quality, Energy, Economy, Environment, LCA.

1 INTRODUCTION

It has been several times pointed out that the building and real estate sector has a serious impact on the environment. The construction and the operation of building, in fact, accounts for up to 40% of the energy and materials resources and contributes 40% of the CO_2 released in the developed countries. Moreover, a lot of substances dangerous to health come from materials involved in the construction, maintenance and cleaning up of buildings.

The increasing consciousness of such pressure exerted by buildings on the environment opens another demanding job for designers and technicians, along with the traditional tasks concerning the energetic and economic issues.

As it is well known, several methods of analysis are currently available for each of these main fields. Referring to the energy characteristics, for example, the overall heat transmittance of the envelope is one of the most important parameter to be taken into account; at present, it is subject to international and domestic standards. With respects to the economic features, the pay-back time of the design options is probably the most common method adopted world-wide. Finally, the environmental performances of building are currently evaluated by means of the pollutant emissions released by the HVAC system.

But in the field of assessing the overall quality of buildings another question is now arising: how to deal with these important fields of analysis in a joint view? By selecting the sustainability of the buildings as the main goal to be pursued by designers, we will refer here to some environmental features for linking economic and energetic performances.

With this aim, the rate of involvement of renewable sources will be here assumed as the linking parameter between energy and environmental characteristics. In turn, the economic and environmental features will be joint by means of the evaluation of the cost of the saved CO_2. Moreover, the environmental issue will be further addressed by means of new methods, like the ecoprofile, that allows the assessment of the whole impact exerted by the building through its life cycle.

In this work the "three E" (Energy, Economy and Environment) issues will be approached in a joint view, by applying some of the previously cited methods to a typical dwelling of the Italian building stock.

This should lead to the singling out of an overall indicator of the environmental sustainability. Such indicator, suitably related to other performances of the buildings, like the durability of materials and the indoor performances (thermal, acoustic, visual and IAQ), could be proposed as a tentative measure of the whole quality of buildings.

2 ENERGY, ECONOMIC AND ENVIRONMENTAL REQUIREMENTS OF BUILDINGS IN THE TRADITIONAL APPROACH

2.1 Energy issues

Among the various parameters utilised for defining the energy performances of a building, the heat overall transmittance of the envelope can be assumed as the most representative. It, actually, takes synthetically into account the whole thermal features of the building and can be easily utilised to evaluate the energy demand and the energy requirement for the climatisation of buildings through a given period of time (e.g., a season or a month). Not by chance, in fact, several international standards assessed for the evaluation of the energy consumption in the climatisation of buildings expressly refer to this parameter like, for example a recent Italian law (UNI, 1993).

2.2 Economic issues

The economic compatibility of the design options is always one of the primary concern of designers and it does not require to be further pointed out. We simply would like to signal here that, along with the costs supported for implementing the design choices, the payback time of these technical solutions should be suitably taken into account.

2.3 Environmental issues

Environmental sustainability is today a major issue to be accomplished when approaching technical and policy problems related to the land management. Urban administrations, at this regard, are called to match new requirements, since cities are directly involved in the world attempt of minimising greenhouse gas emissions, as established, for example, by the Kyoto protocol (UNFCC, 1988). In this sense, the building sector represents one of the main fields of intervention.

Therefore, sustainability policies are often embodied in the design process of buildings, by paying more attention to the environmental suitability of the utilised materials and to the pollutant emissions of HVAC system.

3 ENERGY, ECONOMIC AND ENVIRONMENTAL FEATURES: A TENTATIVE APPROACH OF A JOINT VIEW

The design and the production of energy-efficient, environmentally sound and economically affordable residences is beginning to be considered an important goal world wide. The Building America Program, for example, through the Consortium for Advanced Residential Buildings (CARB), is currently developing a new innovative home on a community scale (Griffiths and Zoeller, 2001).

Many other methods and interventions could be cited in the filed of the development of cost-effective, energy-efficient residences. Actually, what is lacking is a systematic link among energy, economic and environmental features of a building and the availability of methods able to provide, even at a rough level, a comprehensive judgement of its whole quality. Clearly, this is far to be considered an easy job: but new international standards, particularly concerned with environmental problems, just call for such methods.

In order of pursuing the whole quality of buildings, suitable links among the previous issues should be assessed. By recognising a central importance to the environmental requirements we will suggest here some simple parameters that could be adopted, as a first attempt, for linking the energy and the economic aspects to the environmental ones. This approach could be considered as a tentative address for a joint view of the “3E” problem in the building design.

3.1 Linking energy and environmental performances: ratio between renewable and non renewable energy

With the aim of taking simultaneously into account energy and environmental performances of buildings we propose here a synthetic indicator simply given by the ratio between the amount of renewable and fossil energy sources needed for accomplishing all the HVAC and DHW requirements of the assigned building.

It could be roughly assumed that the greater is the value of this ratio the lower is the impact on the environment. Clearly this assumption does not take into account the pressure exerted on the environment by the renewable energy systems

3.2 Linking environmental and economic performances: cost of the saved CO_2

The measures adopted in buildings with the aim of preserving the environment are generally supposed to provide a saving in the greenhouse gases released in the atmosphere. These savings, in turn, would involve a change in the costs for the realisation or the restoration of buildings. By ascribing to the released CO_2 the role of representative greenhouse gas, we propose to adopt the cost of the saved CO_2 as the indicator for the link between the environmental and economic performances of buildings.

3.3 Linking energy and economic performances: cost of the saved energy

On the other hand, increasing the saving of energy in the climatisation of buildings generally does involve a rising of the costs for the construction or the refurbishment of buildings. This suggests to assume the cost of the saved energy as the indicator for the link between economic and energy performances of buildings.

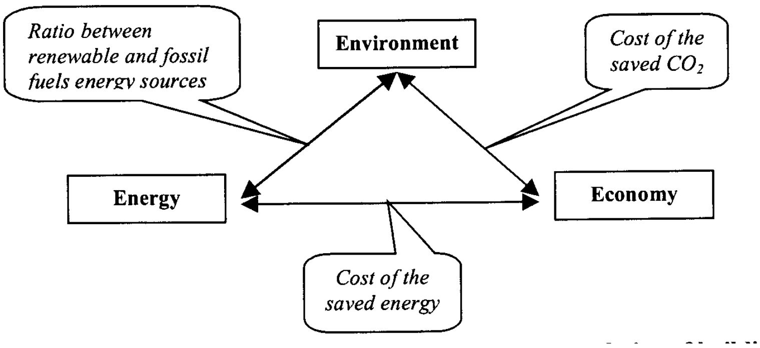


Figure 1. Visual representation of the "three E" approach in the design of buildings.

Figure 1 reports a visual representation of the "three E" approach, along with the parameters adopted for linking together each issue, that is environmental, energy and economics.

4 FURTHER ENVIRONMENTAL CHARACTERISATIONS: THE LIFE CYCLE IMPACT

Although the amount and the cost of the saved CO_2 have been previously indicated as the main parameters for ranking the environmental features of a building, it's obvious that others pollutant matters are emitted during the duty cycle by the climatisation and DHW generation systems; moreover, during the construction phase of the building, several others pollutants are released and a noticeable amount of energy is also involved for the production of the buildings components. In other words, the environmental impact of the building system should be more correctly regarded on the basis of a life cycle analysis. This will enable also the evaluation of the environmental sustainability of buildings.

4.1 A method for assessing the environmental sustainability of buildings: the ecoprofile

With the aim of assessing the environmental sustainability of buildings, the methodology of the ecoprofile is gaining a wide popularity among the environmental analysts. It, mainly referring to the Life Cycle Assessment (LCA) procedures, enables the evaluation of energy, materials and air pollution issues involved in the building design, from the building up to the demolition phases (Cole and Ruseeau, 1992; Potting and Blok, 1993; Buchanan and Honey, 1994; Fossdal and Edvardsen, 1995; Trustly and Meil, 1999).

The ecoprofile methodology is essentially focused on the impact exercised by the materials involved in the buildings production and construction on some important environmental precincts. For the building sector the considered environmental ambits of impact are generally the following: the depletion of fossil fuels, the global warming potential, the acidification, the production of photochemical ozone and the eutrofication.

These ambits are characterised through the method by means of suitable indicators. The fossil fuel depletion is usually accounted for by means of the amount of the energy related to the burning of these fuel sources. The global warming potential is generally evaluated by means of the released carbon dioxide. NO_x is supposed to contribute to the eutrophication by means of the chemical oxygen demand (COD). The acidification effect can be assessed by means of the emissions of SO_2 and NO_x. Finally, hydrocarbons are utilisesed for evaluating the VOCs, that contribute to the photochemical ozone creation.

These indicators of the buildings environmental impact call for the availability of crucial data about the building materials. For example, the evaluation of the GWP requires data of the amount of energy embodied in the materials. All the remaining indicators can be utilised only starting from the knowledge of the pollutant emission factors of materials, that is the emission of a given pollutant released by the functional unit (generally, the mass) of the considered material.

Unfortunately, the lack of data about the embodied energy and about the pollutant emissions released by building materials during the whole life cycle, represents the main constraint for the application of the ecoprofile methodology.

Moreover, available data referring to the embodied energy are affected by a strong unhomogeneity that, in the practice, makes ambiguous the comparison (Cellura et al., 2000) among them and the application to other countries (BRE, 1994; Cole and Rousseau, 1992; Worrel et al., 1994; Boustead and Hancok, 1979).

Emission factors show the same problems presented by the embodied energy. As a consequence literature data (Van de Vate, 1995; Frischknecht et al., 1994; E.U., 1995; Fritsche et al., 1995) should be adopted only for early stage analyses.

In order of overcoming this lack of data, some of the present authors (La Gennusa et al., 2001) have proposed a simple indirect method for assessing emission factors of some relevant pollutants released by the building sector through the whole life cycle. The method starts from the knowledge of type and amount of energy involved in the production of a given material and utilises the pollutant emission factors of each energy source in the assigned country (Onufrio and Gaudioso, 1993).

5 TOWARD THE WHOLE QUALITY OF BUILDINGS: AN APPLICATION

5.1 Description of the example

The previously introduced approach is in the following illustrated by means of an example application to an apartment belonging to an intermediate floor of a building situated in a mild Mediterranean climate, characterised by 800 degree days (DD).

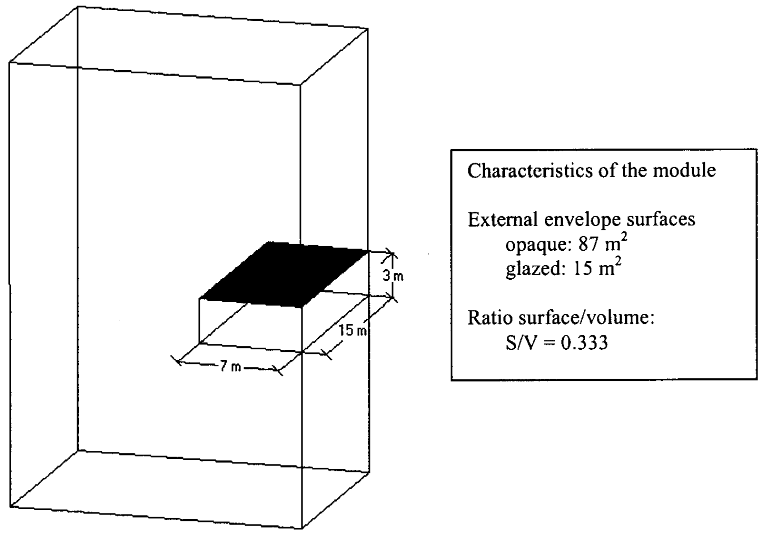


Figure 2. Geometric descriptions of the example module.

Figure 2, along with its table, shows the main geometric features of the building module.

In order of singling out the environment, energy and economy features of different design choices, two configurations of walls and HVAC and DHW systems have been selected for the example building. These choices depend on the design characteristics of two cases: case A is characterised by a low building up and installation cost, by a low thermal insulation; case B is characterised by a high initial cost and by a high thermal insulation. Other main assumptions about the cases are summarised in table 1.

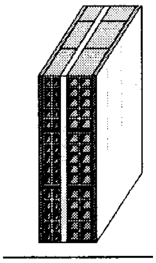
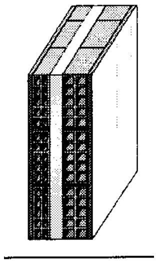
Table 1. Main design options of cases A and B

	Case A	Case B
Costs for materials production and installation	low	high
Thermal insulation of the envelope	low	high
Windows characteristics	single glazed	double glazed
Summer cooling	heat pump	heat pump
Winter heating	oil furnace	natural gas furnace
DHW	electric boiler	solar collectors

Table 2 reports the physical dimensions and the thermal resistance of the layers constituting the vertical walls of the example module.

Table 2. Physical and thermal characteristics of the envelope walls for cases A and B

	Case A	**Case B**

Layer		Thickness [cm]	Thermal resistance [m^2 K/W]		Thickness [cm]	Thermal resistance [m^2/K W]
Internal plasterboard		2	0,03		2	0,03
Hollowed bricks		12	0,27		12	0,27
Insulation layer		3	0,73		6	1,46
Hollowed bricks		8	0,26		8	0,26
External plasterboard		2	0,03		2	0,03

5.2 Environment, energy and economy: the results of the single issue approach

By utilising literature data for the embodied energy and for the emission factor of CO_2 of materials and by applying the indirect method previously cited for the evaluation of the emission factors of the other pollutants, we have performed a comparison between case A and case B, for a building life time of fifty years. Data concerning costs of building materials and costs of HVAC and DHW systems here closely refer to the present Italian economic situation (Calvino et al., 2001): this means that absolute values should be considered only as indicative, while results present a good reliability in the comparison between the two cases.

The single issue approach to energy, economy and environmental ambits has been carried out by taking into account separately some different phases of the building management, that is: the realisation of the building envelope (“Building”), the realisation of the HVAC and DHW systems (“HVAC+DHW system”), the aggregate of the previous ambits (“Building+HVAC+DHW”), the duty cycle of the whole building (“Dutycycle”) and the whole aggregate (“Total”).

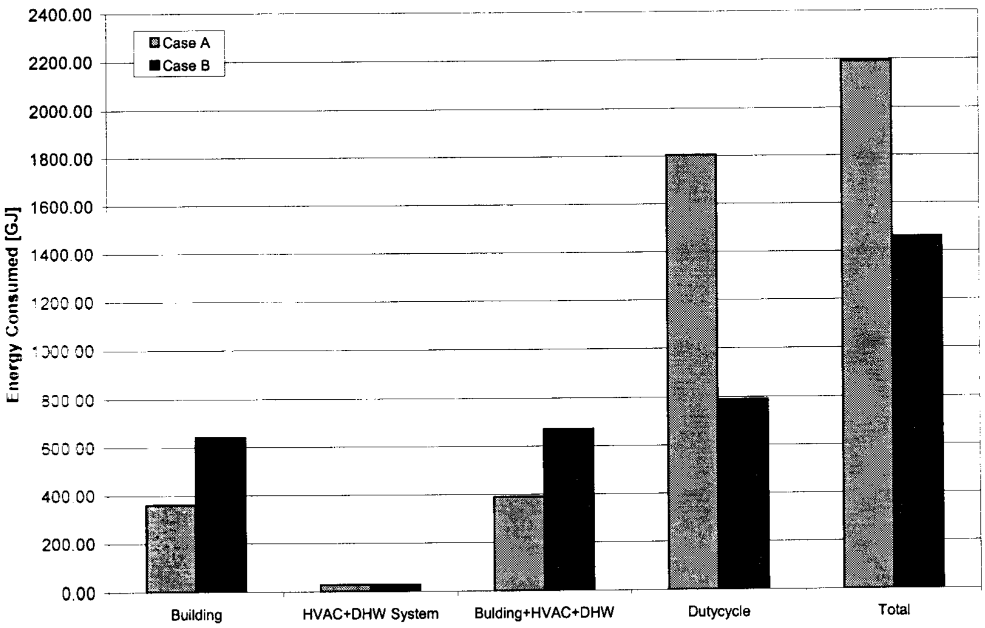


Figure 3. Energy involved in management of the building modules of cases A and B.

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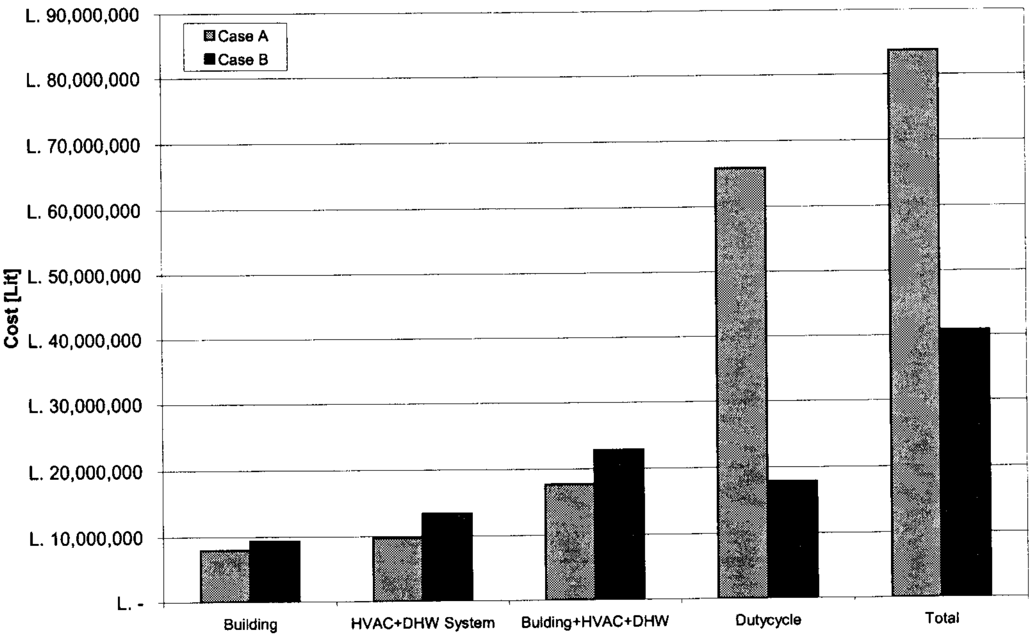

Figure 4. Costs referring to the building modules of cases A and B

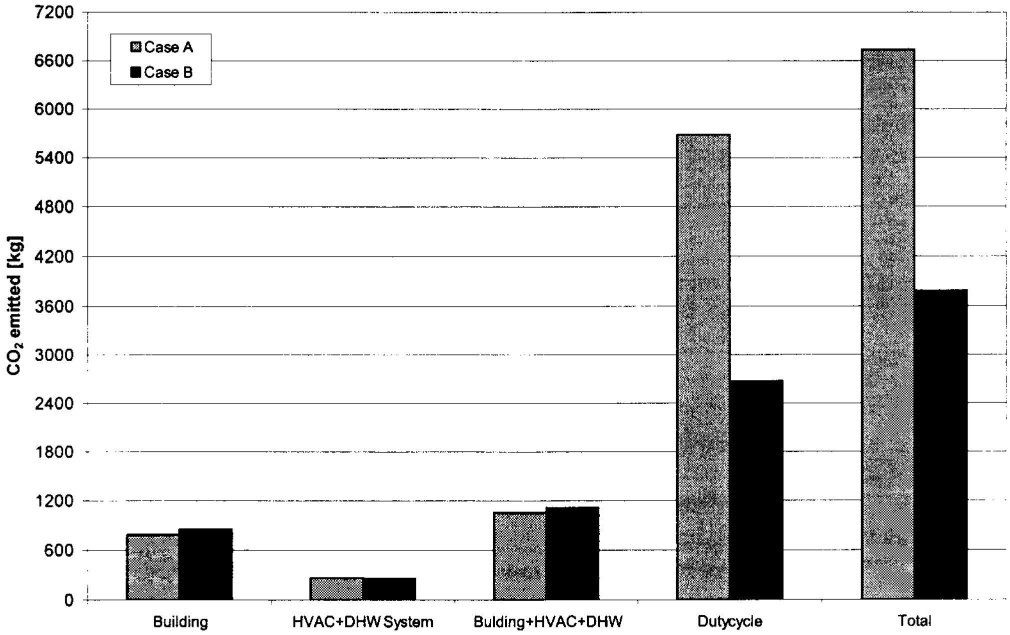

Figure 5. CO_2 emitted by the building modules of cases A and B.

Figures 3, 4 and 5 respectively apply to the energy, economy (1936,27 Lit = 1 EURO) and environmental issues for the example modules of cases A and B.

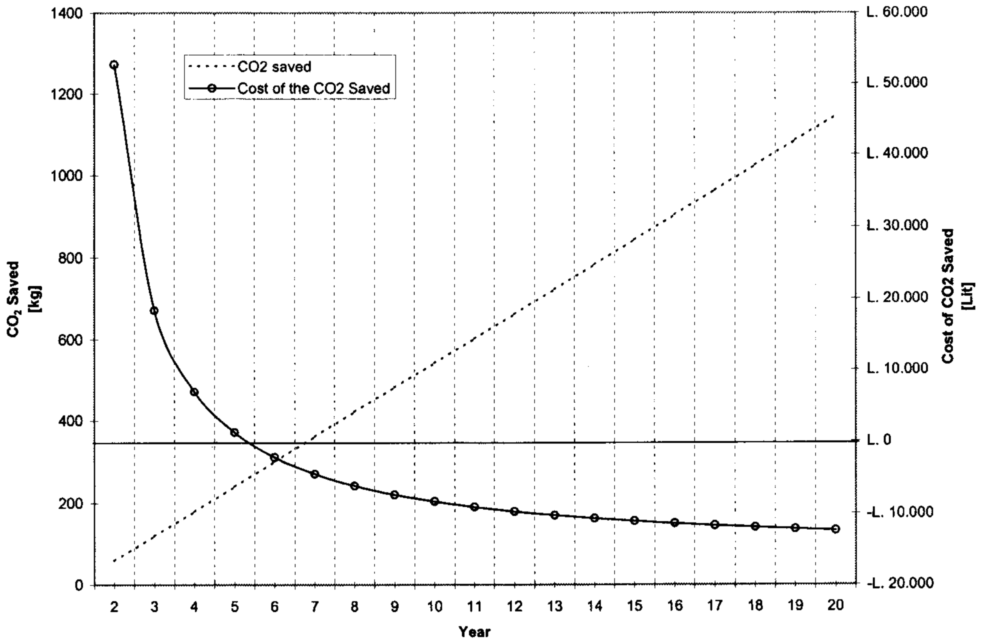

Figure 6. Payback time of the technical options of Case B.

Although referring to an indicative example, these graphs suggest some interesting points. The case B presents higher values of energy involved, costs and CO_2 emitted in the production and installation phases than the case A; but, by accounting for the duty cycle (fifty years, in this example), it shows a noticeable improvement with respect to case A.

Figure 6 allows the graphical evaluation of the payback time of the design options of the case B, assuming the case A as the reference option.

5.3 Environment, Energy and Economy: the results of the integrated approach

The classical approach analysis certainly allows the evaluation of important characteristics of the buildings behaviour (like the payback time and other relevant features), but it is not able to provide a comprehensive view of the whole performance of buildings.

This can be tentatively addressed by means of the integrated approach presented in the previous paragraphs. By applying the method synthesised in Fig. 1 to the building modules of cases A and B, we can obtain the graphical representation of Fig. 7, where on the axes the parameters adopted for linking the energy, economy and environment features are reported: the cost of the saved energy, the cost of the saved CO_2 and the ratio between renewable and fossil fuels. In this figure points on the axes represent the values of the parameters for case B with respect to case A.

About the graph, it is interesting to note that the more is the value reached on the axis the more is the impact on the issue represented: in other words, the distance from the origin is a measure of the negative effect of the parameter. For this reason, on the axis representing the involvement of the renewable energy sources we have reported the complement to the unity of the ratio between renewable and fossil fuel sources.

In this way, the area of the triangle constituted by the segments joining the points on the axes can be assumed as a measure of the whole impact exerted by the building on the three ambits with respect to the reference case (the case A, in this example). In this figure the area of the triangle, in incoherent units, is 0.99.

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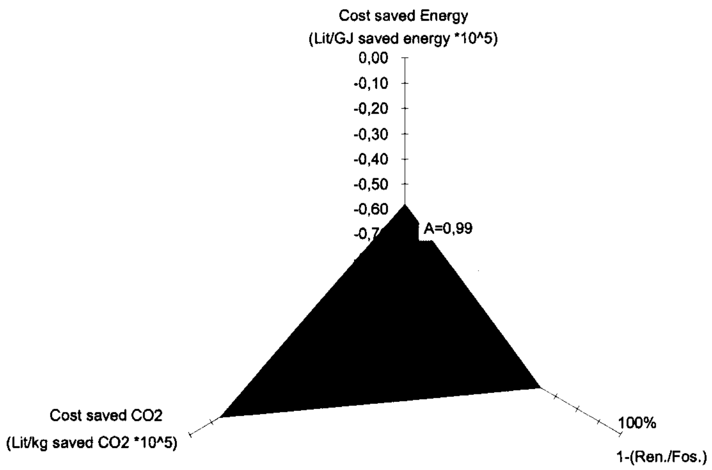

Figure 7. Graphical representation of the parameters representing the integrated approach of the building analysis (results of case B with respect to case A)

But, as it has been pointed out, an accurate evaluation of the environmental impact should account for not only the release of carbon dioxide. By means of the indirect methodology of analysis previously cited (La Gennusa et al., 2001), it is possible to assess the pollutant emissions involved in the construction and the management of a building. Table 3 reports the absolute values and the differences referring to the emissions of SO_x, NO_x, VOC and CO_2 for the cases A and B of our example.

Figure 7 and Table 3 can be considered as the main tools for a tentative approach to the whole quality of buildings and for coping with the requirements of the environmental sustainability of buildings.

Table 3. Pollutant emissions during the lifecycle of cases A and B

		Pollutant emissions			
		SOx kg SOx	NOx kg NOx	VOC kg VOC	CO_2 kg CO2
CASE A	Building - Construction phase	67,8	29,7	0,32	786
	HVAC - Construction phase + Dutycycle [a] - (gasoline)	540,0	290,1	2,97	12636
CASE B	Building - Construction phase	72,8	32,2	0,35	853
	HVAC - Construction phase + Dutycycle [a] - (natural gas)	57,2	68,2	4,59	2950
DIFF. B-A	Building - Construction phase	5,1	2,5	0,03	67
	HVAC - Construction phase + Dutycycle [a]	-482,8	-222,0	1,62	-9686
	Total	-477,7	-219,4	1,65	-9619

(a) The duty cycle here includes the energy amounts required for space heating and cooling and for DHW.

The duty cycle here includes the energy amounts required for space heating and cooling and for DHW.

Of course, graphs like that of Fig. 7 can be usefully adopted for comparing among them several design options. For example, in the case of the presence of two alternatives (in addition to the base case), the values of the areas of the pertinent triangles could be adopted for judging the building whole impact: in Fig. 8 the bigger triangle would show a whole impact of 0.99, while the smaller one would have a whole impact of 0.33, that is remarkably lower.

Clearly the use of the triangle areas for ranking different options is only a rough method for analysing the whole quality of a building: it, in fact, implicitly assumes that the effects of the selected ambits (energy, economy and environment) are characterised by a linear behaviour and that same increments (or decrements) on different axes have the same impact on the ambits. This is really hard to be stated. At this stage, the triangle characteristic of a design option must be adopted only as a visual synthetic representation of the whole impact of a building, while the parameters reported on the three axes represent an actual measure of the impact on the issues that they are supposed to link.

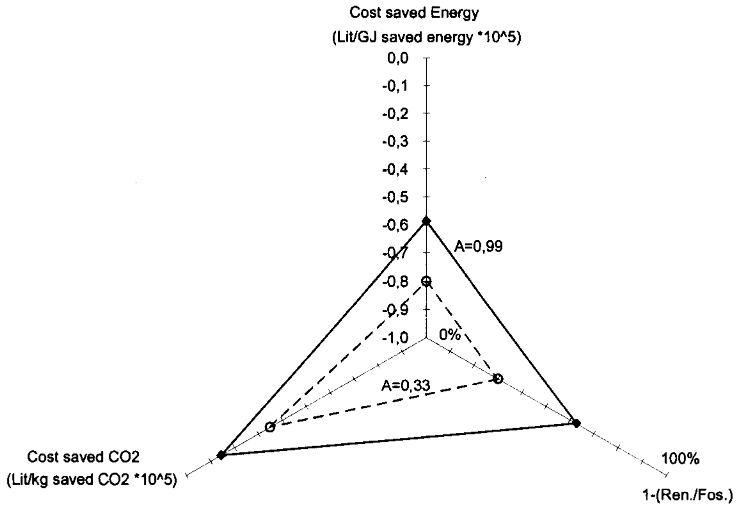

Figure 8. Triangles representing the whole impact of two different design options with respect to a base case

6 CONCLUSIONS

But another question now arises: can be considered the environmental, economic and energetic analyses here depicted as the only judgement elements for ranking the suitability of a building design, or should them be coupled with other issues referring to the indoor performances realised by a building?

Actually, the main goal of a building is to provide a safe and comfortable space where people can perform their work and life activities. As that, the indoor performances of a building should be usefully embodied in the analysis concerning its whole quality: acoustical, thermal, visual and air quality issues should be taken into account, along with the previously treated parameters. This would lead to synthetic representations like this reported in Fig. 9 (Nucara et al., 2000), where the main aspects of the indoor quality are reported.

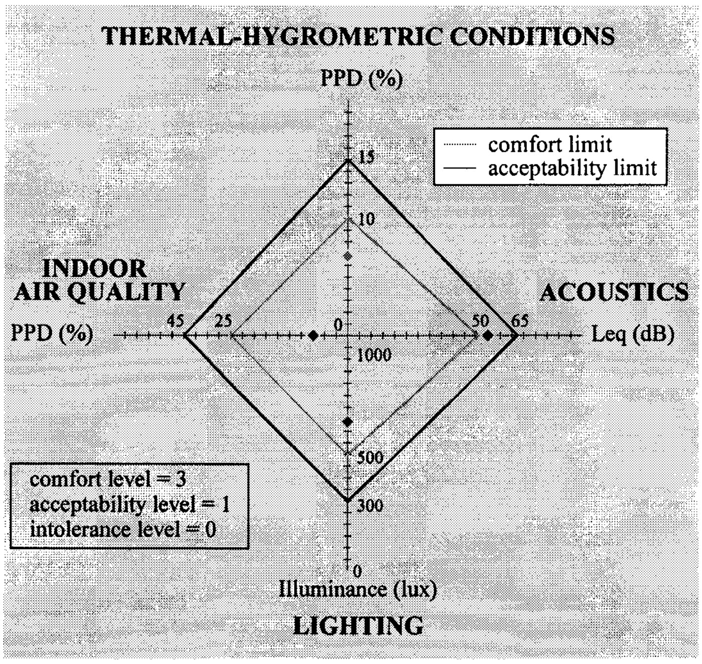

Figure 9. Example of *quality diagram* referred to one of the schools examined.

A suitable link of graphs like that depicted in Fig. 9 with graphs like that of Fig. 7 would allow to address the problem of singling out a suitable indicator of the whole quality of buildings.

This, in turn, should be further related to other important performances of the buildings (e.g., the durability of materials), and to performances referring to the urban facilities (e.g., the access to the public transportation network).

These simple notes shows that the obtaining of an unique indicator of the whole quality of a building still requires a deep and long research effort, if ever it should be possible to attain it.

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But the search for more useful methods and parameters for synthetically ranking the performances of buildings is a fascinating way that surely deserves the efforts of researchers.

7 REFERENCES

1. Boustead, I., Hancock, G.F. 1979. *Handbook of Industrial Energy Analysis*. Ellis Horwood, Chichester.

2. Buchanan. A.H., Honey, B.G. 1994. “Energy and carbon dioxide implications of building construction”. *Energy and Buildings*, Vol. 20, pp. 205-217.

3. Building Research Establishment. 1994, UK.

4. Calvino, F., La Gennusa, M., Rizzo, G., Scaccianoce, G. 2001. “Prestazioni energetiche, economiche ed ambientali degli edifici: un approccio integrato per la sostenibilità ambientale e la certificazione energetica”, *Department of Energetics and Application of Physics, internal unpublished report* (in Italian).

5. Cellura, M., La Gennusa, M., Rizzo, G. 2000. “Availability of materials emission data for assessing buildings ecoprofiles: an analysis of the Italian case”. Proceedings of *The Fourth International Conference on ECOBALANCE*. Tsukuba, Japan.

6. Cole, R.J., Rousseau, D. 1992 “Environmental Auditing for Building Construction : Energy and Air Pollution Indices for Building Materials”. *Building and Environment*, Vol. 27, No. 1, pp. 23-30.

7. European Commission 1995. “ExternE, Externalities of Energy. Vol. 6, *Wind and Hydro. EUR* 16525 EN.

8. Fossdal, S., Edvardsen, K. I. 1995. “Energy consumption and environmental impact of buildings”. *Building Research and Information*, vol. 23, n. 4 1995.

9. Frischknecht, R. *et al.* 1994. “Inventare fur energiesysteme: Beispiel regenerative Energeisysteme”. Brennstoff Warme Kraft 47 426-431.

10. Fritsche, U.R. *et al*. 1995. “Gesamt-Emissions-Modell Intergrierte Systems (GEMIS)”. Version 2.1, OEKO Institute, Darmstadt.

11. Griffiths, D., Zoeller, W. 2001, “Cost-Effective, Energy-Efficient Residence”, *ASHRAE Journal*, April 2001, www.ashraejournal.org.

12. La Gennusa, M., Nucara, A., Pietrafesa, M., Rizzo, G. 2001. “Managing sustainable building design and indoor environment performances”. Accepted for presentation to *PLEA 2001 – Renewable Energy for a Sustainable Development of the Built Environment*. 7-9 november 2001, Florianopolis, Brazil.

13. Nucara, A., Pietrafesa, M., Rizzo, G. 2000. “Toward the assessing of the whole energy and environmental quality of non residential buildings”. *Proceedings of “PLEA 2000 - Architecture, City, Environment”*. Edited by Koen Steemers and Simos Yannas, pp. 182-86. James & James Science Publishers, London.

14. Onufrio, G., Gaudioso, D. 1993. “Emissioni di gas a effetto serra in Italia. 1. Emissioni di CO_2 dal settore energetico”. *IA – Ingegneria Ambientale*, vol. XXII, n. 5.

15. Potting, J., Blok, K. 1993. “The environmental life cycle analysis of some floor coverings”. *Contribution to the First SETAC World Congress, Lisboa, 1993*. Utrecht.

16. Trustly, W. B., Meil, J. K. 1999. “Building life cycle assessment: residential case study”. *Proceedings of “Mainstreaming Green: Sustainable Design for Buildings”*. Chattanooga, TN.

17. UNFCC, 1988, *United Nations Framework Convention on Climate Change, 1988*, Report of the Conference of the Parties on its third Session (Kyoto, 1-11 dec., 1997).

18. UNI Standard 10344. 1993. *Building heating - Energy requirements calculation method*. UNI, Milan (in Italian).

19. Van de Vate, J. F. 1995. “Greenhouse gas emission from the fuel energy chains of various energy sources: a tentative assessment”. *Proceedings of the World Clean Air Conference 1995*. The Finnish Air Pollution Prevention Society, Helsinki, 28 May-2 June.

20. Worrell, E., van Heijningen, R.J.J., de Castro, J.F.M., Hazewinkel, J.H.O., de Beer, J.G., Faaij, A.P.C., Vringer, K. 1993 “New Gross Energy-Requirement Figures for Materials Production”. *Energy*, Vol. 19, No. 6, pp. 627-640.