INDUSTRIAL ESTATE RETROFITTING: SELECTION OF SUSTAINABLE STRATEGIES USING MCA

Maria Cristina GRILLO
Department of Civil, Environmental and Mechanical Engineering, University of Trento – Italy, maria.grillo@unitn.it

Antonio FRATTARI
Department of Civil, Environmental and Mechanical Engineering, University of Trento – Italy, antonio.frattari@unitn.it

Michela DALPRÀ
Department of Civil, Environmental and Mechanical Engineering, University of Trento – Italy, m.dalpra@ing.unitn.it

Summary

The Italian economic boom of the Sixties strongly modified the shape of the cities with the construction of productive areas and buildings closed to the historic center. During the subsequent decades, because of the technological revolution and the new logistic needs of the industrial sector, many of these buildings were progressively abandoned and left to a degradation state.

Although their little appreciation, those industrial buildings have an high historic, social and cultural value, because they constitute an element of memory and identification for the community of a territory. For this reason it is important to reintroduce them into the cities and the surrounding environment. Furthermore industrial buildings, usually characterized by big sizes, good accessibility, flexible internal partitions and large pertinence areas, are good candidate for rehabilitation, since they can be easily converted in a wide range of possible use destinations. The focus point is how to convert this existing estate in a sustainable way, in order to reduce the need for new constructions and optimize the intrinsic qualities of forsaken industrial spaces.

The work presents the project for the functional and energy retrofitting of a disused factory located in Udine (Italia) for which several architectonic and technical solutions were hypothesized. The selection of the best design option was made comparing the different hypothesis by using a multi-criteria approach, based on the combined use of LCA, LCC and energy performance evaluation. Thanks to this integrated method it was possible to choose the most adequate solution from a whole sustainability perspective.

Keywords: industrial buildings, functional and energy retrofitting, LCA, LCC, MCA

1 Introduction

1.1 Italian industrial buildings position

The Italian building stock is composed for the largest part (75 %) of buildings elder than thirty years (ISTAT, 2008). Most of this stock mainly consists in two building typologies: residential buildings and factories.

While residential buildings are considered as an affective and economic asset for their owners and for this reason they are well maintained and subjected to restoration or retrofitting process, the widest part of the industrial building estate has been forsaken during the last fifty years. Many factories were built during the Italian economic boom of the Sixties, in order to meet the international increasing demand of industrial products. This process strongly contributed in modifying the shape of the Italian cities through the construction of wide productive areas along the borders of the historic centers. But during the subsequent decades these buildings were subjected to a fast aging process, due to the technological revolution of the production systems and also to the new logistic needs of the industrial sector. For such reason, many of these industrial constructions were considered obsolescent, progressively abandoned and left to a degradation state.

1.2 Industrial buildings: advantages in retrofitting

Nowadays meeting forsaken industrial buildings inside the Italian urban areas is fairly common. The question is: are we sure that we want these buildings are left dying along the streets of our cities?

For answering this question we have to be aware that, although their little appreciation, industrial buildings have an high historic, social and cultural value, because they constitute an element of memory and identification for the community of a territory.

Often abandoned productive buildings are considered marginal elements of the urban context. This means to belittle not only their "physical structure", but also the importance of what they testify. Under this perspective the retrofitting of the industrial forsaken estate is the conservation of a symbol and demonstration of the social history. Reintroducing productive constructions into the active part of cities, connecting them with the surrounding environment, is the best way for assigning them a new importance.

In light of these considerations, it is also fundamental to take into account that industrial buildings, usually characterized by big sizes, good accessibility, flexible internal partitions and large pertinence areas, are good candidate for rehabilitation, since they can be easily converted in a wide range of possible use destinations.

The focus point is how to convert this existing estate in a sustainable way, in order to reduce the need for new constructions and optimize the intrinsic qualities of forsaken industrial spaces.

2 Methodology outline

The following paper presents the project of restoration of a disused factory built in the Sixties. Scope of the study is the definition of strategies for sustainable renovation of this building able to take into account the aspects related to: the selection of sustainable materials in terms of environmental performance, the building energy performance, the flexibility and adaptability of the inner space and the total cost for construction and maintenance.

For a better consideration of all these aspects, an evaluation methodology based on the use of *MCA (Multi Criteria Analysis)* was developed and applied to different hypothesis of building retrofitting, in order to estimate the best design solution.

3 Discussion

3.1 Project description

The building is a store located in the suburbs of Udine, built in the Sixties. It is divided into two blocks with two different vaulted roofs, which covers a total area of 574 m^2 on a unique level. The average height of the roof is 6,70 m. The vertical structures are in prefabricated concrete, ground floor is in concrete, while roof beams are in steel. The external walls are in concrete blocks of 20 cm thickness; hollow flat blocks covers the roof beams.

Fig. 1 *The building in its actual position*

Aim of the project is to convert the building in an office, defining an interesting space from the architectural point of view and at the same time reducing energy demand and operational costs by using low environmental impacting materials.

According to the commitment requirements, the architectural project of the building was developed for maximizing the use of the inner space. For this reason it was decided to lower the level 0 of nearly 150 cm and dividing the total height of the construction into five different levels. In this way it was possible to design a space in which double height and walkways systems give dynamicity to the simple shape of the construction, also introducing green elements inside the hall and along the perimeter of the building itself.

Fig. 2 *The three levels of the restoration project*

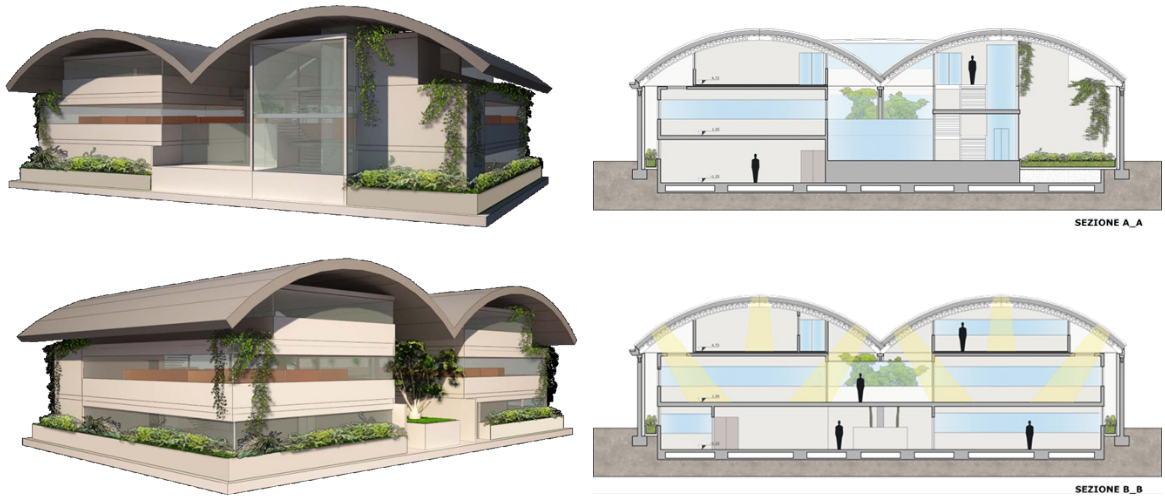

Fig. 3 *Two sections of the building and its internal volume*

3.2 Envelope hypothesis

For what concerns the energy aspect, the calculated current building energy need for heating is 31 kWh/m^{3}year. This means that there is the necessity to well insulate the existing envelope for strongly reducing the consumption from a so high value to a value lower than 8 kWh/m^{3}year (Italian A class).

The core question is which kind of envelope is able to satisfy at the same time all the aspects (environmental, social and economic) characterizing the sustainability concept.

For this reason as first step of the envelope design three solutions were hypothesized. The first one consists in insulating with ETICS (External Thermal Insulation Composite Systems) the existing envelope, the second one consists in using an internal insulation system, while the third one is based on the use of “the envelope within an envelope” system.

3.3 Configurations analysis

The proposed solutions were analyzed by using a combination of tools and software.

For the assessment of the environmental impact during construction and maintenance the software ECOSOFT (IBO – Austria) was used; and the building energy need was calculated according to the Italian standard for thermal energy performance (UNITS 11300/2008 – part 1). The cost analysis of the intervention was performed dividing it into two steps: the first one considered only the construction cost, while the second one focused on calculating the maintenance costs. These costs depend from the number of substitutions of the building components and the energy demand of the construction during the considered life span. After have estimated these two parameters it was possible to evaluate the total cost for the maintenance phase.

3.3.1 LCA for construction and maintenance

For performing the LCA calculation of the three building envelope scenarios, some assumptions were considered. First of all, the existing structure was estimated in a good position and for this reason no substitutions of the structural parts were hypothesized. Only some additional structural elements were taken into account because of the necessity to help the old structure to bear new loads coming from the new horizontal and vertical partitions and from the new destination of use.

In the *ETICS (External Thermal Insulation Composite System)* solution EPS was used as main insulation materials for walls, mineral fiber was used on the roofs and XPS panels in the ground floor. Instead in the second *solution (ITI – Internal Thermal Insulation)* wool glass panels both for walls and roofs were used, while for the ground floor XPS panels were used again. In the *EWE* configuration *(Envelope Within the Envelope)* no operations were made on the existing structure, but the design solutions were totally oriented to define a new building inside the existing one, totally independent from it. Wood was chosen as new inner material. In particular the new envelope is formed by X-lam panels insulated with a wood fiber ETICS and glazed parts with wooden frame and high insulated double panes. The LCA of the three building solutions for construction and maintenance phases was performed for a life span of 50 years, giving the following results:

Tab. 1 *LCA results*

	GWP	**POCP**	**AP**	**EP**	**ODP**	**PE nr**
	kg CO_2 eq.	kg C_2H_2	kg SO_2 eq.	kg PO_4--- eq	kg CFC-11 eq	MJ
ETICS	396548,42	263,51	2679,39	316,61	0,0211	9100609,42
ITI	526841,41	261,24	3116,46	342,98	0,0347	10237332,01
EWE	168556,89	163,10	1526,40	150,15	0,0147	5108936,48

Table 1 shows similar results for what concerns *ETICS* and *ITI* solutions, and at the same time highlights a huge difference between these two configurations and the third one. This difference is mainly caused by two different factor: the presence of a *smaller envelope* in the EWE hypothesis (with a resulting minor use of materials) and the choice to design this solution totally adopting *natural and renewable materials*, such as timber, wood fiber or hemp fiber. Graphs below illustrate how the combination of these two aspects addresses to a global save of the environmental impact: comparing EWE and ETICS solutions, the overall average reduction is equal to 44 %, while comparing EWE to ITI solutions, this value rises up 53 %.

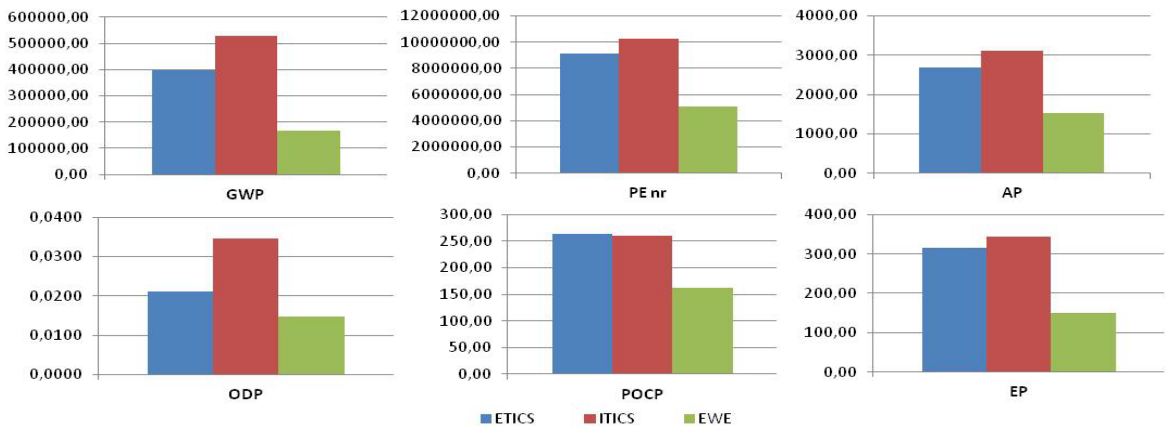

Fig. 4 *Histograms of the LCA parameters*

3.3.2 Building energy performance

One of the main objectives of the renovation project was the building energy retrofitting. The calculated energy demand of the building is currently equal to 23,4 kWh/m^{3}year.

Improving U-values it is possible to minimize thermal losses through the envelope, reaching an high level of energy performance. For such reason particular attention was paid in insulating with an appropriate thickness of insulating material every envelope part, reducing the building thermal transmittance of elements from a set of values higher than 1 kWh/m^{2}K to one lower than 0,2 kWh/m^{2}K.

The calculation of the energy demand was performed according to the methodology described in the Italian standard UNI-TS 11300/2008 part 1, based on the EN-ISO 13790/2008. By using this methodology, all three hypothesis could achieve a value of design energy need lower than 6 kWh/m^{3}year, classifying the building as an A class. In the ETICS case the average U-value for opaque elements is 0,177 W/m^{2}K and 1,3 W/m^{2}K for windows and glazed surface; in the ITI case they are respectively 0,174 W/m^{2}K and 1,2 W/m^{2}K and in the EWE case 0,175 W/m^{2}K and 1,05 W/m^{2}K.

In **Table 2** it is possible to observe that the total energy demand of the building is equal to:

Tab. 2 *Energy calculation results*

	U-value opaque parts	**U-value glazed parts**	**EP**	**Energy need**	**Energy need (50 years)**
	W/m$_2$K	W/m^{2}K	kWh/m^{3}year	kWh/year	kWh
ETICS	0,177	1,30	5,91	20678	1033895
ITI	0,174	1,10	5,94	20790	1039497
EWE	0,175	1,05	5,37	17222	861079

Also in this case we can observe the similarity between the first two configurations, while the EWE hypothesis is again quite far from them. Thanks to a minor volume to heat, the building energy demand is lower than the other two cases, respectively of the 9,1 % and 9,6 %.

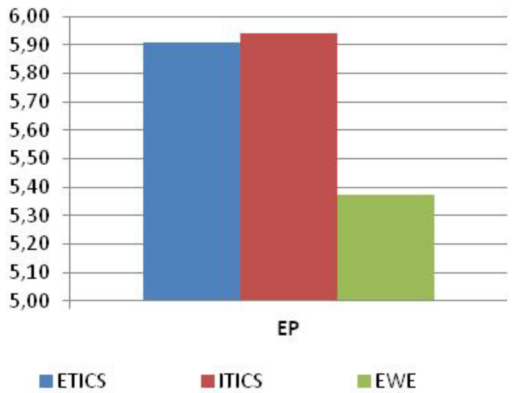

Fig. 5 *Histograms of the EP values for the three solutions*

3.3.3 LCC for construction and maintenance

Also aspects related to economic costs were considered in the analysis of the three configurations. In this case factors concerning construction costs, replacement costs and maintenance costs (for heating) were estimated, taking also into account discounting costs.

Costs were calculated for the same life span of 50 years (supposing that after this range of time the building will need to be again totally modified), considering all changes and replacement operations that are necessary for each hypothesized envelope.

Furthermore, maintenance costs related to building use (heating) were calculated, considering an annual interest rate equal to 1,2 %. **Table 3** presents the costs analysis as described above:

Tab. 3 *Costs evaluation*

	construction and replacement	maintenance	total
	€	€	€
ETICS	712824	180658	893482
ITI	775754	181637	957391
EWE	525950	150461	676411

Again we can note the similar values characterizing the first two solutions, while the third one is again the "best" solution in terms of construction and maintenance.

Despite the choice of natural materials, which are commonly more expensive than synthetic materials, the smaller quantity of surfaces to retrofit and the presence of the external existing envelope respectively reduce the necessity of new materials and replacement operations. Furthermore, the major efficiency of the EWE envelope reduces the amount of cost for building maintenance.

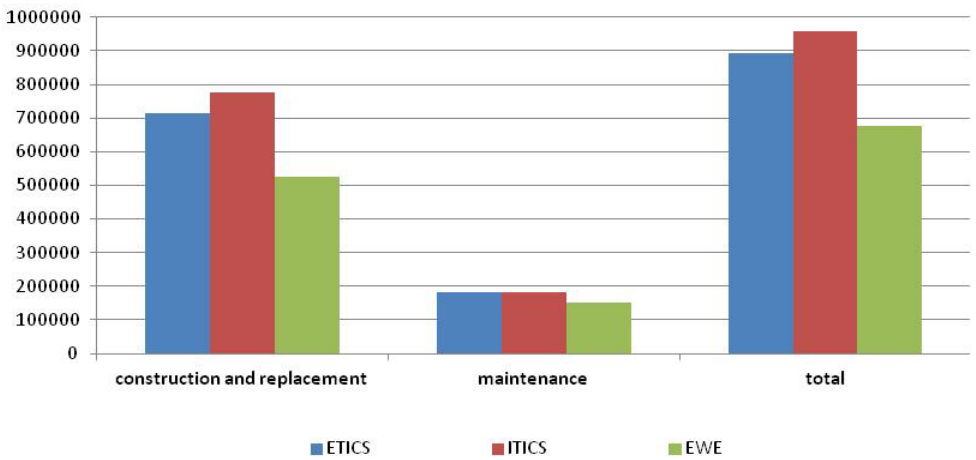

Fig. 6 *Histograms of the costs for the three solutions*

In terms of improvement percentage, the EWE solution is better than the ETICS one of 26,2 % for construction and replacement and 16,7 % for maintenance, with an overall costs reduction of 24,3 %. Compared to the ITI hypothesis, the EWE improvement is: 32,2 % for construction and replacement and 17,2 % for maintenance, with an overall reduction of 29,3 %.

3.3.4 Reversibility of the intervention

Another important principle considered in designing this intervention is the *adaptability,* because an adaptable project allows for easier changes in spatial organization and life-styles of building occupants, reducing whole life cycle costs, demolition waste and impacts on the environment.

For assessing the *"adaptability level"* of the proposed solutions, two significant and objectively evaluable parameters were selected: the *construction type* (dry construction system, wet traditional systems or mixed systems), and the *type of connection* between different layers or parts composing the building (welding, connectors, merging shapes). In light of reversibility of the construction element, a score was assigned to each adaptability feature listed above, as it is illustrated in **Table 4**:

Tab. 4 *Definition of a score system for assessing construction adaptability*

construction type		joint type	
dry construction system	1	merging shape	3
mixed systems	0,5	connectors	2
wet traditional system	0	welding or sealants	1

The final adaptability level is given by multiplying the value assigned to the type of construction with the value assigned to the type of joint and it is always in the range between 0 and 3. The highest is the value, higher is the possibility to de-construct and recycle a specific building component. As illustrated below, because of a major use of dry construction systems EWE is also the best solution in light of adaptability.

Tab. 5 *The score system applied to the three building solutions*

recyclability potential	**ETICS**			**ITI**			**EWE**		
	construction type	joint type	**RP**	construction type	joint type	**RP**	construction type	joint type	**RP**
vertical walls	0	1	**0**	0,5	2	**1**	1	2	**2**
groundfloor	0	1	**0**	0	1	**0**	0	1	**0**
inner partitions	1	2	**2**	1	2	**2**	1	2	**2**
intermediate floor	0,5	2	**1**	0,5	2	**1**	0,5	2	**1**
roof	1	2	**2**	1	2	**2**	1	2	**2**
total RP	**5**			**6**			**7**		

3.4 How to compare configurations

In order to perform a final and more comprehensive comparison of the three solutions, *MCA (Multi-Criteria Analysis)* was applied to the project. For this reason each parameter (LCA parameters, EP value, global costs, level of adaptability) had to be normalized and weighted.

As first step the six parameters considered in LCA were summarized in a single indicator, minimizing them before and after that, assigning the following weights to each one of them:

Tab. 6 *Weighting system for LCA parameters*

LCA parameters	**GWP**	**POCP**	**AP**	**EP**	**ODP**	**PE nr**
weights	4	1	3	3	2	5
%	0,222	0,055	0,167	0,167	0,111	0,278

This weighting system was selected on the basis of the international literature and the results of an interview to stakeholders.

Also energy performance index, economic cost and level of adaptability were normalized, by using a *minimization formula* (1) for what concerns cost and energy performance and a *maximization formula* (2) for the adaptability level.

$$\text{minimization: } Mij^* = M\min / Mij \tag{1}$$

$$\text{maximization: } Mij = Mij / M\max \tag{2}$$

In this way it was possible to define four indicators for each designed solutions, in the range between 0 and 1 (**Table 7**). These indicators were again weighted in order to obtain a single synthetic index able to give information on the whole sustainability of the proposed project strategies. In this case the weighting system which can be assigned to the four parameters is not fixed like it happens with LCA parameters.

In **Table 7** it possible to note how the final indicator changes according to different weights associated to the parameter set:

***Tab.** 7 Sustainability parameters and different hypothesis of weighting system for assessing the global index of sustainability*

	LCA index	EP index	Cost index	Adaptability index	Total	Global index		
						ETICS	ITI	EWE
ETICS	0,536	0,909	0,757	1				
ITI	0,446	0,904	0,707	1				
EWE	1,000	1,000	1,000	1				
weights_A	5	5	5	5	20	0,729	0,729	1,00
weights_B	5	3	3	1	12	0,699	0,660	1,00
weights_C	4	4	2	2	12	0,727	0,711	1,00
weights_D	3	5	5	3	16	0,755	0,748	1,00
weights_F	1	4	5	2	12	0,782	0,776	1,00
weights_G	3	5	1	4	13	0,751	0,769	1,00

These results summarize that the EWE solution is the most effective in the set of design alternatives selected for this case study: it is the most performing solution, independently from the value assigned to the different weights.

4 Conclusion

From this work, which is part of a wider research on the strategies for sustainable retrofitting of existing buildings, two main aspects can be underlined.

Considering only three hypothesis of envelope, the comparison between different solutions is quite simple; the complexity increases when the number of design alternatives increases too. In these cases having the possibility to compare with a single indicator a so huge number of parameters becomes fundamental in order to simplify the process of selection of the best design choices. Furthermore the use of different weights for each feature to take into account in the design process is also interesting in light of assigning more importance to a characteristic rather than another one, in order to meet specific requirements from the commitment.

A second aspect which should be highlighted is the effectiveness of the choice to use the design strategy of the *envelope within an envelope* for retrofitting a building characterized by big dimension and inner space totally free from structural elements. This independence of the new envelope allows designers to perform architectural choices that can increase the value of the building, without loading excessively the existing structure. In this way a construction with important values (as described in the introduction) can be again used without substantially changing its imagine, giving it back to the city.

Acknowledgement

Thanks to the Polo Group – Le Ville Plus, owner of the building, for making this work possible with its disposability, to Michela Dalprà and Antonio Frattari for the help in making it feasible.

References

[1] ALWAER H., CLEMENTS-CROOME D. 2010. *Key performance indicators (KPIs) and priority setting in using the multi-attribute approach for assessing sustainable intelligent buildings*. Building and Environment, Vol. 45, pp. 799–807.

[2] BRADLEY P.E., KOHLER N. 2007. *Methodology for the survival analysis of urban building stocks.* Building Research and Information, Vol. 35, No. 5: pp. 529–542.

[3] BRIBIÀNI. Z., CAPILLA A.V., USÒN A.A. 2011. *Life cycle assessment of building materials: comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency improvement potential*. Building and Environment, Vol. 46: pp. 1133–1140.

[4] BRIBIÀN I Z., USÒN A.A., SCARPELLINI S. 2009. *Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification.* Building and Environment, Vol. 44: pp. 2510–2520.

[5] BULLEN P., LOVE P. 2011. *Factors influencing the adaptive re-use of buildings*. Journal of Engineering, Design and Technology, Vol. 9, No. 1: pp. 32–46.

[6] COLE R.J., KERNAN P.C. 1996. *Life-Cycle Energy Use in Office Buildings*. Building and Environment, Vol. 31: pp. 307–317.

[7] DING G. K. C. 2005. *Developing a multicriteria approach for the measurement of sustainable performance.* Building Research & Information, Vol. 33, No.1, pp.3–16.

[8] ERLANDSSON M., BORG M. 2003. *Generic LCA-methodology applicable for buildings, constructions and operation services—today practice and development needs.* Building and Environment, Vol. 38: pp. 919–938.

[9] KOHLER N. AND HASSLER U. 2002. *The building stock as a research object.* Building Research and Information. Vol. 30 No. 4: pp. 226–36.

[10] KOHLER N. AND YANG W. 2007. *Long-term management of building stocks.* Building Research and Information. Vol. 35 No. 4: pp. 351–62.

[11] REY, E., *Office building retrofitting strategies: Multicriteria approach of an architectural and technical issue*. Energy and Buildings, vol. 36, no. 4, 2004, pp. 367–372.