Energetic Analysis of historical buildings by means of a typological research

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ABSTRACT

According to the European directive 2002/92/CE, degree 311/2006, as from July 2009 all the existing buildings must equipped with an energetic certification to be shown when sold or rented. Probably this disposition, together with economic incentives made available for improvement interventions of the energy performances, will lead to a remarkable reduction in the consumption of energy attributable to the existing buildings.

In Italy, around 40% of residential buildings were built before 1957, and about 78% of them are inhabited by at least one person. Therefore, for these kind of buildings it is necessary to either reduce energy consumption and to have them certified.

The use of simplified procedures is therefore important for two main reasons in order to meet the above requirements: on one hand, to reduce the costs relevant to the issuance of the energy labeling (we count about 800.000 transactions per year, excluding rents), on the other hand to obtain indications regarding the consumption of energy which could promote improvement interventions to the existing real estate.

Considering the variety of the stock building, it is therefore difficult to define simplified methods for the energy certification unless the buildings are first subdivided into homogeneous groups based on the period of construction and typology.

This paper presents the investigation which has been carried out on medieval and renaissance buildings and which are still inhabited nowadays in the cities of Pisa and Pistoia.

The aim is to define a correlation between the geometrical and energy parameters, representative of the identified typology. Such correlation and its subsequent classification is based on the investigation of the thermo-physical characteristics of the external walls and flooring, and on the modeling of the energetic behaviours resulting from the data deriving from the investigations performed on a number of flats.

1. INTRODUCTION

The European directive 2002/92/CE, adopted in Italy as from October 2005, was enacted in order to cut down the energetic consumption in residential buildings. It imposes to analyse the consumptions subdivided according to the final use of energy (winter, summer, lighting and hot water consumption) for assignment of the energy label.

The Italian Decree laws, in particular the decree 311/06, fix to 1 July 2009 the term by which in Italy the certification for selling and renting will also be required for each apartment. The same Decree establishes that artistic-historical buildings are not included in the limitations provided for new buildings for what is concerned with the control of final energy consumption.

The Italians residential buildings are more complex than in the other European countries since there are houses which date back to several periods and are still nowadays used as private houses.

The ISTAT census of 2001 realized that historical buildings (built till 1957) are the 40% of the whole: buildings built before 1957 are 10.932.418 upon the whole of 27.268.880. The 78% of these buildings are still inhabited by at least one person [1].

Moreover, according to what set forth in the cultural assets code (decree 22 January 2004 n.42) all buildings constructed more than 50 years ago, thus before 1957, can be subjected to restrictions and therefore be excluded by the obligations provided for by the recent provisions of the law"… in all cases in which the observance of the provisions would require an unacceptable modification of their peculiarities, in particular as regards their historical or artistic character"(art. 3 degree 311/06)

Yet all buildings must have the energetic label when being sold or rent starting from July 2009.

Despite the law obligations, it would be recommendable to incentivize and promote interventions to the above buildings since they have a great share in the national energetic consumption which cannot be ignored, also considering the Kyoto protocol that will come into force in the near future.

It was estimated that by improving the efficiency of plants such as conditioning, heating, lightning, it will be possible to cut down energy consumption and emissions (figure 1,2) [2].

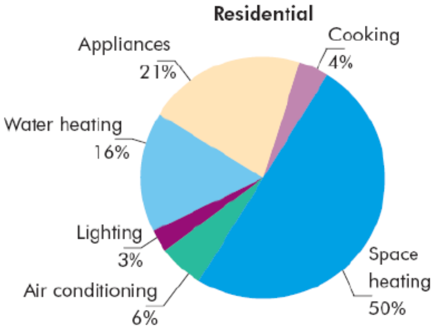

Figure 1- Primary energy saving by improving energy performance of residential buildings

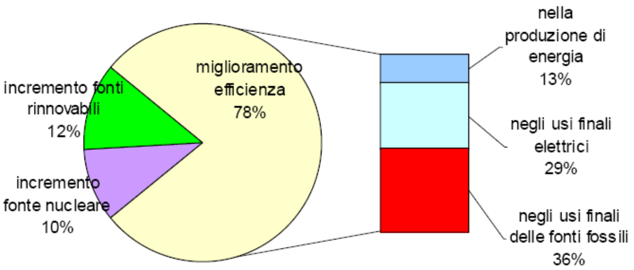

Figure 2- Emission of CO_2 avoided

To summarize, the energy labeling obligations involve the need to define simplified methods able to meet the large number of requests at lower costs.

2. PRELIMINARY CONSIDERATION

The buildings and the component elements of the buildings found in the historical centers are heterogeneous, indeed it is not possible to leave out a preliminary classification of the existing real estate in the course of an historical-typological investigation.

The subdivision into a homogenous group of buildings allows to compare the houses belonging to such group through significant correlation parameters from which it is possible to define similar behaviours.

In the case in point, the above analysis has led to the identification of homogeneous groups of buildings in order to evaluate their energetic behaviour.

Medieval and Renaissance buildings were chosen in Pisa and Pistoia. The choice is relapse in this two towns because these have a similar urbanistic pattern, shaped since 1100 till 1500, which is still visible, in spite of a lot of transformations.

In these towns, we have singled out four different prototypes: schiera-houses, line-houses, tower-houses and noble houses (figure 3). The tower house expands in height with many floors while the ground floor is used for commercial purposes, the other ones are habitations.

The schiera-house is created by two elementary blocks one on top of the other, to which is added another floor for the bedrooms (figure 4A). In the schiera-house lives just one family: the shops are on the ground floor and the living area on the first and second floors. The first floor is for daytime use and the second floor for the bedrooms. In the urban weave the houses join together thus forming a city (figure 4B).

The schiera-house evolves into the line-house (figure 4C). The schiera-houses, no longer sufficient for the new needs of the inhabitants, are joined together thus creating one-family houses that expand horizontally over one floor and no longer vertically. This involves demolition of one stair and positioning of the access to the flats in a central position with respect to the prospect. Bringing together two previously separated buildings involves placing the windows in axis among them and their lining up. Passages with stairs are opened to allow access to houses at different heights. This way we obtain flats of about 120 m^2 arranged on 3-4 floors [3].

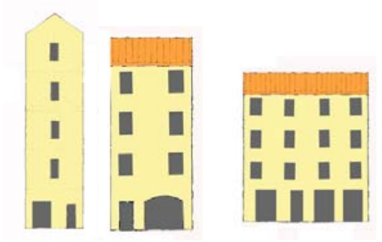

Figure 3- Outline of the typology (from left to right):torre-house, schiera-house and linea-house

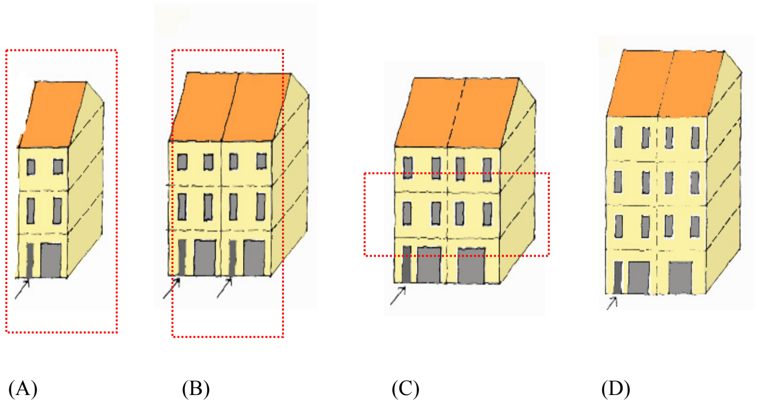

Figure 4- Evolution of the typology (from left to right): the inhabited units pass from the vertical disposition to the horizontal disposition.

Both in Pisa and Pistoia these three kinds of buildings are still existing. However, the historical events (wars, different way of life) caused the single apartments to change. The outside remains the same, but inside the apartments are made one, destroying the original feature.

For this reason it was singled out an "hybrid" type of building still featuring something of the previous ones and on which the energy analysis was carried out.

Figure 5 shows the internal evolution of a flat on the first floor of a building in Pisa. The block was originally divided in tower-line-line. The two houses in line were then joined together and the tower house was included within. The changes made afterwards lead to the present distribution (figure 6), where the flats are found either in the line and in the tower. We found about 85 apartments like this out of the 94 apartments examined, so they are undoubtedly more that the apartments which have preserved their original structure.

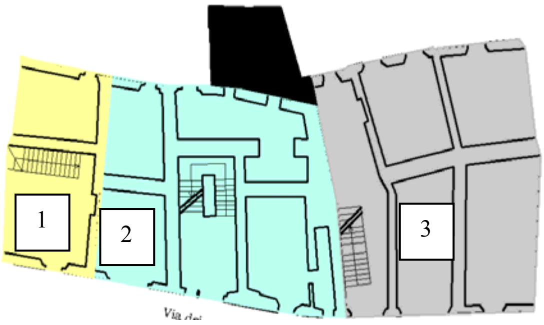

Figure 5- Original composition of the building: 1 torre-house; 2 linea-house; 3 linea-house

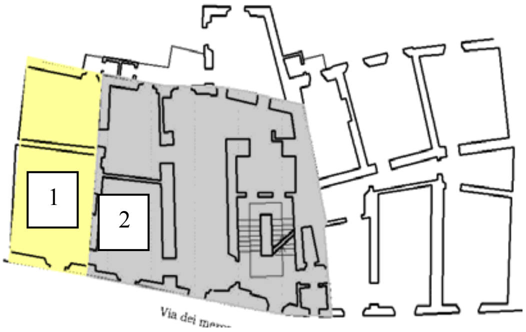

Figure 6- Apartment originate by torre-house and linea-house

Based on the above, we carried out *in situ* investigations supported by bibliographic research [4] and cadastral documentation in order to go back to the original composition of the walls, of the ceilings and windows.

Both schiera-houses, line-houses and tower-houses have sac walls. The thermal characteristics of the materials used for modeling have been deduced from the recommendations set forth in CTI R03/3 November 2003 [5] which report the thermo-physical characteristics of the wall and ceiling components that are often found in historical housing.

The thickness of the outer walls was deduced from cadastral plans and then checked on spot, when possible. The thickness ranges between 34 and 64 cm. In tables 1-3 are reported the basic materials used for the walls and ceilings, and their energetic behaviour is defined.

Table 1. Thermophysical characteristic of “hybrid” type walls

	**Element**	**Conductivity (W/mK)**	**Permeability (Kg*10^{-12}/msPa)**	**Mass Volume (Kg/m^3)**	**Specific heat (J/KgK)**
	External plates	0.9	18	1800	879
	Solid bricks	0.72	37.5	1800	920
	Cobblestones	0.66[1]	18	764	920
	Solid bricks	0.72	37.5	1800	920
	Internal plates	0.7	18	1400	879

Table 2. Thermophysical characteristic of horizontal elements

	**Element**	**Conductivity (W/mK)**	**Permeability (Kg*10^{-12}/msPa)**	**Mass Volume (Kg/m^3)**	**Specific heat (J/KgK)**
	Floor made of cooked clay	0.72	31	1800	28.8
	Mortal Lime	0.9	18	1800	12.85
	Under floor made of cooked clay	0.72	31	1800	28.8

Table 3. Thermophysical characteristic of windows

	Windows with single glass
	Total solar energy transmittance by the glasses g=0.82
	garbage bin absent
	Presence of wooden shutters
	Absence of frame classificatio
	wooden frame thickness 100 mm.
	glass thickness 4 mm
	glass conductivity 1 W/mK

Figure 7 shows the comparison among the thermal transmittance according to the thickness both in sack walls and solid walls. In both this elements thermal transmittance it’s elevate because of the low thermal performace of the materials that composes this kind of walls.

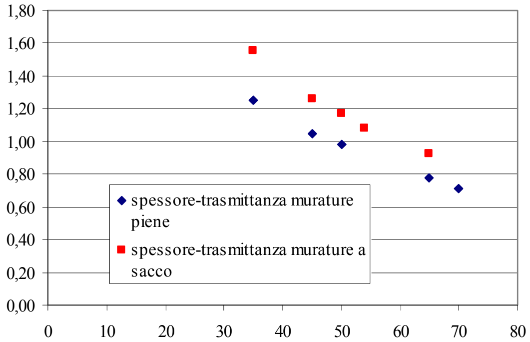

Figure 7. Trend of the thermal transmittance in opaque vertical structures according to the thickness of walls

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3. RESEARCH METHOD AND RESULTS

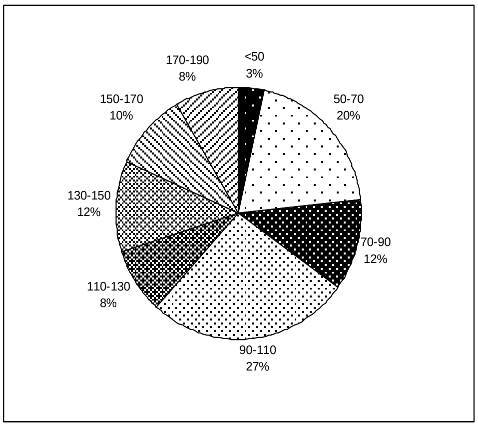
The aim of this research is to define a simple method to arrive at the energy label for the so called “hybrid” type of apartments. 94 apartments were examined and studied by the correlation method.

To make a simple method to arrive at the energy label, it would be desirable to back to the energy consumption of a flat trough simple geometric parameters as square measures, gross volume and so on. For example in the literature we find methods, studied for new buildings, that allows to find out the range of energy consumption of a flat through the geometric parameter S/V [6]- ratio easily computable also for the house owner-.

According to the correlation method, has been found out the significant geometrical parameters that describes the energetic behavior of an apartment of the “hybrid” type. By apposite correlation form, the significant geometrical parameters that we found, were directly correlated with the energy consumption of the generic flat.

First of all, by the geometrical analysis we found that:

- the gross square measure is from a minimum of $50\ m^2$ to a maximum of $170\ m^2$. The average data are between $50 – 70\ m^2$ and $90 – 170\ m^2$. Few flats are less than $50\ m^2$ and more than $170\ m^2$ (picture 8)
- the gross height varies between 2,55 and 4,55 m. The 28% of flats has height between 3,00 and 3,30 m.
- The gross volume varies much more from 200 to $750\ m^3$. The highest percentage is between 250 and $300\ m^3$ (picture 9)



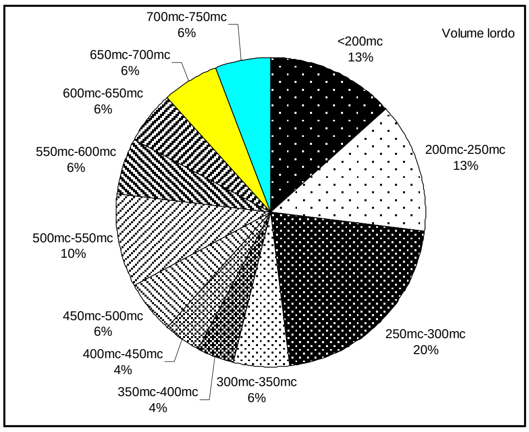


Figure 8- Percentage distribution of flats for gross area

Figure 9- Percentage distribution of flats for gross volume

- The ratio S/V presents a large variability, with the 29% of flats in a rage from 1,0 to 1,1. The following table summarize the more frequent values of the geometric parameters.

Table 4 summarize the most significant geometrical parameters witch control the energetic performances, defined by a crossed analysis of the data defined above.

Table 4. Range of variation of dimensional parameters

gross height	$3,0\ m<h_L<3,30\ m$
gross square measure	$90\ m^2<S_L< 110\ m^2$
gross volume	$250\ m^3 <V_L<300\ m^3$

For each apartments, it has been calculated the energy use for heating (Q_h) with relative heat loss and solar gain.

Once the geometrical and thermal parameters were known, one or more correlations were found, which were available to unite these quantities (geometrical and thermal). Because the geometrical parameters are very changeable, it was not possible to identify just one correlation able to estimate the energetic behavior of an historical apartment. As said, this approach is instead possible for new buildings (for example the correlation

Q_h-S/V [7]). Using just one correlation, we found out big errors between the real value of Q_h, calculated by models, and the value of Q_{hc} (i.e. the Q_h ensue from the correlation method).

For this reasons we analyzed separately both heat loss and solar gain components of Q_h to find out, for each component, the correlation with geometrical parameters; in particular we analyzed the single terms of the following equation, given according to the technical Norm EN 832:

$$Qh = Q_L - \eta(Q_{si} + Q_i) = \lfloor(Q_g + Q_t + Q_a + Q_v) - Q_{se}\rfloor - \eta(Q_s i + Q_i)$$

Q_g – ground heat loss.

The typology of buildings analyzed have got the apartments arranged vertically from the first floor. So there are not surfaces at direct contact with the ground. That for the term Q_g it's always zero.

Q_t– transmission heat loss (0°C).

This terms includes losses heat through opaque surfaces, windows and thermal bridges.

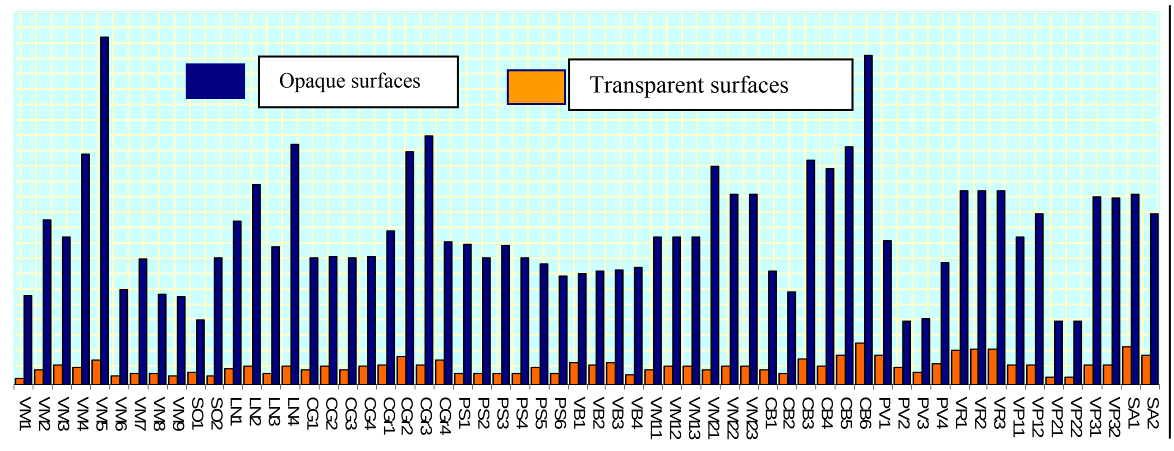


Figure 10 – Opaque surfaces and windows toward outside, divided for flats.

Table 5 shows the share distribution of the window and opaque surfaces on the whole surfaces towards the outside, visible also in figure 10. Only the 3% of the examined flats does not respect the distribution of table.

Table 5 percentage opaque and window surfaces on the whole exchanging with outside:

% opaque surface on the whole surface toward outside	% transparent surface on the whole surface toward outside
87,7%	12,3%

Not withstanding the window surfaces is limited, its energetic weight is 20-30% of the transmission heat loss, because of the low thermal resistance of glass and frames [8].

Table 6 sums up the share distribution of Q_t components, in which the energetic weight of thermal bridges is about the 5% of the whole energy lost for transmission.

Table 6 percentage of energy lost through opaque components, windows and thermical links on total Q_L

% energy lost through opaque surface	% energy lost throught transparent surfaces	% energy lost throught thermal bridges
63-75-%	20-30%	5-7%

Q_a – heat loss from other appliances

The examined flats have a big percent of surface exchanging with prefixed temperature spaces (stairs spaces, near by flats, attic); this percent is bigger that the one exchanging with outside. Figure 11 shows a standard flat map from witch it's possible to see what said below.

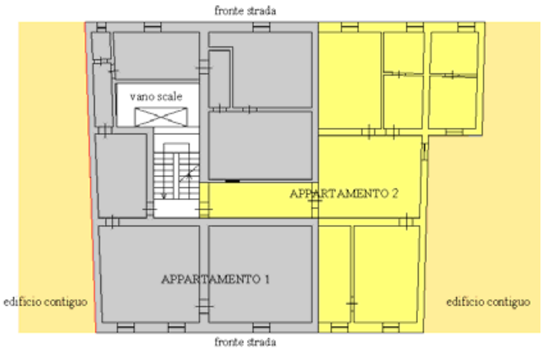


Figure 11- Example of plan distribution with prevalence of exchanging surfaces with prefixed temperature spaces.

Table 7 shows the percentage distribution of exchanging surfaces at different temperatures (18˚C for the near heated spaces, 7˚C for stairs spaces and passages, 2˚C for under roof) and table 8 shows the average percentages of the two kind of surfaces.

Table 7- Percentage distribution of exchanging surfaces at different temperatures

percentage distribution of surface neighbouring with zones at fixed temperature			
	18°	7°	2°
interfloor	87,66	6,44	0
attic	52,88	11,6	35,51

Table 8- Percentage distribution of external and internal surfaces

percentage distribution	
exchanging with outside (T 0°C)	exchanging with zones at fixed temperature
21%	79%

As it's possible to find out from the tables above, the area percentage exchanging at the different temperatures of 18˚C, 7˚C, 2˚C, is influenced by the location of the flats in the building: inter-floor have got a most important share of area exchanging at 18˚C; the flats located at highest floor, instead, have got a percentage not unimportant of exchanging area with the attic, that has been considered at 2˚C. For this reason, has been decided to use, instead of the real value of the surfaces exchanging at different temperatures, the ponder over surface. This passage has been done by corrective factors of the areas exchanging at the different temperature.

Q_v- ventilation heat loss.
Ventilation heat loss, for the whole flats, it is the 11% of the Q_L total value.

Q_{se} – passive solar gain on opaque surfaces
The passive solar gain on opaque surfaces doesn't go over the 3% of the Q_L because of the shading among building.
Table 9 synthesize the energetic weight of the single components of outflow on the Q_L total.

Table 9- Synthesize the energetic weight of the single components of outflow on the Q_L total.

Q_t	Q_a	Q_v	Q_{se}
38%	51%	11%	0%

The thermal utilization factor (η) of the passive solar gain on windows and internal gain (Q_i+Q_{si}) it's the only parameter that regards the dynamic effects of heat transfer. For the analyze buildings the thermal capacity it's high. So the η factor, in the whole of examined apartments, it's included in the values 0,98-1,0.
For the whole of examined flats, the product $\eta(Q_i+Q_{si})$ it's the 15%-21% of Q_h.

4. CONCLUSIONS

Trough the crossed analysis of geometrical and thermic data, a simple methodology was defined.
In this way it's possible to know the energetic performances of an apartment with a good approximation. Differently from the simplify methods used for new buildings [8-11], it's not possible to know consumption through calculus of the correlation of only one geometric parameter with the thermal performance, but trough different ones (figure 12)
In pictures 13 – 18 these are the parameter which allow to define corrective factors to have the Q_{hc} value. These factors applied to heat loss, solar and internal gain values of the average buildings, will serve to modify them according to the geometrical variations of the average buildings. The mistake in using this methodology is between 1% and 18% (few cases); in majority of cases, more mistakes between Q_{hc} and Q_h not higher the 8%.

Figure 12- schematic method

With this research we tried to find a procedure for configuration which could determinate the energetic performances of historical flats in a simple way to come at a certification label [12].

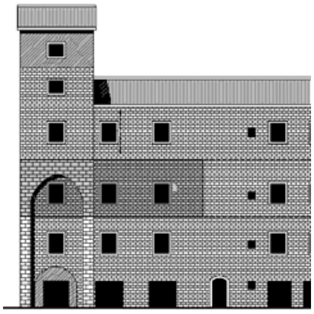
Surfaces –opaque and transparent- (m^2)					
30-50	50-70	70-90	90-110	110-130	
1	1,55	1,97	2,55	2,95	

Figure 13- "hybrid" type: corrective factors for transmission heat loss

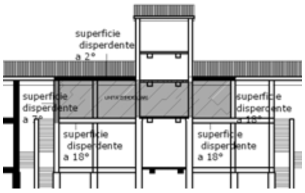
ponder over surface (m^2)										
20-45	45-75	75-95	95-110	110-140	140-170	170-200	200-230	230-275	275-290	
1,0	2,0	2,6	4,5	4,9	6,1	7,2	9,5	11	11,80	

Figure 14- "hybrid" type: corrective factors for heat loss from other appliances

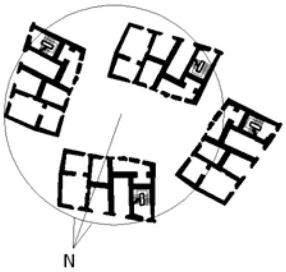
	Windows Area (m^2)								
	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13
nord	0,39	0,54	0,64	0,67	0,71	0,76	0,8	0,7	0,5
sud	0,99	0,95	0,89	0,8	0,78	0,45	0,30	0,25	0,2
est	0,1	0,16	1	0,78	0,7	0,75	0,83	0,9	0,95
ovest	0,15	0,20	0,50	0,73	0,76	0,91	1,17	2,19	2,19

Figure 15- “hybrid” type: corrective factors for passive solar gain on windows

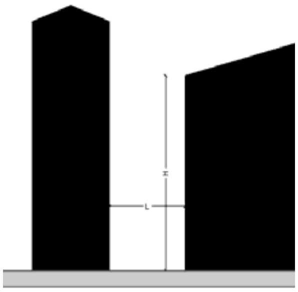
	
per ogni valore di L e H	0

Figure 16- “hybrid” type: corrective factors for passive solar gain on opaque surfaces

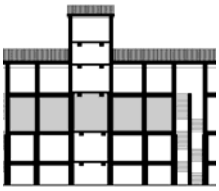
Net volume(m^3)							
100-200	200-300	300-400	400-500	500-600	600-700	700-800	
1,0	1,25	2,0	2,70	3,50	4	4,65	

Figure 17- “hybrid” type: corrective factors for ventilation heat loss

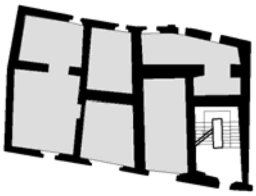
Net area (m^2)							
<40	40-60	60-80	80-100	100-120	120-140	140-160	
0,60	1,0	1,30	1,7	2,15	2,27	2,32	

Figure 18- “hybrid” type: corrective factors for internal gain

NOMENCLATURE

Q_h energy use for heating (MJ/anno)
Q_t transmission heat loss (MJ/anno)
Q_v ventilation heat loss (MJ/anno)
Q_g ground heat loss (MJ/anno)
Q_a heat loss from other appliances (MJ/anno)
η thermal utilization factor

Q_{se} passive solar gain on opaque surfaces (MJ/anno)
Q_i internal gain (MJ/anno)
Q_{si} the passive solar gain on windows (MJ/anno)
Q_{hc} correlate energy use for heating (MJ/anno)

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