HIGH DENSITY BUILDING STOCK RETROFIT THROUGH SOLAR STRATEGIES AND HYBRID VENTILATION SYSTEMS

A comparative analysis on a case study of social housing in Modena, Italy

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Abstract. The very actual theme of building stock retrofit includes wide ranges of possible actions, especially in social housing. Multi-criteria assessments should be lead to evaluate the proper operational approach (considering social, structural, maintenance, thermal and economic parameters). The lower-impact actions typically involve improvements on the building skin, such as insulation and window replacement, while the higher-impact solutions lead to demolition and re-building. Overall, building retrofit through solar technologies represents a relevant strategy to achieve significant energy saving. In this context two solutions have been compared for an early '80s social building in Modena. The former consists in the application of passive systems to optimise solar gains and active technologies to generate energy. The latter is based on demolition and re-building of a newly designed block according to best practice principles. The performance of solar strategies efficiency has been evaluated through parametric markers, while multizone thermodynamic and CFD analysis have been used to estimate the effects of passive cooling technologies.

Keywords. High density building; stock retrofit; solar strategies; hybrid ventilation; social housing.

1. Introduction

Building stock retrofit through solar strategies usually presents more critical situations than re-building options. Furthermore actions on existing buildings in general generate limited results due to a lack of integrated design strategies and costs.

It is possible to achieve high energy performances operating on various aspects: thermal insulation, window substitution, energy production systems and passive thermal gains. A higher level of operation should also include a functional requalification of buildings, with solutions such as junctions and plan rationalisations. Besides these priority objectives, structural adaptation should be lead to fulfil anti-seismic regulations.

A strengthened routine consists of applying less inexpensive systems in a short term (such as exterior insulation finishings) neglecting other strategies with a better payback time (such as solar ones).

The case study presented shows a comparison of two options in a social housing building in Modena (Italy,1981): a building retrofit and an optimised re-building..

2. Solar strategies for energy efficiency

Energy efficiency through solar strategies can be codified as below:

- Structural interventions
- Super-structural interventions

The first category includes strategies using solar gains together with new additions, substitutions or spatial redistribution. Examples are given by:

- Solar greenhouses added to the building;
- A new plan arrangement and an increase of well-oriented transparent surfaces;
- Substitution or reconstruction of the building skin (walls or roof) with active elements.

The second category includes systems applied as a superimposition on the existing building, like:

- Solar panels (PV or thermal) added to the walls or roof;
- Rainscreens integrated with active elements;
- Closure of existing terraces or balconies with windows as a function of solar gains;
- All types of solar screens to control radiation, better if working as passive protection and active production

Both the interventions modify the original building layout in its shape, function and structure: all of them should be assessed according to the adaptability potential of the building.

As to the formal aspect, an analysis of the original layout should be lead to balance the new intervention with the existing building. Hence a distinction between the 'before' and 'after' is desirable to avoid to upset the original configuration. This approach is justified by the history of architecture, as many buildings show the stratification of interventions through the time due to technical or cultural transformations. There are legal aspects related to this issue: some authors (Cecere et al., 2012) talk about a 'right to intervene' on existing buildings, though considering their identity and 'original meaning'.

The main purpose of an efficiency enhancement through solar strategies is to maximise the gains of the exposed surfaces in their morphologic and functional asset. In many cases this goal is achieved with passive systems such as solar greenhouses. These devices contribute to the reduction of energy consumption in relation to climate, orientation and shape of the building skin. A proper operation of the greenhouse also depends by the active control of the users as they can adjust the devices according to their perception of comfort. The thermal exchange with the indoor environment occurs in little percentage through the partitioning wall and mostly due to convection of air between ventilation grids.

An important formal aspect is also given by solar greenhouses, especially when users open or close their windows creating in such a way a variable facade (self-expression). In addition to the energy potentials, the system has a further functionality given by the addition of a new 'architectural' volume that can be used as a terrace, a winter garden or a place for recreation.

In general the operative phases of an energy efficiency intervention using solar strategies can be listed in five guidelines:

- Indentify the 'solar potentials' of the building with relation to the orientation of its surfaces;
- Indentify the adaptability possibilities of the formal, functional and structural aspects;
- Definition of the applicable active/passive solar strategies;
- Analysis of the formal, functional and structural consequences of the intervention;
- Evaluation of solar gains and quantification of the payback time.

The most binding condition in case of addition of solar greenhouses to an existing building is the construction of an adjacent belt free from functional, structural and environmental restrictions: this is essential to lay the foundations and to rise the new structural elements, as a junction with the existing building structure is to be avoided due to regulations and costs. The question of adaptability of the added greenhouses concerns two aspects: functionality of the new spaces and the use that people do of the new devices, affecting on their proper operation.

On the contrary, energy efficiency strategies through active systems of energy production are typically set on the roofing surfaces. In some cases it is possible to use the existing surfaces if they are properly oriented, otherwise a new structure has to be raised: this last hypothesis requires a structural and functional verification and has to be designed to maximise the sun-exposed surfaces. As to the structure, it is desirable to use light framework adopting materials like steel or wood.

The following verification should compare different hypothesis of design on the same case study in Modena, in terms of costs and technology and in relation to its original potentials.

3. Phase A: building retrofit.

The existing C-shape building has a court open on the north side. The lateral branches have three storeys (on Via Arezzo and the continuing of Via Terranova) while the south-facing block has five storeys (on Via Terranova). The east-west axis of the Social Housing area is oriented 24° towards south and the blocks have a good exposure to solar radiation (Figure 1).

Figure 1. Orthophoto of the case study, view of the existing building, view of Gallaratese.

The building is compact, with no balconies, and pillars on the main facade give it a layout reminding the decade-older ‘Gallaratese’ building, by the architects Aymonino and Rossi.
Sizes of dwellings range from one to four bedrooms flats, as the analysis of the floor plans shows. Most of the apartments have one or two bedrooms (respectively 36.6% and 35.5%), mainly distributed as a multi-storey building (73.1%). Some dwelling have functional lacks such as single side ventilation and lounges oriented towards north (17.2%): these aspects create problems of insufficient indoor natural lighting and ventilation.

The gross surface of the whole building is 7522 m^2 on 93 dwellings (served by 7 stairwells); urban density corresponds to 101 dwellings per hectare. The building footprint is a rectangle of 69.2 m by 59.2 m and has a total area of 3612 m^2 (Figure 2).

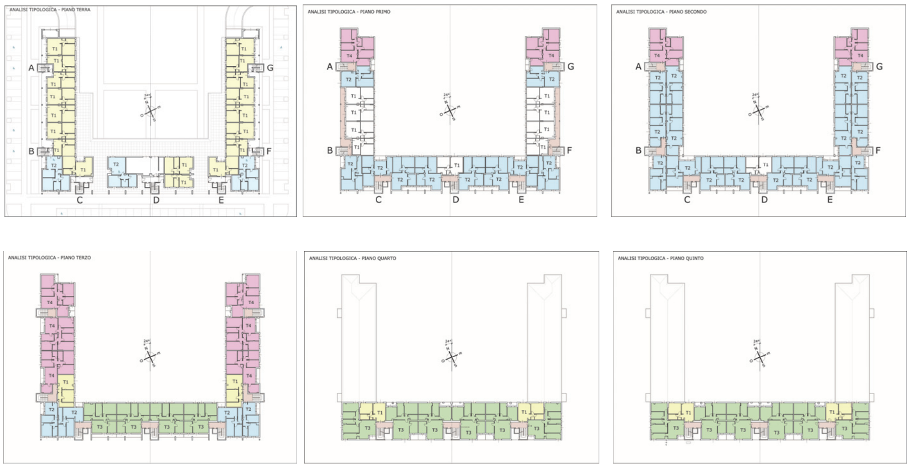

Figure 2. PEEP Building Terranova-Arezzo: typology analysis of the six functional levels.

Building retrofit proposal through solar technologies consists of three strategies:

- Strategy 1: thermal insulation of the building envelope (exterior insulation finishing system);
- Strategy 2: thermal gains (solar greenhouses);
- Strategy 3: energy production (PV).

The implementation of these three different strategies to the building allows to achieve remarkable increases of energy performance, functional and architectural quality, enhancing the building energy rating and its market value. The aspect that has a greater impact is without doubts the addition of solar greenhouses that create a new configuration of the building. (Figure 3).

It is possible to define the solar performance of the building using two main markers: PV potential of an exposed sloping roofing surface and the vertical exposed surface allocated to solar greenhouses. When referred to the territorial unit (hectare), these parameters allow a comparison of solar performances in the two hypothesis (phase A and phase B) (Figure 4).

Figure 3. Solar greenhouses addition: ground floor and first floor plan.

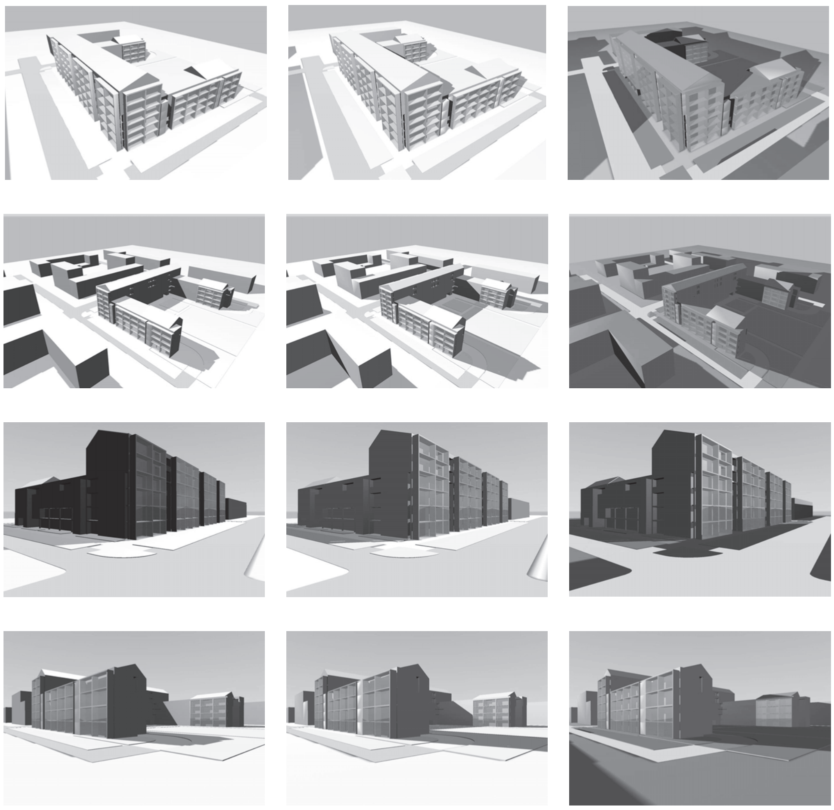

Figure 4. Model Shadow Analysis: summer solstice, equinoxes, winter solstice.

4. Phase B: Building substitution.

Nowadays the subject of building substitution is highly debated among urban and landscape planners as it allows a regeneration without consuming new areas. It also represents one of the most resourceful possibilities to apply the very best newly designed solar strategies. Moreover it is applied to areas that are already equipped with urban infrastructures and this makes it quite advantageous. However building substitution becomes quite complex when many residents need to be transferred elsewhere during the process.

In the case study, this hypothesis has been declared as 'very remote feasibility' by the authority manager itself (ACER Modena). A possible solution to be experimented could consist in moving the residents in a temporary building during the period of construction, and using it in rotation for other similar interventions in the same area.

It comes obvious that building substitution should hence be considered in very few cases with highly critical situations, such as functional, energetic, structural and social degeneration. However the gap of costs between a forceful retrofit and a building substitution is decreasing quickly, especially when a payback time in the long-term period is considered. For this reason a reflection on the 'magnitude of the intervention' on the time scale becomes desirable. It is necessary to analyse and understand the possible hierarchies of the intervention, both technical and economical, and also to reconsider the social and environmental expectations re-calibrating the cost-benefits rate in a long-term time.

An interesting aspect on this matter is that a social housing building, when at high level of energy efficiency, can activate other renovation processes on private buildings as well.

The phase-B design program (building substitution) highlights various features and potentialities (Figure 5):

- To maintain the same number of dwellings or to increase it;
- To maintain the same building footprint;
- Definition and aggregation of minimal urban typology units (MUTU) with maximised sun-exposed surfaces;
- Definition and aggregation of minimal building typology units (MBTU) suitable to implement passive solar strategies;
- Possibility of using the ground floor of the building as an urban space;
- Functional re-definition of all the dwellings;
- Optimisation of vertical and roofing sun-exposed surfaces (solar greenhouses and PV);
- Passive cooling strategies through cross ventilation and a ventilation shaft;

- Optimisation of green surfaces (courtyard and green roofing) to mitigate the summer heat and hold the first flush.

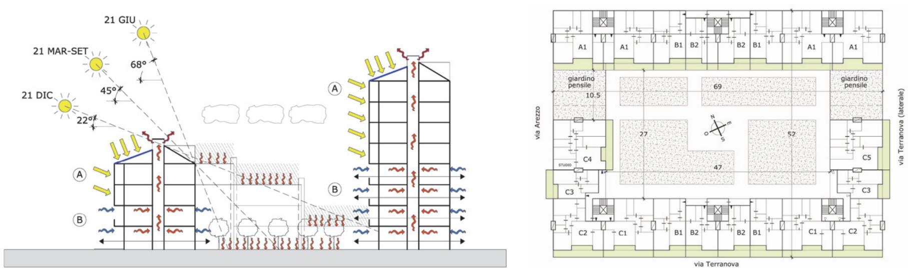

Figure 5. Energy concept with solar and cooling strategies, plan type.

The ventilation shafts turn also into architectural marks and work as an hybrid device in the cooling-heating of the building. The adoption of passive cooling systems in summer allows to save a great amount of energy and permits the building to be self-sufficient. Natural ventilation systems have to be integrated with HVAC since the requirements of the cold season (insulation, airtightness, heating and mechanical ventilation) contrast with the warm season ones (thermal mass, solar screens and natural cross ventilation).

The proposal in the case study consists of an integrated design of the building formal, technical and structural features to maximise solar gains in winter (Figure 6) and free cooling in summer (Figure 7) in order to severely reduce the total amount of energy consumption of the year.

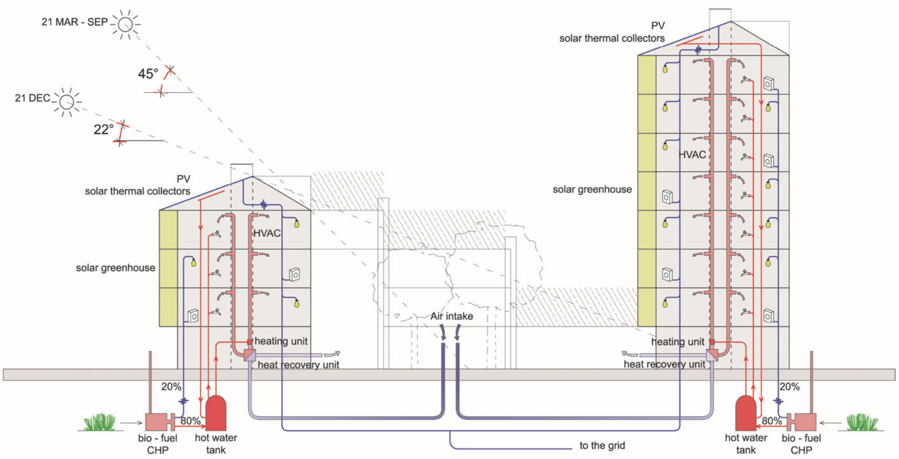

Figure 6. Winter energy concept: solar gains and HVAC system.

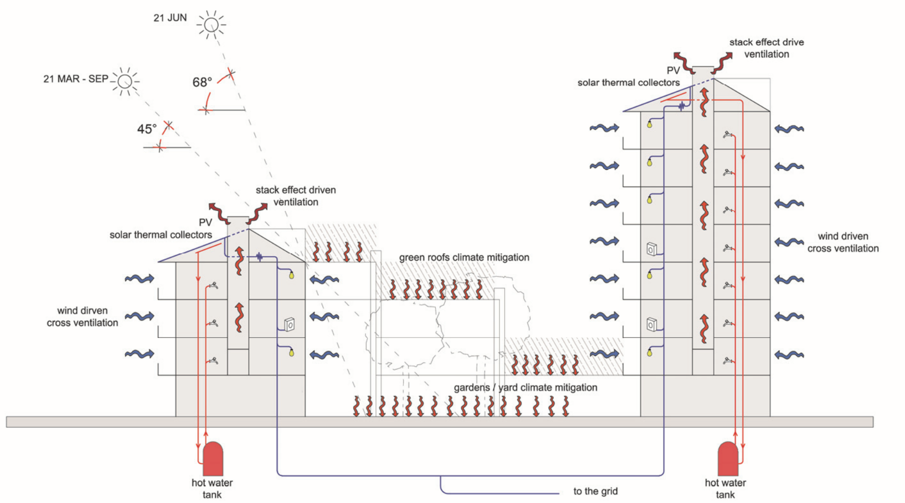

Figure 7. Summer energy concept: free cooling and heat mitigation.

As Barbolini (2014) has pointed out, in general solar greenhouses are distinctive elements of sun-oriented fronts and, together with sun-oriented roofs, can be considered a paradigm of contemporary solar architecture, combining spatial and energetic benefits and conveying the core concept of efficiency. Gaspari et al. (2013) have suggested that these systems can also be considered in a retrofit as an addition to the existing building, operating as a formal requalification, as shown in phase A.

In the last part of verification of the design strategies for the re-building intervention, it comes advantageous to highlight some interesting data (Figure 8):

- The percentage of dwellings with cross ventilation is 100%;
- The orientation of the lounge/solar-greenhouse system is 89.4% to South, 7.4% to East and 3.2% to West;
- MUTU urban density is 89 dwellings per hectare;
- The shape ratio S/V (gross external building surface/indoor heated volume) is 0.3, meaning a high compactness and limited dispersions;
- The percentage of green areas (courtyard and green roofing) related to the building footprint is 25.3%;
- The gross average size of the dwellings is 87 m^2 (solar greenhouses excluded), suited to the average family members of social housing lodgers.

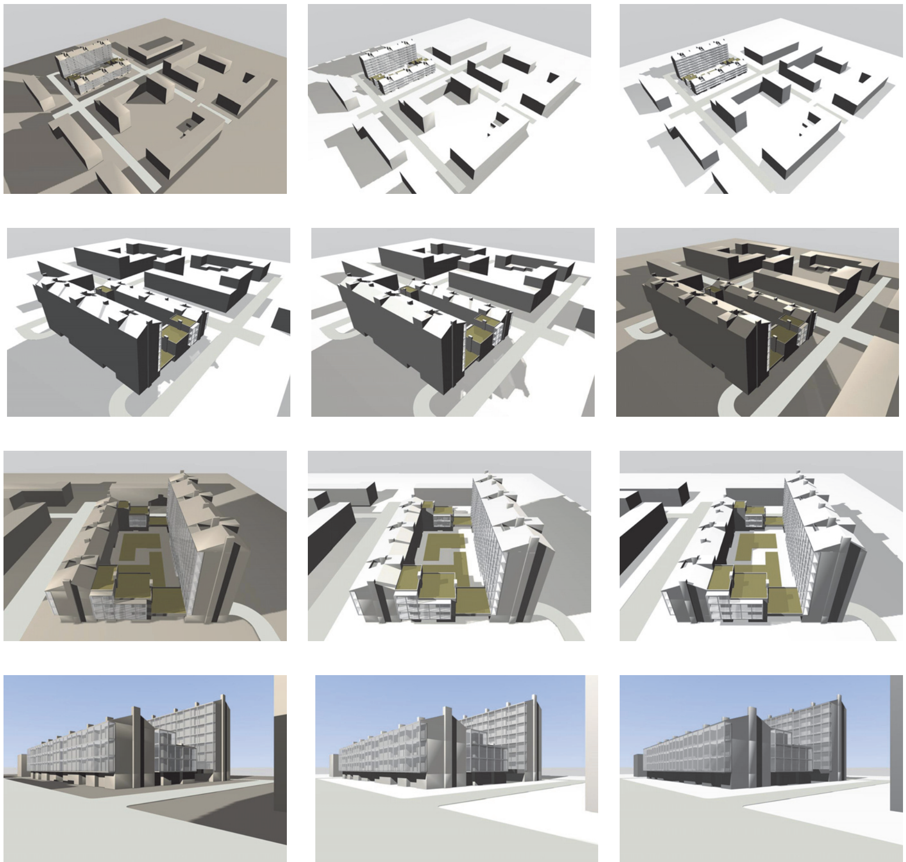

Figure 8. Phase-B shadow analysis, summer solstice, equinoxes, winter solstice.

4. Conclusions.

The comparison of the two hypothesis shows that the building substitution costs seven times more than a retrofit. It is clear that the gap between the interventions is very marked, but long-term considerations should be given. Besides the costs of a phase-A retrofit, it is relevant noticing that the building is already thirty years old (1981) and will require higher and not proportional costs of ordinary and extraordinary maintenance in the close future. Plus, the functional criticality still remains and will require further expenses to re-partition the dwellings. Finally a long-term assessment points out higher maintenance costs for a building still with some criticalities.

On the other hand the phase-B hypothesis generates a new building in compliance with current standards and regulations, with little management costs and irrelevant ordinary and extraordinary maintenance costs.

High environmental and functional quality and the resetting of energy consumption complete the profile of advantages of a building substitution operation. This extreme solution provides new tools in the regeneration process of buildings, enhancing its efficacy beyond mere energy questions (Figure 9).

RENDIMENTO DELL'AGGREGATO URBANO - PEEP Terranova-Arezzo				
efficientamento energetico vs sostituzione edilizia	FASE A		FASE B	
	min	max	min	max
INDICATORI TECNOLOGICI				
SISTEMI ATTIVI				
IT.1a: superficie captante inclinata totale (mq)	910		845	
IT.2a: potenza FV teoricamente disponibile (kWp)	130	182	121	169
IT.3a: produzione annua totale ragguagliata (kWh)	135.390	189.547	130.371	182.520
IT.4a: potenza FV ad alloggio (kWp)	1,4	2	1,3	1,8
IT.5a: produzione annua ad alloggio (kWh)	1.456	2.038	1.387	1.942
IT.6a: potenza FV per ettaro (kWp)	141	198	114	159
IT.7a: produzione annua per ettaro (kWh)	147.164	206.029	122.992	172.189
SISTEMI PASSIVI				
IT.1p: superficie captante verticale totale ragguagliata (mq)	1.465		2.846	
IT.2p: superficie captante media per alloggio (mq)	16		26	
IT.3p: superficie captante per ettaro (mq)	1.382		2.345	
ELEMENTI DI FORMA				
URBANA				
EF.1u: unità minima tipologica urbana - UMTU	esistente		isolato chiuso + dotazioni urbane al contorno, lati 110,5 x 96	
EF.2u: impronta urbana, *urban footprint* (Ha)	1,06		1,06	
EF.3u: capacità insediativa - densità (alloggi/Ha)	88		89	
EF.4u: diritto di captazione; A: sup. attive, P: sup. passive				
ARCHITETTONICA				
EF.1a: unità minima tipologica edilizia - UMTE	linea + ballatoio		linea + ballatoio	
EF.2u: impronta edilizia, *building footprint* (Ha)	0,215		0,215	
EF.3a: totale alloggi (n°)	93		94	
EF.4a: totale piani fuori terra (n°)	4	6	4	8
EF.5a: superficie totale lorda residenziale (mq)	7521		8.217	
EF.6a: superficia media lorda alloggi (mq)	81		87	
EF.7a: superficie totale lorda P.T. a negozi e servizi (mq)	104		2.145	
EF.8a: volume totale lordo (mc)	25148		34.452	
EF.9a: superficie totale disperdente (mq)	8312		10.415	
EF.10a: rapporto di forma - S/V (indice)	0,33		0,30	
EF.11a: tipologia di copertura	capanna a colmo traslato / copertura piana		capanna a colmo traslato / tetto giardino	
EF.12a: inclinazione di falda, *tilt* del FV integrato	20° (37%)		20° (37%)	
EF.13a: volume serre solari (mc)	4162		4.765	
EF.14a: aggetto serre solari (m)	1,5	3,6	1,50	2,50
VALUTAZIONE ECONOMICA:				
VA.1: stima di costo dell'intervento	2.300.000	2.645.000	16.000.000	18.400.000
VA.2: rapporto di costo fase A/fase B	ca. 15% della fase B		ca. 7 volte la fase A	
DATI CLIMATICI:				
località	Modena (Italy)			
gradi giorno	2.258			
latitudine	44°39'24'' N			
longitudine	10°55'12'' E			
altezza solare (azimut) al solstizio estivo	68°			
altezza solare (azimut) agli equinozi primaverile ed autunnale	45°			
altezza solare (azimut) al solstizio invernale	22°			
Radiazione globale annua sulla superficie orizzontale (kWh/mq)	1430			

Figure 9. Comparative table of performance for phase-A and phase-B.

It is relevant to notice that the sun-exposed vertical surfaces (solar greenhouses) in the B hypothesis are double than in phase-A. This is important for two reasons:

- A good design strategy focuses its actions on maximising the greater well oriented and sun-exposed vertical surface (solar greenhouse);
- A solar design strategy provides every dwelling with an external space (solar greenhouse) that has a bioclimatic/energetic and functional avail.

These considerations confirm that greater importance should be given to passive systems: they combine environmental comfort and functionality together with a formal and architectural component. These features still remain valid in a Zero-Energy perspective, that will dictate in the next future a reconsideration of the building skin efficiency and its integration with renewable-sources energy-production systems. Furthermore the goal of achieving a Plus Energy Building still remains primary in order to compensate the average inefficiency of the existing building stock.

A strategy for a building energy retrofit cannot exclude the adoption of active surfaces to reduce the electric needs from the grid: this strategy can be associated to a process of addition of volumes or devices for thermal gains when the boundary conditions are favourable (orientations, sun exposure, surrounding buildings...). When a building substitution is possible, it is advantageous that the design concept is aimed to maximise the sun-exposed and well-oriented vertical surfaces to apply passive thermal-gaining devices, better if solar greenhouses.

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