LOW3 – A MEDITERRANEAN NET ZERO ENERGY BUILDING

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ABSTRACT

The LOW3 (low energy – low impact – low cost) prototype developed by UPC-Barcelona Tech for the Solar Decathlon Europe 2010 competition is a energy self sufficient solar house based on three main principles: a *low energy* demand, a *low impact* on environment and a *low cost* architecture with a strong focus on the economy of means.

LOW3 explores the thermal capacity of intermediate spaces in contributing to a low energy architecture as well as it explores spatial qualities, creating in-between spaces for innovative ways of living.

The first building shell of LOW3 is based on an industrialized greenhouse structure with a lightweight polycarbonate skin, optimized in its bioclimatic performance through openings for cross ventilation, shading devices, vegetation, an evaporative cooling system and integrated solar systems. As a *microclimatic skin* it modifies the thermal behaviour of the interior, where a highly insulated, minimum housing unit of 42 m2 is located.

Whereas the interior housing unit is actively conditioned through a radiant heating and cooling system and a ventilation system with heat recovery, the intermediate space of LOW3 is designed to create comfort conditions exclusively through passive strategies.

The bioclimatic mechanisms of LOW3 work well, although temporary overheating of its upper intermediate spaces cannot be avoided solely through passive strategies. Thermal simulation programs shows difficulties in their performance prediction of this spaces mainly due to unpredictable and generally high ventilation rates. Monitoring results of LOW3 obtained during the competition in June 2010 in Madrid and since January 2011 at Sant Cugat del Vallès (Barcelona) confirm their good thermal performance.

Through the analysis of its bioclimatic performance, energy efficiency, space quality and cost aspects LOW3 contributes to the knowledge generation in the field of Mediterranean *net zero energy buildings*.

LOW3 actually starts working as a *LIVING LAB* platform for sustainable architecture at the UPC-Barcelona Tech Campus in Sant Cugat del Vallès (Barcelona) with an ongoing research and evaluation agenda.

KEYWORDS

Solar Architecture, Net Zero Energy Building, Intermediate Spaces, Bioclimatic Architecture, Passive Solar Design, Integrated Solar Technologies

1. INTERMEDIATE SPACES IN DOMESTIC ARCHITECTURE

Intermediate spaces in housing are an issue as long as architecture exists. The transitional spaces between interior and exterior are defined through their special qualities in the field of light, temperature, as well as visibility, privacy and security. In terms of energy demand and building comfort, intermediate spaces have a long tradition in domestic architecture. One of the first bioclimatic elements was the south orientated porch with a roof overhang as shading device like the solar house described by Socrates around 400 B.C.(Figure 1) [1]

With the availability of glass as building material, closed *sunspaces* like the glazed galleries of the *Pescadia* at La Coruña (Figure 2), dated in the 18th century, found their way into domestic architecture. Later on, experimental housing projects like *The growing house* (1932) by Martin Wagner (Figure 3) or the *Regensburg housing* units (1982) by Thomas Herzog (Figure 4) explored intermediate spaces as energy saving means as well as functional elements in the residential building sector. [2]

From the 1990's on concepts for low energy architecture like *Passive House* or *Minergie* buildings questioned the energetic function of *sunspaces* whereas solar technologies got integrated more and more into the building skin.

Fig 1: Socrates

Fig 2: Pescaderia

Fig 3: Martin Wagner

Fig 4: Thomas Herzog

The LOW3 (*low energy – low impact – low cost*) prototype, is a energy self-sufficient solar house or *net zero energy building* based on three main principles: a *low energy* demand, a *low impact* on environment and a *low cost* architecture with a strong focus on the economy of means.

As an experiment it explores the conversion of a standard agriculture greenhouse into a microclimatic building skin which creates intermediate spaces as well as it integrates active solar technologies.

2. THE LOW3 PROTOTYPE SOLAR HOUSE

Today's flexible and changing social constellations in our society, new ways of living and working, as well as frequent changes of use led the UPC team to explore a alternative, growing housing concept based on modularity in space, structure and installations, as well as the combination of interior highly insulated housing modules with a lightweight microclimatic building shell. The resulting intermediate spaces enrich the spatial concept of LOW3 and create through their bioclimatic optimization additional useful space and volume for the occupants.

The main 3 concepts of LOW3 are:

LOW ENERGY: Passive solar architecture and effective bioclimatic design minimises the energy demand of the LOW3 house.

LOW IMPACT: The use of sustainable and reusable materials allows minimizing the environmental impact of the project in construction and during use. LOW3 aims to fulfil the important objective of closing the water and material life cycles.

LOW COST: Low-cost and low-tech solutions together with dry construction methods allow a modular and quick assembly, converting a green house structure into an innovative solar housing concept.

The sequence of interior, intermediate and exterior layers creates singular and special living spaces.

Fig.5: General view LOW3 south facade

Fig. 6: Interior view LOW3

The bioclimatic design prolongs the period of time the occupants can enjoy the intermediate spaces of their house at zero cost and zero energy, doubling the available space of the dwelling. For the cost of one house, they obtain another intermediate dwelling space.

2.1 BIOCLIMATIC CONCEPT OF LOW3

The microclimatic building skin of LOW3 employs a standard industrialized greenhouse structure, based on galvanized steel profiles and polycarbonate panels as skin. The polycarbonate panels used, specially treated for resistance against UV radiation, have a thickness of 10 mm with 4 layers (3 chambers) and a U-value of 2.8 W/m2K with a visual light transmission of 42% and a solar factor of 0.52 for white or “opale” modules, and a visual light transmission of 72% and a solar factor of 0.77 for translucent or ”cristal” modules. Constructive detailing allows an elevated air-tightness of the building shell in comparison with standard agricultural green houses. (Figure 7)

Fig.7: General view LOW3

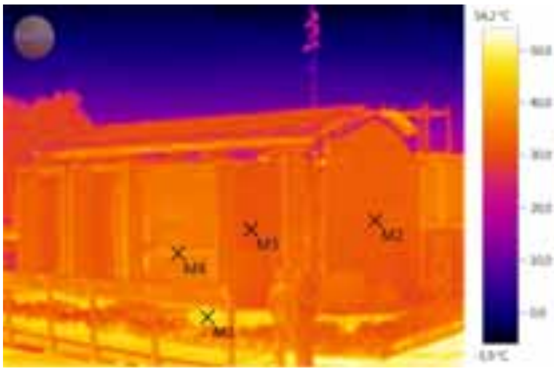

Fig. 8: Thermo graphic image LOW3

Through basic bioclimatic mechanisms, mainly adapted from the agricultural sector like movable sun protections, evaporative cooling, cross ventilation through extensive openings and passive solar use, the intermediate space can be thermally regulated and its period of use expanded during the year without any kind of additional energetic or economic cost. Figure 8 shows a thermo graphic image of LOW3 indicating surface temperatures of the outer building shell.

The dwelling space expands towards the intermediate space, when its climate conditions meet the comfort requirements for a certain activity or uses. Every façade or roof segment contributes through its design and function to this objective.

2.2 INNER LIVING MODULES

The inner living modules of LOW3 form the minimum housing unit of 42 m2, basic requirement of the competition. 3 living modules and 1 wet module, containing bathroom, kitchen and all main installations of the prototype, are placed strategically inside the greenhouse, taking advantage from the generated microclimate and other services like solar hot water and electricity generation of the microclimatic building shell. (Figure 9)

The living modules consist of a micro laminated wood structure and OSB board cladding and are highly insulated through 20-25 cm of wood fibreboards and cellulose with an overall U-value of 0.15 W/m2K and an elevated air-tightness.

Fig.9: Floor plan of LOW3

Fig. 10: Kitchen module with direct access from intermediate spaces

Small window openings and one main access door at the north side contrast with the complete glazed south façade.

As Figure 10 shows, the kitchen module opens to the intermediate space, allowing evacuating internal thermal loads from cooking as well as access to the wet module from outside, turning it into the core of the house and a shared infrastructure for different constellations of use.

2.3 SOUTH FAÇADE

The south façade of the LOW3 prototype is designed to convert from a closed translucent collector façade into an open porch of the house. 3 of its 4 façade segments allow being opened through folding doors. Automated sunscreens protect the intermediate and interior spaces from excess of direct solar radiation. The screens, composed of resistant glass fibre, have a solar transmission value of 7% and a visible light transmission value of 8%. (Figure 11)

The façade segment corresponding to the "wet" module, containing bath and kitchen, consists of a façade integrated solar flat plate collector of 7,2 m2 which due to its vertical integration and dimension allows to achieve a solar fraction for domestic hot water of 87,3%. (Figure 12)

The combination between opened or closed façade as well as opened or closed sun screens, allows to convert the greenhouse from a open and ventilated shading roof into a closed buffer space which captures solar energy.

Fig 11: South façade open with shading device

Fig. 12: South façade closed

Direct solar radiation can be captures by the inner living modules in winter, whereas in summer glazed areas of the inner modules are consequently shaded through the geometry of the construction.

2.4 SOUTH ORIENTED PITCHED ROOF SEGMENT WITH BACK-VENTILATED PHOTOVOLTAIC INSTALLATION

LOW3 integrates a 4.2 kWp photovoltaic installation with an annual production of 6.000 kWh of electricity to provide energy self-sufficiency for the house. In accordance to the principles "LOW cost" and "LOW impact" standard polycrystalline PV technology has been used.

The PV modules are integrated into the roof structure using a galvanized steel framework creating a double skin which allows free circulation of air through a gap of 20 cm between inner polycarbonate roof cladding and PV array.

The photovoltaic installation is oriented south with an inclination of 19º, close to the optimum. The PV array shades the south oriented roof surface and avoids overheating of the intermediate space below. By having a high degree of back ventilation through a natural stack effect, heat is carried away, allowing modules to work nearer to their optimum temperature and efficiency.

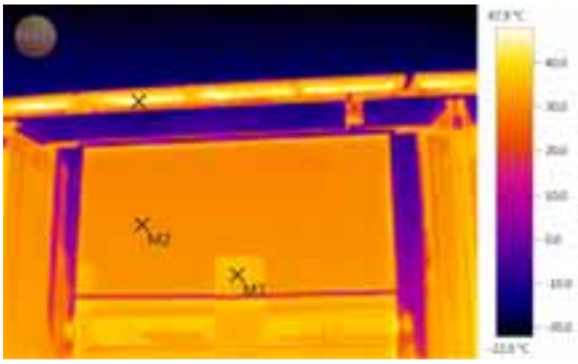

Fig.13: Thermo graphic image solar installations

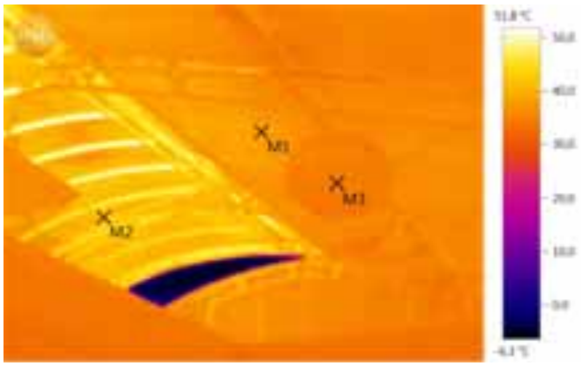

Fig. 14: Thermo graphic image roof construction

Figure 13 shows the elevated temperature of the PV array (M1=46.5ºC) whereas figure 14 shows a significantly lower inside surface temperature of the south roof of (M1=37.7 ºC).

PV modules are organized in strings of 6, thus allowing an easy modular preassembly on the ground and an efficient roof installation with electrical connection points in the lower part of the roof accessible from the façade. Back ventilation evacuates higher thermal loads caused by the PV array.

2.5 NORTH ORIENTED ROOF SEGMENT WITH OPENING MECHANISM FOR CROSS VENTILATION

The north part of the roof consists of a curved polycarbonate surface on metal substructure, with a standard green house opening mechanism, based on one central single phase motor and a horizontal mechanical axe which allows very slow lifting and closing of the whole roof segment. A movable outer shading device would be the most effective strategy to prevent overheating. Inside, easy accessible and movable solar protection has been planned. In combination with an opened roof and a cross ventilation, heat evacuation has been considered to be sufficient, as well as easy maintenance is assured. Due to technical reasons this shading devices have not been installed during the competition week in Madrid, leading to higher thermal loads through incident solar radiation. Figure 14 shows the thermal performance in general and the difference of inner surface temperatures between the two roof segments.

2.6 NORTH FAÇADE

The north façade of LOW3 consists of fix polycarbonate cladding only interrupted by small window openings and a door. A 20 cm air gap between inner living modules and outer building shell allow all main installations between modules to be placed, easy accessible from the outside. No shading device is foreseen, thermal loads are evacuated through the roof opening above.

2.7 EAST AND WEST FACADES

East and west façade consist of fixed white polycarbonate cladding without openings. Outer solar protection, through a back-ventilated textile sunscreen have been foreseen to mitigate the high quantity of undesired solar radiation at morning and evening hours in summertime, but due to technical reasons could not be mounted during the competition week in Madrid.

2.8 ACTIVE MECHANISMS FOR CLIMATE CONTROL

Besides the mentioned roof and facade openings, movable and fixed sunscreens, or bioclimatic optimization of the prototype, a row of active mechanisms contributes to the viability of the concept. Temperature Sensors at different spaces of the prototype, sensors for relative humidity, as well as a meteorological station, send their data to a building management system, which controls automatically shading devices as well as the roof opening or adiabatic cooling devices, to optimize the microclimatic building shell and its contribution to the overall energy performance and comfort of the prototype. (Figures 15 and 16)

Fig.15: Building Control system and sensors

Fig. 16: Microclimatic building skin with opened roof

At the intermediate space an evaporative cooling system has been installed especially for the competition week in Madrid, due to the effectiveness of adiabatic cooling at the dry summer climate there.

3. THERMAL DYNAMIC BUILIDNG SIMULATION OF LOW3

For the thermal dynamic simulation of the prototype in the pre-competition stage the program Bioclim with the simulation motor Comfi has been used to analyze and optimize the thermal performance especially in the field of its bioclimatic mechanisms. At the post-competition stage actually DesignBuilder and EnergyPlus are used for a more exact evaluation of the prototype and a comparison between simulated and real building performance.

3.1 BOUNDARY CONDITIONS, LIMITATIONS OF THE PROGRAMMES

Due to the special concept of intermediate spaces of LOW3 and certain limitations of the Bioclim program, it was not possible to simulate winter and summer conditions within one unique building model, as the exterior skin transforms from a closed translucent facade in winter into a almost dematerialized shadow spending roof with wide openings at the south façade as well as at the roof in summer. As a result, the summer simulation was realized considering the outer building shell almost totally inexistent, a boundary condition that does not correspond exactly to the prototype.

3.2 RESULTS OF BUILDING SIMULATION

Building simulation showed that through an optimization of bioclimatic features (Figure 17) like shading devices, cross ventilation and evaporative cooling, intermediate spaces could be prevented from overheating in summer, maintaining inside air temperature almost at the level of outside air temperature. Together with the protection of the interior living modules from direct solar radiation, this leads to a calculated annual overall cooling demand of around 70 kWh/m2/y (Bioclim) and 30 kWh/m2/y (EnergyPlus), considering 22-25ºC air temperature as comfort condition.

A maximum cooling power of 2.500 W resulted to be necessary to maintain comfort conditions inside the living modules during summer.

Fig.17: Bioclimatic features of LOW3

For the winter case, intermediate spaces work as a greenhouse with a high absorption of solar radiation mainly through the south facade and a corresponding rise of the air temperature up to 35-40 ºC during sunny winter days. Due to the relatively good air tightness and U-value of 2.8 W/m2K of the polycarbonate building skin, roof or south façade must be opened to prevent overheating.

During the day intermediate spaces can be used at comfort conditions, inner living modules can be opened or generated hot air can be used for the mechanical ventilation system. At night intermediate spaces work as buffer space, reducing the heat losses of the interior living modules, maintaining their temperature slightly above outside temperature.

Both programs calculated an annual overall heating demand of 15 kWh/m2/y, with a maximum heating power of 2.000 W necessary to maintain comfort conditions inside the living modules in winter.

3.3 CRITICAL DEBATE OF RESULTS

Results of the Bioclim simulation helped to compare and define basic strategies of bioclimatic mechanisms within the LOW3 project at an early design stage. Nevertheless due to the use of complex intermediate spaces, difficult to be simulated correctly especially for the summer case with high cross ventilation rates, more sophisticated simulation tools like EnergyPlus led to more detailed and adjusted results.

In a third stage simulation results will be analyzed critically and compared to field measurements of LOW3 over a period of 2 years at Barcelona Tech. Only this feedback through performance evaluation under real conditions and through a longer period will allow to describe the capacity of building simulation tools like Bioclim or EnergyPlus in the performance prediction of complex intermediate spaces.

4. BUILDING PERFORMANCE IN MADRID – JUNE 2010

During the competition week from 17^{th} to 25^{th} of June 2010, different monitoring activities were carried out at the LOW3 prototype. The SDE organization realized measurements of the interior air temperature at two different zones of the building, the main living room and the subsidiary area or bedroom. The LOW3 team installed data loggers type TESTO 175-T2 and TESTO 175-H2 in the inside of the living area as well as in the intermediate spaces of LOW3 to monitor the thermal behaviour of the building during the competition. Ambient air temperature of the *Vila Solar* was given by the organization.

4.1 BOUNDARY CONDITIONS

The LOW3 prototype was located at the north end of the *Vila Solar* (lot Nº2) near the "Kings Bridge" with a direct south orientation and without any significant shading from the surrounding. Due to the deadlines of the competition, fixed exterior sunscreens at the east and west façade of the prototype as well as interior sunscreens under the northern roof segment could not be mounted. This resulted in a considerably higher thermal impact of incident solar radiation during the day, getting the thermal comfort conditions to its limits.

The roof opening of the prototype was limited due to the competition regulations regarding the maximum height of the building, resulting in a limitation of the cross ventilation.

Another important aspect were the frequent public visits to the house, resulting in an non optimized use of shading devices, and additional inner heat loads. Also the evaporative cooling system described did not work constantly due to technical problems of the pump, reducing its contribution to a moderate micro climate.

4.2 RESULTS OF MEASUREMENTS

Figure 18 shows the air temperature performance of the lower intermediate space (main terrace) and upper intermediate space (upper floor) in comparison to the outside air temperature and interior air temperature inside the living modules during the competition week in Madrid.

Analysing the critical moments of midday and afternoon hours, for the upper intermediate space (upper floor) a 2-3 ºC higher air temperature than the exterior air temperature can be stated, due to the mentioned boundary conditions mentioned in 4.1.

On the other side the lower intermediate space (shaded terraces) benefits naturally more from the stack effect and cross ventilation, as well as from the evaporative cooling mechanism, resulting in a of 2-3 ºC lower air temperature in comparison to the exterior temperature during the competition week.

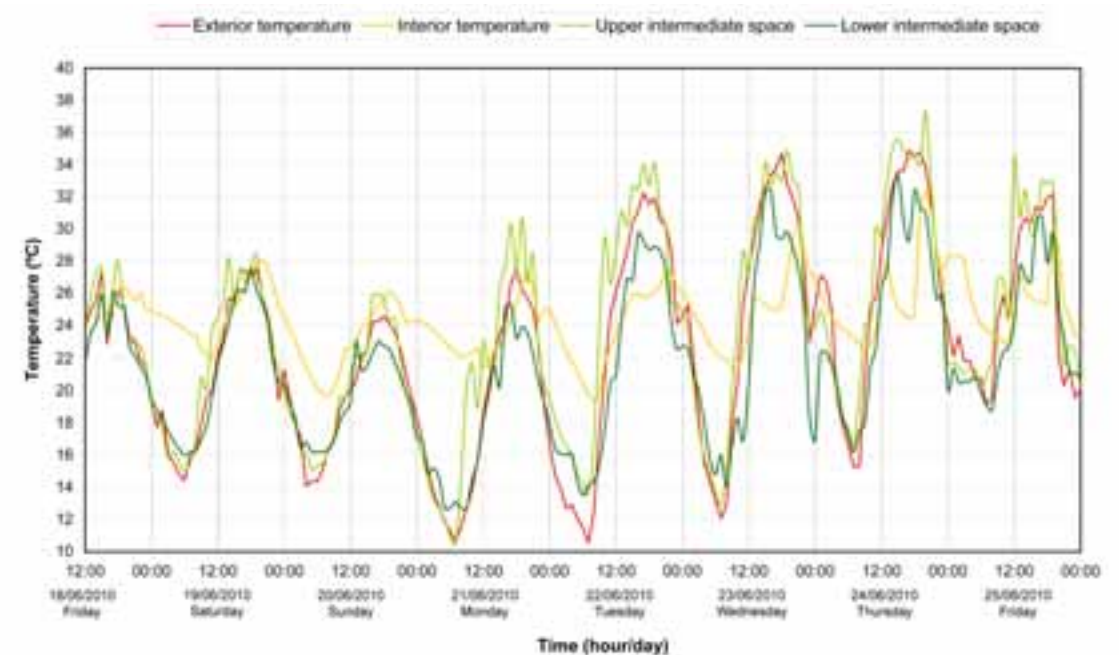

Fig.18: Measurements competition week in Madrid, June 2010

The inside temperature shows strong variations due to the circumstance that the living modules were totally opened during large periods of the day for public visits.

4.3 CRITICAL DEBATE OF RESULTS

The measurements carried out in Madrid show a slightly higher air temperature in the intermediate spaces of LOW3 than the thermal dynamic simulation predicted. This seems to be mainly caused by the not optimized realization of the prototype as well due to a not optimized utilization and performance of the bioclimatic mechanisms as described in 4.1. A significant improvement can be expected, once all designed bioclimatic features of LOW3 are correctly installed and managed by the building management system.

5. SUBJECTIVE PERCEPTION OF THE INTERMEDIATE SPACES IN MADRID

Besides thermal dynamic simulation and the monitoring of the prototype during the competition week, a more subjective and personal evaluation of the quality of the created intermediate spaces is important to complete this first evaluation.

5.1 SPACE QUALITY

The intermediate spaces of LOW3 have been explored by the international jury of the architecture contest of SOLAR DECATHLON EUROPE, Glenn Murcutt, Louisa Hutton and Patxi Mangado, which stated in their final verdict that these spaces in LOW3 are *useful as well as poetic*, and traditionally a very important feature in the transition between interior and exterior in Mediterranean architecture. The flexibility for different uses of these spaces, created through the use of a low-budget, off-the-shelf greenhouse where another reason for the jury to give a first prize in this category to LOW3.

Figure 20 shows the transition between interior, intermediate and exterior spaces at the ground floor of LOW3.At the same time, the availability of a second floor showed to be useful as space for storage, horticulture, relax or especially for social events, offering another "free" 45 m2 of very special quality. (Figure 21)

Fig.20: Lower floor space LOW3

Fig. 21: Upper floor space LOW3

5.2 COMFORT CONDITIONS

The terraces of LOW3 as well as the upper floor space showed to be attractive areas during the competition week in Madrid. The entrance of visitors from the outer terrace into the covered and protected greenhouse space at the south façade was generally perceived as a significant improvement in terms of thermal comfort. The upper floor space was perceived as a fresh, ventilated area with its very special character between inside and outside, making higher air temperature acceptable. Only during the 3 hot and sunny days at the end of the competition week, and especially between 14.00 and 20.00 hours, the thermal conditions were perceived as "at the limit" or uncomfortable, with temperatures temporarily above 33ºC.

5.3. EVAPORATIVE COOLING AND CROSS VENTILATION STRATEGY

The evaporative cooling system was installed on a stop and go basis, as its continuous function would have resulted in an elevated consumption of fresh water. The subjective perception could be described as a temperature drop of 3 to 5 degrees when water was dissipated nearby. In combination with shading devices as the south façade and a constant cross ventilation of the building, the greenhouse terrace spaces offered good comfort conditions during the whole competition week.

6. NET ZERO ENERGY BALANCE

LOW3 can be considered as a *Net Zero Energy Building* as the amount of energy generated through renewable energy sources on-site, in this case through solar thermal and solar photovoltaic systems, is equal to the amount of energy the building needs throughout the year as residential unit for 2 to 3 persons. With a PV electricity production of 6.000 kWh/y and a solar thermal production of 2.850 kWh/y this balance is made for the average calculated energy demand of the unit and does not include the embodied energy of materials or the energy needed for construction.

7. GLOBAL RESULTS

The intermediate spaces of LOW3 show to be useful, economic and energetically efficient. Nevertheless their bioclimatic performance has to be designed carefully to prevent overheating and reduce undesired heat loads on the building, although their definition as temporary spaces includes the acceptance of temporary discomfort.

The monitoring results of the competition week are giving a first impression of the performance of LOW3, but further evaluation is undergoing to quantify the thermal contribution of its intermediate spaces to the overall energy performance of the prototype.

Industrialized steel construction and low cost technology from the agriculture greenhouse industry offer an economic way of creating intermediate spaces for new constructions as well as for refurbishment projects.

8. CONCLUSIONS

The exploration of alternative housing programs mainly based on shared facilities, co-housing, or adaptive housing typologies gives a special meaning to intermediate spaces as community, connection and temporary areas in housing.

Intermediate spaces within innovative housing concepts like LOW3 are therefore relevant to be explored regarding their economic characteristics, their energetic performance and their spatial qualities, following a large tradition in domestic architecture.

The potential activation of intermediate spaces through a combination with geothermal systems or heat recovery and air preheating for interior spaces are further interesting aspects to be explored in the field of energy efficiency on the way towards net zero energy buildings in Mediterranean climates.

LOW3 will be monitored and evaluated during 2011 and 2012 as *Living Lab* for energy efficiency and sustainable architecture at the ETSAV School of Architecture at its Campus Sant Cugat and will hopefully contribute to this important field of research.

ACKNOWLEDGMENTS

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