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Summer Comfort in Exposed Concrete Free Running Buildings

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Abstract

The paper deals with a research carried out within the project CASA "Comfort for sustainable housing in the Alps", concerning the definition of an integrated rating system of inner comfort from a thermal, visual, acoustic and IAQ point of view. A preliminary phase of the project is presented, regarding the evaluation of a free running single building made of two distinct parts: a prevalent E-W body with exposed concrete envelope and a timber element intersecting the first one. The main aim is to investigate which complex wall solution better resolves thermal comfort parameters evaluated during a significant summer week period, time of execution and costs.

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Keywords: Inner comfort, adaptive comfort, exposed concrete envelope, free running building, dynamic simulation, thermal bridges

1. Introduction

Researches and technical applications on sustainability in the building sector usually concerns energy saving and system efficiency issues. In the last 40 years regulations focused mainly on the building-plant system and, also thanks to considerable investment in research, led to the creation of a body of law and standards that serves as reference and guide for more accurate thermal analysis of buildings in both winter and summer. At a closer look, European Directive 2010/31/EU [1], known as "Near Zero Energy Buildings", together with the definition of a common general framework for a methodology for calculating the integrated energy performance of buildings and a system for their certification and rating, pays attention on two important issues concerning a wider and more integrated concept of energy and environmental sustainability: the importance of passive and natural systems for heating, cooling, ventilation and

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lighting; occupants' comfort conditions, both thermal, visual, acoustic and IAQ. In particular, this last topic is indeed tied to the energy one, but it has been often neglected assuming that an energy efficient building always allows comfortable living conditions.

In this context, the scientific project CASA, which stands for "Comfort per l'Abitare Sostenibile nelle Alpi" (Comfort for sustainable housing in the Alps), has been conceived. The main purpose of the project is the definition of a rating system of the environmental comfort from a thermal, visual, acoustic and internal air quality point of view, integrating all these aspects and leading to the evaluation of the components parameters showing direct influence on the building thought as organic entity. The analysis and validation of the results are conducted via numerical simulations and with on field real time measurements on actual buildings designed to be an open air laboratory. These buildings present same shape, geometry and exposure, but different construction materials and bearing structure (timber, masonry and concrete). Some changes to the finishing or smaller portions of the building could be implemented during the monitoring phases of the project to test other possible solutions.

This paper presents a preliminary phase of the project regarding the evaluation of a free running single building made of two distinct parts: a prevalent E-W body with exposed concrete envelope and a timber element intersecting the first one. The aim of the project is to investigate which complex wall solution better resolves thermal comfort parameters evaluated during a significant summer week period, time of execution and costs.

2. Methodology

In order to better define the concrete building envelope, the first step of the research has been a careful bibliographic review of recent buildings with exposed concrete facades, followed also by construction sites visits. Besides thermal and energy aspects, in fact, difficulties concerning the construction phase have been taken into consideration, particularly the concrete casting and the system installation. Two different envelope typologies have been identified (see section 3.1) for which a proper definition of the elements connection has been deeply investigated. Thermal bridges have been evaluated with a finite element software (Comsol Multiphysics) following standard UNI EN ISO 10211:2008 [2]. Each technical and construction detail has been designed and integrated. In particular, the wall solutions have been tested according the UNI EN 15026:2008 [3] procedure with the dynamic software WUFI (Wärme un Feuchte Instationär). This approach takes into account water filtering via diffusion and capillarity through the wall from inside to outside and vice versa. Once all the details have been tested and approved, a building thermal model has been designed for Energy Plus computation. The engine is able to count, for each thermal zone, the hours wherein the operative temperatures violate a particular category of the adaptive comfort theory as defined in the UNI EN 15251:2008 standard [4]. Two different analysis have been performed for each envelope typology. Results have been analyzed with Wolfram Mathematica.

3. The design of the building under investigation

The building under investigation is free running made of two volumes: a single level body elongated in shape, partially underground with an exposed concrete envelope both sides and a smaller two levels body with timber structure (Fig. 1). The former hosts the kitchen on one side and the sleeping rooms and the restrooms on the other. The latter acts as main entrance and hosts the living room on the ground floor, a small studio at the first floor and a double-height on the dining room that, being on the intersection of the two volumes, is the central space of the house. The timber body is characterized by wide openings while the concrete one by smaller ones, originating vertical cuts. Due to their proper position, light enters the inner spaces differently during the day. Besides, the front is rotated of 20 degrees towards SE, so after 3 pm it is no more exposed to direct solar radiation in summer. On the one hand this is useful because it prevents from possible overheating, on the other one it can cause a certain discomfort for the occupants. So, wide openings have been designed on the west façade, properly shaded with an overhanging 1 meter long.

Fig. 1 Render of the concrete building under analysis

3.1. The concrete envelope

Great attention has been paid to the envelope of the exposed concrete body. After a careful state of the art, two main solutions have been identified.

- Type 1. Inspired by the architecture of Valerio Olgiati, a Swiss architect [5], W1 presents a double concrete layer for the walls, the inner one with bearing function and a thinner finishing one on the outside, separated by an insulating material. Horizontal structures S1 are plate concrete slabs with radiant floor and insulation on the inside (so as to solve thermal bridges, see section 4.2). Roof is a green structure SG. One critical issue of this choice is the necessity of managing properly the systems that usually must be integrated in the casting. Moreover, even if it is not probably the best choice considering the LCA approach, the expanded polystyrene is one of the best material for what concern the ease of installation and the behavior in contact with moisture and water of the concrete casting. Construction phases are particularly complex and challenging: in fact, it is necessary to build the inner bearing concrete wall and, after being struck, to position the insulating material and proceed with the casting of the outer façade. The latter, having no bearing function, must have a minimum proper thickness so as to allow the cast shaking. This delicate stage is necessary since, given the exposed concrete wall, generation of air bubbles must be avoided and concrete must be as homogeneous as possible.
- Type 2. Inspired by the architecture of Miller and Maranta, Swiss architects [6], W2 is characterized by an exposed concrete façade more traditional. It counts, from outside to inside, on a concrete layer, an insulating material and a plaster board finishing. Horizontal structures S2 are plate concrete slabs with radiant floor and insulation on the outside (so as to solve thermal bridges, see section 4.2). Roof is a green structure SG. The construction of the concrete structure is simpler than the previous one, because the external envelope can be casted and the shuttering completely struck before proceeding with the inner structure.

Finally, the timber body is characterized by framed walls W3 with hemp fiber insulation and high-density wood fiber ones on the outside. Slabs S3 have the same layers but with metal corrugated sheet on the outside and ventilation layer below.

The main characteristics of the building elements are defined in Table 1.

4. Results and discussion

4.1. Thermal analysis in dynamic mode

Transient evaluation of building performance defined by UNI EN 15026:2008 is based on an advanced method of dynamic analysis of moisture transfer phenomena, taking into account hourly variation of internal and external climate conditions as well as the hygroscopic characteristics of the materials. Several phenomena often neglected in steady state analysis are considered: drying of initial construction moisture, moisture accumulation by interstitial condensation due to diffusion in winter, moisture penetration due to driving rain exposure, summer condensation due to migration of moisture from outside to inside, exterior surface condensation due to cooling by longwave radiation exchange, moisture-related heat losses by transmission and moisture evaporation.

The analysis is based on the local TRY file, while the rain deposition on a vertical surface has been considered following the BSR/ASHRAE Standard 160P [7] depending on the element exposure, the wall layers, rainfall intensity and wind speed. For each opaque element of the building envelope, water content, relative humidity, moisture flux distributions and their temporal variations has been calculated using software WUFI.

Neither of the two solutions (Type1 and Type2) presents inner or superficial condensation. Anyway, the outer concrete surface is porous and allows rainwater to seep through the superficial layers of the walls. Besides, moisture content inside the insulating layer is very low, so mold growth is limited. It's interesting to notice that a vapor barrier was initially considered following steady state analysis, while now it has been found to be damaging because it prevents moisture transfer from outside to inside, reducing the wall drying.

For what concerns slab Type2, unlike what was stated by the traditional Glaser analysis, no condensation occurs because the upper limit of relative humidity is never reached.

4.2. Thermal bridges analysis

Although the two envelope typologies have the same thermal transmittance U-value, they substantially differ concerning the constructive details, the structural joints and so the possible thermal bridges. For the sake of brevity, results of two meaningful joints are hereafter discussed.

4.2.1. Connection wall-roof

In both cases, insulation layer is continuous so the two thermal bridges are comparable, difference being around 3%. The advantage of Type2 over Type1 is mainly due to inner finishing in fibre-cement and air cavity, having a higher thermal resistance than the simple concrete layer.

4.2.2. Connection wall-ground slab

This connection is quite complex because it separates three different thermal environment: heated space (living rooms), unheated space (garage) and external environment. Besides, the garage is completely underground so the ground temperature must be taken into consideration as well.

Again, Type2 presents a building solution where the insulation layer is continuous so thermal bridges is very low, near 0.077 W/mK. On the contrary, Type1 presents a thermal bridge value higher than 0.2 W/mK because of the concrete layer continuity. In fact, the inner concrete layer (characterized by a high thermal conductivity) is continuous between the floors down to the basement spaces, where the temperature is lower. In addition to energy losses, there is the risk of superficial moisture due to low temperature profile of inner walls.

Table 1. Thermophysical properties of the elements under investigation: S thickness, M mass, U thermal transmittance, C_i internal thermal capacity, C_e external thermal capacity, f_d decrement factor, φ thermal delay factor.

Element	S *(m)*	M *(kg/m²)*	U *(W/m²K)*	C_i *(kJ/m²K)*	C_e *(kJ/m²K)*	f_d	φ *(h)*
W1	0.601	894	0.184	76.419	-	0.07	8.90
W2	0.535	590	0.178	32.651	-	0.23	11.15
W3	0.320	123	0.198	26.247	-	0.05	6.20
S1	0.485	764	0.285	13.070	58.097	0.02	10.07
S2	0.470	751	0.291	147.838	58.655	0.05	8.13
S3	0.312	67	0.210	21.453	18.335	0.16	10.64
SG	0.520	587	0.177	92.844	65.843	0.14	10.64

4.3. Comfort analysis

The building has been analyzed for what concerns occupants comfort conditions considering the two different structure configurations, Type1 and Type2. As previously stated, the building is free running so greatest attention have been paid to summer conditions. Following are the results in summertime (in particular, the central week in August when the highest daily tempertaure on the construction sites are experienced) about three rooms: kitchen, with concrete envelope and SO exposure; living room, with timber structure and SO exposure; sleeping room, with concrete envelope and SE exposure. As stressed in section 2 "Methodology", in order to control all the phases of the process and to perform a simulation as nearer as possible to true users' behavior and conditions, calculation has been made using Energy Plus and the preprocessor OpenStudio by NREL (National Laboratory of the U.S. Department of Energy). Output have been analyzed with the help of Wolfram Mathematica, a powerful and versatile tool.

4.3.1. Temperature trend

In Fig. 2 external and internal air temperature trend of Type2 is plotted as an example. In both configurations, sleeping room presents lower temperature values due to small openings and SE exposure, preventing afternoon overheating. The kitchen and the living room, both with SO exposure, present comparable inner environments. Anyway, temperature swing in the latter is higher due to the limited thermal inertia of the timber walls.

It's important to notice that Type2 building is generally characterized by higher temperatures than Type1 configuration. This is due to the different thermal mass of the inner layer of the walls, higher in Type1 (characterized by an inner layer of concrete 0.25 m thick against a double plasterboard sheet with air cavity of Type2). Inner partitions are quite different also (a concrete layer in Type1 and a lighter structure in Type2, i.e. a double plasterboard layer with hemp insulation inside), effecting the rooms environment. Slabs also have different thermal mass because of the different position of the insulation material, but this should have minor incidence because of the presence of a double concrete screed giving a similar total thermal mass.

4.3.2. Adaptive approach

The adaptive comfort theory has been applied considering a building of category II "Normal level of expectation used for new buildings and renovations", as stated in standard UNI EN 15251:2008 – Table 1. The number of hours exceeding comfort conditions has been considered as described in Annex G "Recommended criteria for acceptable deviations", recommending 5/9 hours maximum of discomfort a week during occupied period. In Fig 3 temperature trends in the analyzed rooms are plotted against discomfort limits considering category I, II and III.

It can be noticed that comfort conditions are always satisfied in spaces with concrete envelope (temperature trends are always within the category II zone, and with Type1 solution the kitchen is in category I zone). The living room instead presents 48 discomfort hours in Type2 configuration, four of which in zone IV, the worse one that should only be accepted for a limited part of the year. Inner tempertaure, in fact, suffers from high variations due to the light wooden structure of the envelope. The fact that in Type1 configuration this fact does not happen, means that also in the area of intersection between concrete and timber volumes, the massive behavior of part of the structure helps to lower summer temperature within comfort zone. So, the influence of a massive structure not only involves the spaces directly influenced by high thermal inertia, but also affects wider areas of the building.

5. Conclusions

The analysis results show a good thermal performance of concrete, demonstrating that the renewed appreciation of this material finds reasons either in its formal characteristics, and in its thermal properties. The two solutions compared in this work show both pros and cons, but Type 1 demonstrates to perform better on thermal comfort indicators (in particular, thermal performances always comply with the requirements of comfort category I zone as defined by UNI EN 15251) , which are primary on the Project CASA context. This is mainly due to the higher values of thermal mass of wall inner layers, performing a general effect also on the part of the building characterized by a lighter wooden structure. On the other side, Type 1 proves to be more complex in the definition of nodes and details, which lead to increased time of execution and greater costs. Besides, mitigation measures of thermal bridges are less effective, so Type 2 shows a better winter energy performance.

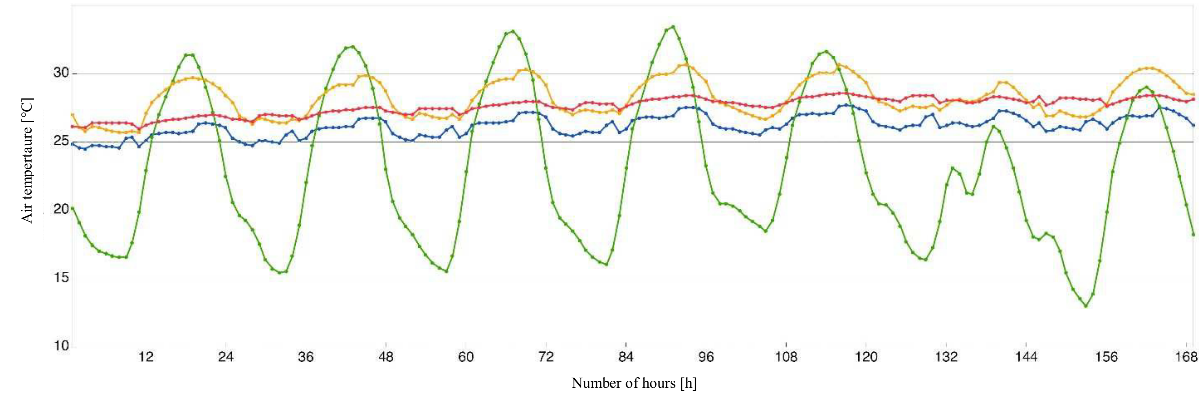

Fig. 2 External (green line) and internal air temperature trend of Type 2: kitchen (orange), living room (red), bedroom (blue)

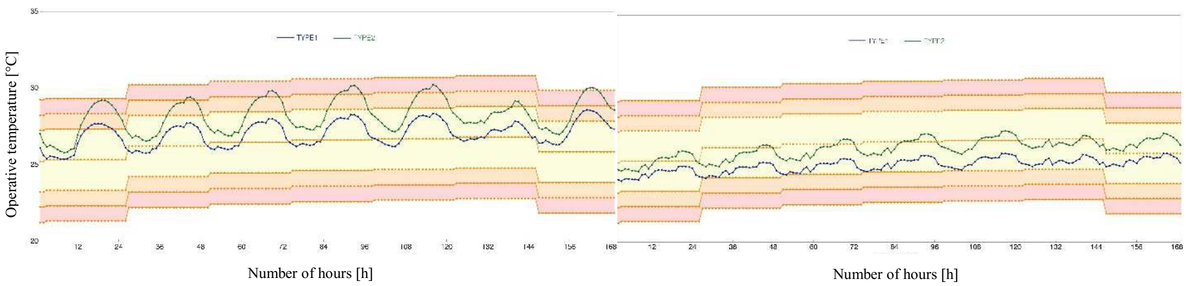

Fig. 3 Temperature trends in the living room (left) and in the bedroom (right) for Type1 (blu line) and Type2 (green line)

Acknowledgements

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