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Energetic and comfort benefits of composite buildings: Learning from vernacular techniques

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Abstract: *Most LCA studies lately have been dealing with the dilemmas which material is more energy-efficient to use: wood or steel, concrete or wood? Unlike to this perception this project takes the idea of Mediterranean vernacular architecture where it has been a tradition for long centuries to compose different – heavy and light-weight – materials in one building. We use Life Cycle Assessment and thermal numerical simulations to compare five houses, built either exclusively with one material or having both materials, either one at the ground floor and one in the first floor or one in all southern façades and the other in the northern walls. Our results show the interest of having massive and light-weight material located in two different places in the house. Especially in the Mediterranean climate it allows an optimal use of the space throughout the year.*

Keywords: Comfort zone, building materials, LCA, climate change

1. Introduction

According to European Union Directive "Energy Performance of Buildings" by 2020 "nearly Zero Energy Building" has to be a norm in all EU countries, which is a significant and ambitious challenge for all member countries [1]. However, in order to be able to propose resilient initiatives, we have to consider that energy savings have also to be combined with adaptability to climate change, as recent IPCC report shows clearly that built environment will have to face more and more frequent extreme summer heat events [2]. Fulfilling these two requirements, of a minimum energy requirement for construction and operation as well as a high adaptability to climate change, is a major goal of the European Union.

But at the same time the fact has to be faced that in order to aim energy efficiency the amount of embodied energy is growing parallel, as embodied energy can represent from 20 to 40% of the total energy consumed during the lifetime of the building [3]. Thus the perspective shifts from the energy consumed during the operation phase to the energy used to produce materials to be used in construction. The mentioned tendency can be seen in the numerous researches in the field of optimisation of material use [4].

One of the best tools to investigate this necessary balance between construction and operation of buildings is the Life Cycle Analysis (LCA) [3]. With LCA, it is possible to show the advantages and disadvantages of using concrete or wood in structures [5]. However the detailed study of Mediterranean vernacular architecture shows that materials are not used separately but rather combined at the scale of the building [6]. In the vernacular architecture of Mediterranean mountain areas – mainly former Osman territories, such as nowadays

Turkey, Bosnia, Albania, and Greece –there is a tradition of composite wood and stone buildings: the ground floor being built with thick stone walls, while the southern façade in the first floor is made with a wooden structure [7].

In the present study we investigate the effectiveness of this method used in vernacular architecture from both energetic and indoor thermal comfort point of view and we evaluate how this technique could be applied in other European regions where climate will become warmer and with higher frequency of extreme events. The objective of this paper is then to study in detail the potential interest of combining material at the house scale.

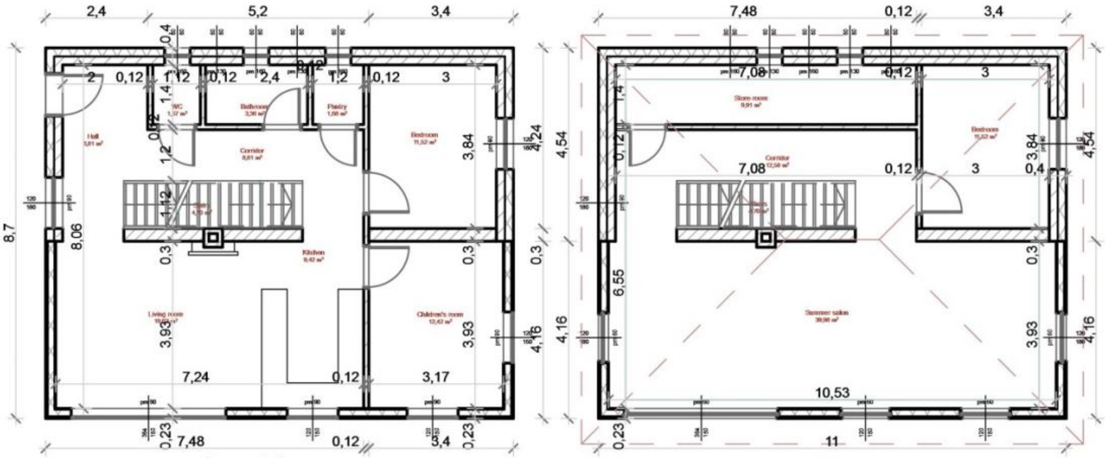
2. Methodology

2.1. Description of the house designs

In order to investigate the effects on energetic performance and indoor comfort of the usage of different materials we propose five different variants of an ideal house. The design principles for the ideal house were the following:

- to make possible flexible use and changing functions according to the seasons
- In winter, it is decided that just the ground floor will be heated.
- Buffer rooms are located to the north of the house.
- The kitchen situated in the winter zone.
- As we studied vernacular architecture, it is also decided not to use cooling system will be used.
- Openings are designed to enable natural ventilation

The design of the house is presented in *Figure 1.*



Ground floor

1st floor

Figure 1: Layout of the house. The position of the materials is changing depending on variants but not the size and organisation of the house. In this variant, North faces are made of concrete and Southern facades are of wood.

The five variants analysed from thermal comfort, energetic and LCA aspects were designed in a way to demonstrate the differences between heavy, lightweight and hybrid structures. The first and second variant (in the following Model 1 and 2) is built with the exclusive use of heavy (reinforced concrete) or lightweight structures (wood). The remaining three variants are designed with the combined use of both mentioned materials: in case of Model 3 the building envelope in the ground floor is made of insulated concrete and on 1st floor is made of insulated wood. Model 4 is using heavy materials on the north side and light materials on the south side of the house. The fifth variant (Model 3 mod.) is a modified version of the Model 3 using uninsulated wood structure in the 1st floor.

2.2. Description of heating scenarios for thermal simulation

Thermal simulations were made with Lesosai 7.4 software, using the SIA 2044 algorithm [8]. The software enables to calculate energetic performance and thermal comfort in various zones within the house. Furthermore, it provides hourly results for the whole year. Indoor comfort was defined with a loose interpretation of European norms [9,10]:

$$18°C < operative\ temperature < 27°C,$$

For simulation three heating scenarios were used on each model.

- not heated: none of the zones are conditioned. All models are investigated under free-floating conditions to see the effectiveness of passive solar heating in each model
- all heated: All zones are heated. All models were analysed in heated case also, in order to evaluate energetic performance of each variant and to have a reference for comparing comfort hours too.
- lower part heated: the idea mimics the usage of traditional dwellings, where it was common to occupy the heated downstairs part of the building during the winter and to move to the unheated lightweight structure in the upper part of the house.

In structure design three types of walls were used: insulated concrete, insulated wood, and uninsulated wood. The insulated concrete wall has 20 *cm* reinforced concrete and 20 *cm* insulation on the outer side. U-value is: 0.18 W/m^2K. Insulated wooden wall has 16 *cm* insulation so the U-value is 0.18 W/m^2K too. In the 'Model 3 mod' an uninsulated wooden structure is used which's U-value is 1.417 W/m^2K. (See *Figure 2.*)

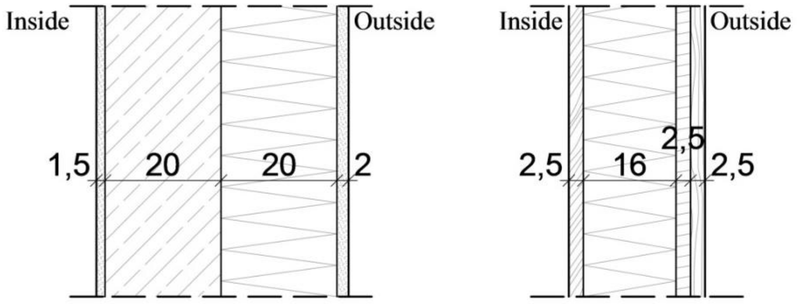


Figure 2: Layer structure of the two types of walls used in modelling

The heating scenarios listed already imply also the usage scenarios suggested. Nowadays designers consider a house usually appropriate for permanent residence, even if it is used only in a part of the year. Opposite to this concept the usage scenario we suggest, is based on the dwellers diverse expectations and habits in winter and summer. In winter inhabitants spend most of their free time indoors, so a pleasant thermal comfort is required and thinking of structures there must be a possibility of passive utilisation of solar energy. On the other hand in summer people spend most of their free time outdoors, and it is more important to provide shelter during the day and a cool indoor climate during the night. One can easily see that these two tendencies need different structures for realisation. While it is advantageous to have big thermal mass and good insolation in the winter, in summer it is more effective to have light structure in order to facilitate quick cooling after sunset. Of course that's means that zoning is needed while planning the house and different zones are used under different meteorological circumstances. One could think for the first sight that this means a loss of the really usable area of the house will see that it has also advantages. This is the idea Mediterranean vernacular architecture was based on and this is, which energetic effectiveness we should like to prove next.

For thermal simulation the meteorological data of Volos, Greece were used. If heated, heating temperature in living- and bedrooms is *20°C*. For the calculation of comfort hours the hourly results of operative temperatures were used as operative temperature represents more relevant the human comfort as air temperature. (In the case of only ground floor heated the comfort data of the non-heated case were imported for the 1st floor.) The software gives hourly results for a whole year to be able to sum up the number of indoor comfort hours.

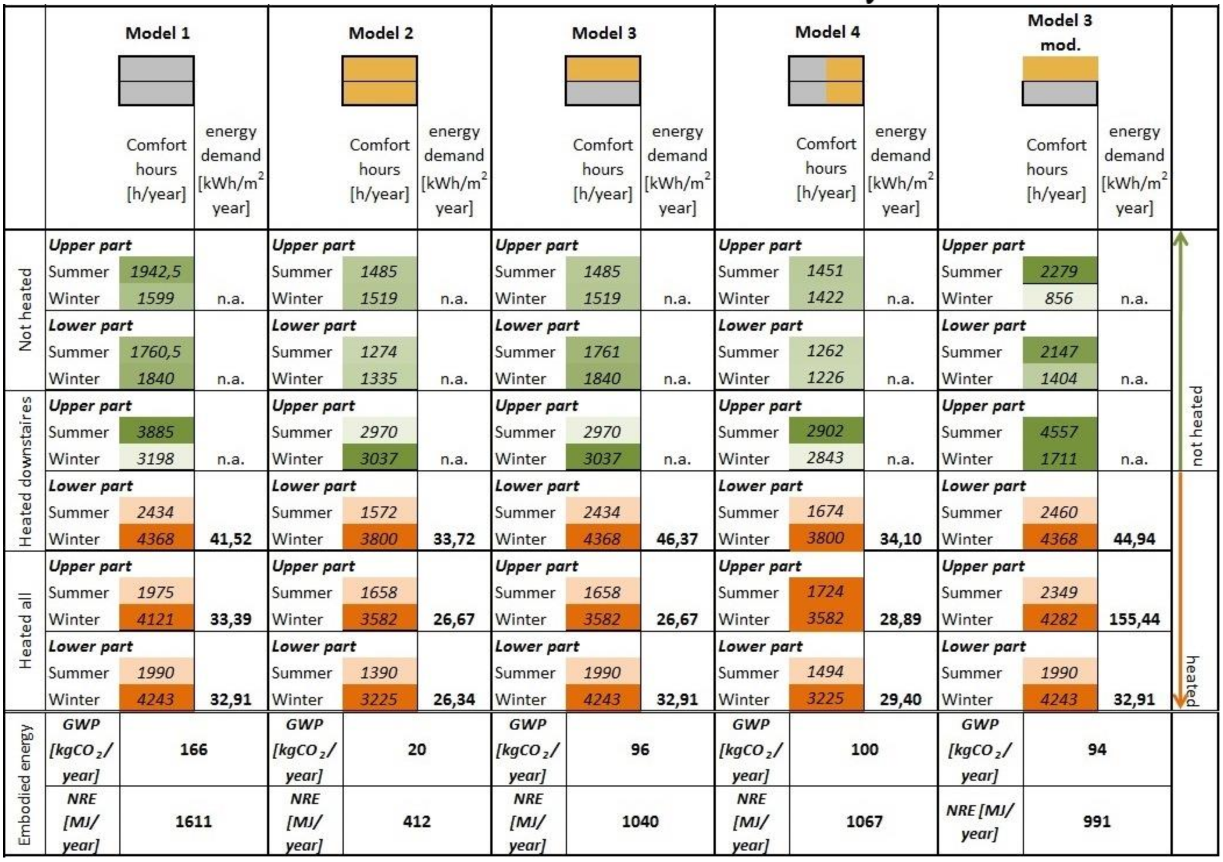
Parallel with the indoor comfort energy demand of heating was calculated too – also on the base of hourly results given by the software.

3. Results

3.1. Results for all simulations

A short résumé of the most important results is seen in *Table 1*. In the columns you see the models listed (with comfort hours per year and heating energy consumption if heated). In the rows data are classified by heating scenario.

These results show clearly the advantage of heating the lower part of the house in winter. Whatever design is used, the number of comfort hours in the lower part is moving from around 3'000 to 8'000 hours. However, the interest is of course less clear in summer as no cooling system was used. Therefore allowing heating in the lower part increases the number of comfort hours from around 1'000 hours during the cold summer nights. Concerning the upper part, similar conclusion can be drawn. It is still interesting to note that heating the upper part actually reduces the number of comfort hours in the lower part, which reduces the interest of having both zone heated and somehow justifies the traditional organisation of the house where the heating source was only localised in the lower part of the house. In the following results we will therefore only consider the simulations where the lower part of the house is heated allowing to use it during all winter and to use the upper part most of the days in summer and some warm winter days.



			Model 1		Model 2		Model 3		Model 4		Model 3 mod.		
			Comfort hours [h/year]	energy demand [kWh/m^2 year]	Comfort hours [h/year]	energy demand [kWh/m^2 year]	Comfort hours [h/year]	energy demand [kWh/m^2 year]	Comfort hours [h/year]	energy demand [kWh/m^2 year]	Comfort hours [h/year]	energy demand [kWh/m^2 year]	
Not heated	***Upper part***	Summer	*1942,5*		*1485*		*1485*		*1451*		*2279*		not heated
		Winter	*1599*	n.a.	*1519*	n.a.	*1519*	n.a.	*1422*	n.a.	*856*	n.a.	
	Lower part	Summer	*1760,5*		*1274*		*1761*		*1262*		*2147*		
		Winter	*1840*	n.a.	*1335*	n.a.	*1840*	n.a.	*1226*	n.a.	*1404*	n.a.	
Heated downstaires	***Upper part***	Summer	*3885*		*2970*		*2970*		*2902*		*4557*		
		Winter	*3198*	n.a.	*3037*	n.a.	*3037*	n.a.	*2843*	n.a.	*1711*	n.a.	
	Lower part	Summer	*2434*		*1572*		*2434*		*1674*		*2460*		
		Winter	*4368*	**41,52**	*3800*	**33,72**	*4368*	**46,37**	*3800*	**34,10**	*4368*	**44,94**	
Heated all	***Upper part***	Summer	*1975*		*1658*		*1658*		*1724*		*2349*		
		Winter	*4121*	**33,39**	*3582*	**26,67**	*3582*	**26,67**	*3582*	**28,89**	*4282*	**155,44**	
	Lower part	Summer	*1990*		*1390*		*1990*		*1494*		*1990*		
		Winter	*4243*	**32,91**	*3225*	**26,34**	*4243*	**32,91**	*3225*	**29,40**	*4243*	**32,91**	heated
Embodied energy	***GWP [kgCO$_2$/ year]***		**166**		**20**		**96**		**100**		**94**		
	NRE [MJ/ year]		**1611**		**412**		**1040**		**1067**		**991**		

Table 1: Results of thermal simulation for all five variants. Number of comfort hours in h, *space heat demand in* kWh/m^2*year*

3.2. Comfort hours during summer for the five variants

Let’s now consider the choice of the five variants, during summer, when only the lower part is heated. The lower part can be used most efficiently either in the model design 1, 3 or 3 modified, which means when a massive and insulated structure is used all around the house. Model 2 (made of wood) or Model 4 (made partially of wood and concrete) have actually around 1’000 less hours of comfort in the lower part than the other models (*Table 1.*). No significant differences can be seen between the three models with concrete on the lower part, which is obvious as they have all the same design on the lower part. For the upper part, large differences can be seen between models. We can see a clear advantage of having a wood non insulated structure in summer compared to the concrete or the wood insulated first floor. It is also clear that the hybrid structure where wood and concrete are combined in both floors (Northern façade in concrete and southern façade in wood) provides the lowest amount of comfort hours during summer.

3.3. Environmental impact vs available space

To be able to distinguish the three variants that seem to be the most advantageous, we considered the embodied energy on materials. It is clear that a house made of wood has a significant consumption of non-renewable energy for the production of the building materials than a house made only in concrete. Furthermore, the three variants where wood and concrete are combined have similar environmental impact, as the position of the material doesn't change the embodied energy and that the major impact comes from the structural materials and not from the insulations materials (the upper part insulated or not does not change the embodied energy of the house). The *Figure 3* shows the results for the 5 variants in term of embodied energy and available space in summer. The available space is being calculated by multiplying the number of comfort hours of both part of the house by the size of the floors.

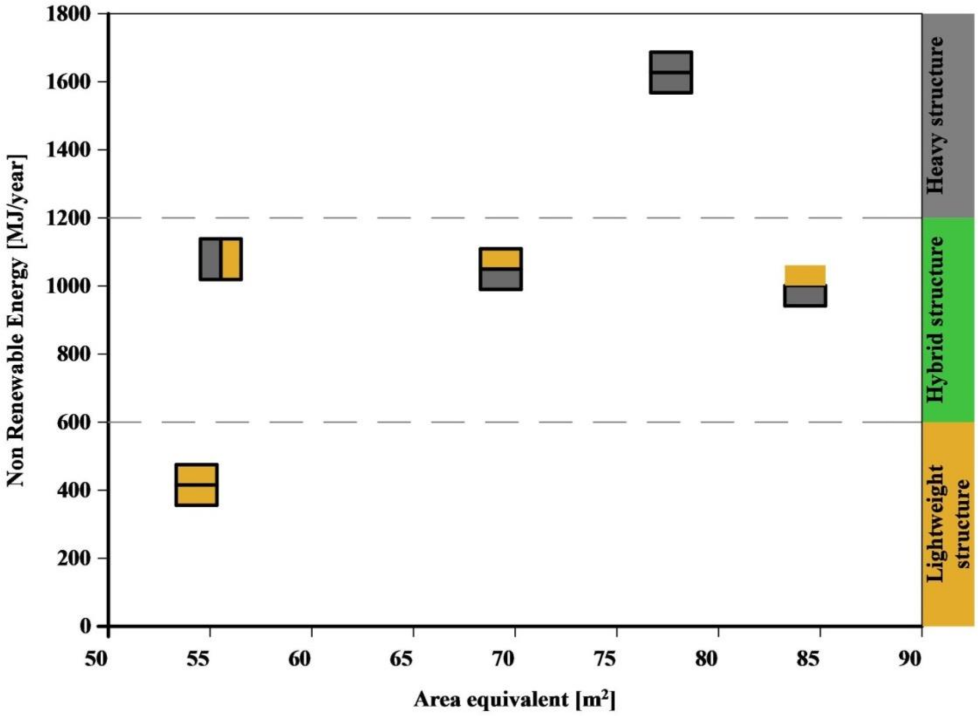


Figure 3: Available space for the five different variants in summer. (Down part is heated) Y axis shows the embodied energy, X axis shows the area equivalent which is calculated:

$$AEQ[m^2] = \frac{CH_{up}[h]}{365\times 24\,[h]} \times A_{up}\,[m^2] + \frac{CH_{down}\,[h]}{365\times 24\,[h]} \times A_{down}\,[m^2];\ where$$

AEQ*: area equivalent;* CH_{up}*: summer comfort hours upper part;* A_{up} *:area upper part;* CH_{down}*: summer comfort hours down part;* A_{down} *:area down part.*

In the *Figure 3,* it becomes clear that there is a need for lower massive part in the house and that an upper non insulated wood structure provides the higher amount of space usable in summer. The *Figure 3*also illustrates very clearly that: 1) Only lightweight structures are not sufficient to achieve a large amount of comfort hours (even in summer). 2) Massive structure has an interest to provide a large amount of comfortable space, but it is made in detriment of the large embodied energy consumed. 3) Hybrid structures allow a good compromise in term of embodied energy between massive and light structures. 4) Depending on how this hybrid structure is designed, the available space can be as good and even better as the fully massive structure.

4. Conclusion

In this study, we have shown that hybrid design allows providing the highest amount of available space with a lower embodied energy than massive structures. Furthermore, it seems clear that not all hybrid designs are interesting but that only one specific is particularly adapted. Having a heated ground floor of massive structure and an uninsulated non heated upper floor is the best compromise in term of embodied energy, heating demand and indoor comfort.

This system is actually the one used in vernacular architecture of Mediterranean regions. Compared to massive concrete houses that are now built in these areas, it is interesting to note that the number of comfort hours is not different (if not a little bit lower), but the embodied energy is twice bigger.

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