Housing type A1								
Scenario	CO_2 annual emissions		CO_2 annual emissions Heating		CO_2 annual emissions Cooling		CO_2 annual emissions Hot Water	
	(Kwh)	(Kwh/ m^2 conditioned)	(Kwh)	(Kwh/ m^2 conditioned)	(Kwh)	(Kwh/ m^2 conditioned)	(Kwh)	(Kwh/ m^2 conditioned)
Original	2236,3	71,4	1391,9	44,5	453,5	14,5	387,8	12,4
Retrofit 1	534,3	17,1	372,2	11,9	125,1	4,0	37,5	1,2
Retrofit 2	39,0	1,2	0,0	0,0	0,0	0,0	37,5	1,2
	(%)	(Kwh/ m^2 conditioned)		(Kwh/ m^2 conditioned)	(%)	(Kwh/ m^2 conditioned)		(Kwh/ m^2 conditioned)
Difference R1 - O	-76,11	-54,3		-32,6	**-27,58**	-10,5		-11,2
Difference R2 - O	-98,26	-70,2		-44,5	**-100**	-14,5		-11,2
Housing type A2								
Scenario	CO_2 annual emissions		CO_2 annual emissions Heating		CO_2 annual emissions Cooling		CO_2 annual emissions Hot Water	
	(Kwh)	(Kwh/ m^2 conditioned)	(Kwh)	(Kwh/ m^2 conditioned)	(Kwh)	(Kwh/ m^2 conditioned)	(Kwh)	(Kwh/ m^2 conditioned)
Original	17728,0	203,1	14382,0	164,7	2519,5	28,9	826,7	9,5
Retrofit 1	9122,6	104,5	7567,5	86,7	1108,0	12,7	447,1	5,1
Retrofit 2	8587,6	98,4	7213,3	82,6	927,1	10,6	447,1	5,1
	(%)	(Kwh/ m^2 conditioned)		(Kwh/ m^2 conditioned)	(%)	(Kwh/ m^2 conditioned)		(Kwh/ m^2 conditioned)
Difference R1 - O	-48,54	-98,6		-78,0	**-43,98**	-16,2		-4,4
Difference R2 - O	-51,56	-104,7		-82,10	**-36,80**	-18,3		-4,4
Housing type B								
Scenario	CO_2 annual emissions		CO_2 annual emissions Heating		CO_2 annual emissions Cooling		CO_2 annual emissions Hot Water	
	(Kwh)	(Kwh/ m^2 conditioned)	(Kwh)	(Kwh/ m^2 conditioned)	(Kwh)	(Kwh/ m^2 conditioned)	(Kwh)	(Kwh/ m^2 conditioned)
Original	20822,0	229,3	19397,0	213,6	703,7	7,7	720,6	7,9
Retrofit 1	10690,0	117,7	9998,6	110,1	350,2	3,9	341,0	3,8
Retrofit 2	9803,8	108,0	9049,7	99,7	413,1	4,5	341,0	3,8
	(%)	(Kwh/ m^2 conditioned)		(Kwh/ m^2 conditioned)	(%)	(Kwh/ m^2 conditioned)		(Kwh/ m^2 conditioned)
Difference R1 - O	-48,66	-111,6		-103,5	**-49,76**	-3,8		-4,1
Difference R2 - O	-52,92	-121,3		-113,9	**-58,70**	-3,2		-4,1
Housing type C								
Scenario	CO_2 annual emissions		CO_2 annual emissions Heating		CO_2 annual emissions Cooling		CO_2 annual emissions Hot Water	
	(Kwh)	(Kwh/ m^2 conditioned)	(Kwh)	(Kwh/ m^2 conditioned)	(Kwh)	(Kwh/ m^2 conditioned)	(Kwh)	(Kwh/ m^2 conditioned)
Original	33902,0	432,4	32740,0	417,0	487,0	6,2	674,0	8,6
Retrofit 1	14182,0	180,9	13770,0	175,6	115,1	1,5	294,5	3,8
Retrofit 2	12477,0	159,1	11893,0	151,7	290,4	3,7	294,5	3,8
	(%)	(Kwh/ m^2 conditioned)		(Kwh/ m^2 conditioned)	(%)	(Kwh/ m^2 conditioned)		(Kwh/ m^2 conditioned)
Difference R1 - O	-58,17	-251,5		-241,4	**-23,63**	-4,7		-4,8
Difference R2 – O	-63,20	-273,3		-265,3	**-59,63**	-2,5		-4,8

Table 6: Housing annual emissions of CO_2

Thus, ventilation, facing the position of the building in the plot and the effect of the UHI can also explain the differences in the emissions between A and B-C types. The exposition of the building to radiation seems not to be the biggest problem if the roof is properly isolated; the simulation was done considering the original non-habited chamber between the outside of the roof and the inhabited space.

c. Retrofit scenarios analysis: Regarding the total annual CO_2 emissions due to use, it should be said that energy retrofitting can lead to a reduction in emissions to the order of 50% by improving the thermal envelope of the house. Results show that A2 type housing is more affected by the urban fabric than by a hypothetical retrofit scenario of its envelope, explained by the high levels of emissions achieved after the retrofit. Meanwhile, A1, B and C housing types are more conditioned by the type of intervention to occur in their façades. There is a clear improvement if the intervention is more restrictive than the limits set by the STBC (see table 8).

	Original Scenario	Radiation	Ventilation	Plot position	Facing
Housing type A1	14,5 Kwh/m^2 cond	Lower	Obstacle/ Narrow St.	Good / UHI	East
Housing type A2	28,9 Kwh/m^2 cond	Higher	Obstacle / Narrow St.	Bad / UHI	East
Housing type B	7,7 Kwh/m^2 cond	Higher	No obstacle / Wider St.	Good	West
Housing type C	6,2 Kwh/m^2 cond	Higher	No obstacle / Wider St.	Bad	West

Table 7: Physical factors affecting cooling conditions

- Temperatures analysis:

The analysis of the temperatures shows how, after the R2 scenario, none of the housing achieves a temperature under 25ºC. This leads to a consideration about the convenience or otherwise of the intervention and whether or not there is a need to use mechanical ventilation. Several studies have shown that night ventilation can succeed in decreasing the diurnal indoor air from 1.5 to 2°C [15] or 3ºC depending on the case [16].

Other authors have investigated the incorporation of thermal inertia, with the aim of taking advantage of natural night-time ventilation. Studies have shown how high thermal inertia walls can result in a reduction of energy requirements of about 20% [17], maintaining comfortable indoor conditions without the help of AC systems [18].

Temperatures analysis			
Summer		Average temperature (ºC) - Te	Temperature fluctuation (ºC) - Ψ Te
Scenario External conditions			
	Original	29,6	4,5
Scenario Internal conditions			
H. Type A1	Original	27,2	4,4
	Retrofit 1	25,95	0,9
	Retrofit 2	26,15	1,3
	Difference R1 - O	**-1,25**	**-3,5**
	Difference R2 -O	-1,05	-3,1
H. Type A2	Original	26,75	3,5
	Retrofit 1	25,2	1,1
	Retrofit 2	26,2	1,3
	Difference R1 - O	**-1,55**	**-2,4**
	Difference R2 -O	-0,55	-2,2
H. Type B	Original	26,75	2,5
	Retrofit 1	25,85	1,5
	Retrofit 2	25,25	1,9
	Difference R1 - O	-0,9	**-1,0**
	Difference R2 -O	**-1,5**	-0,6
H. Type C	Original	25,5	1,0
	Retrofit 1	25,1	0,4
	Retrofit 2	24,75	0,5
	Difference R1 - O	-0,4	**-0,6**
	Difference R2 -O	**-0,75**	-0,5

Table 8: Temperatures for the different scenarios

3.3. The roof

The simulation has shown how transmittance across the roof is very low when a non-habitable chamber intermediates between the external layers and the inhabited space. The real situation of the cases analysed shows how owners have historically removed the intermediate ceiling for aesthetic and spatial reasons.

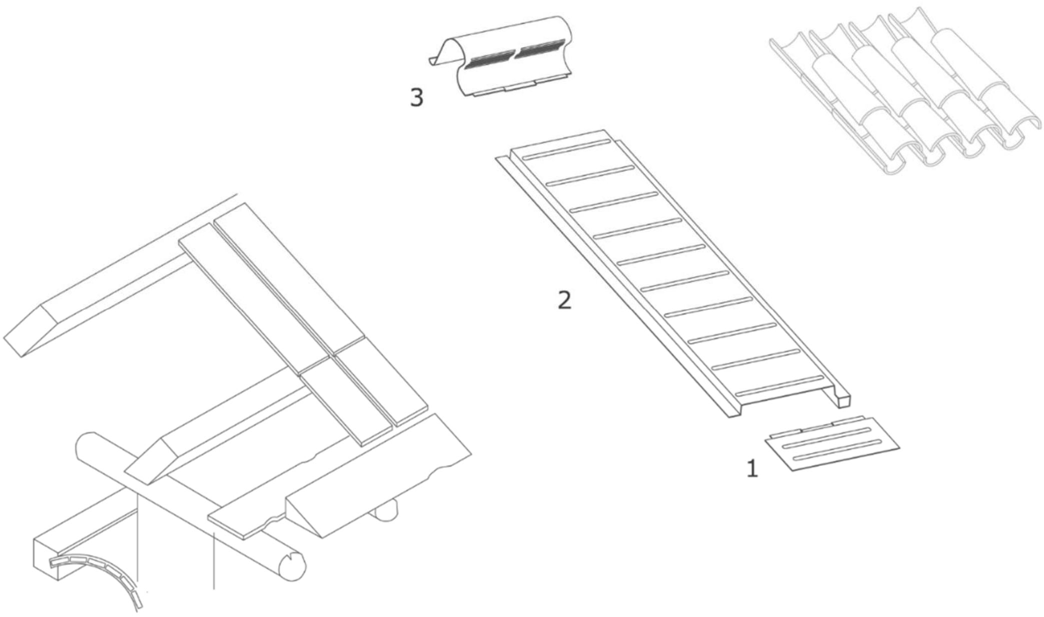

Figure 6: Roof ventilation modules

In the study, it has been analysed how levels of irradiancy can reach 1000 and 1350 W/m^2 on the roof. New techniques developed from the analysis of this case study [19] show how the direct effect of irradiancy can be diminished on these inhabited spaces by providing a 10 cm width ventilation space in between the layers of the roof [20, 21]. The irradiancy can be diminished to values of 250 W/m^2 [22] if combined with a standard layer of 4mm of insulation [23] in standard slopes, from 15 to 60 degrees.

4. Conclusions

The study exposes the simulation of different scenarios at three different levels of intervention: the neighbourhood, the plot and the building. Results obtained reflect that potential reduction of CO_2 emissions is achieved if a retrofit programme is jointly undertaken at the three different scales. Only in this way can the relative importance of one scale over the others be determined. The study has demonstrated how specific actions are needed to reduce indirect emissions generated by the urban-heat-island effect (UHI), as in the case of housings type A1 and A2. The analysis of different materials has demonstrated a potential reduction of a 92,35% in the CO_2 emissions associated with the roads' retrofit. The percentage achieved in the case of pavements, a 82,47%, suggests a more accurate intervention due to their reduced surface. An optimal solution is considered only by intervening with the pavement exposed to most solar radiation.

The analysis of the plot states how buildings are affected by solar irradiancy with peaks of 305 W/m^2 in the southern façades and a constant exposition, in the central hours of the day, to a range of 1000 and 1350 W/m^2 on the roof. It also has been demonstrated how tall buildings can act as obstacles that significantly compromise the ventilation of the nearby houses; as shown in the case of housings type A1 and A2 located in the narrowest streets. Therefore, rather than a possible advantage as shade, they slow down or stop the wind, keeping the area and surrounding buildings warm at night. The effect is not so relevant to types B & C because of their location in the plot and in the neighbourhood.

It could be said that the wide scope of this study has demonstrated the relatively low benefits of the insulation of façades, and how the potential of thermal inertia of walls due to night-time ventilation establishes clear incompatibilities when insulating them if cooling is not going to occur through mechanical means. When referring to the roof, the relatively low CO_2 emissions when simulating traditional characteristics have led to the necessity of implementing a technical-innovative solution [19]. Nonetheless if the study has demonstrated something, it is the tremendous importance of acting properly to reduce CO_2 emissions, depending on the three scale levels exposed: the neighbourhood, the plot and the building.

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