Low Energy Architecture and Reclaiming of Ancient Buildings: an Experimental Case of New Techniques of Air-conditioning

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ABSTRACT**:** It is very difficult to plan interventions of "passive and low energy architecture" in reclaiming of ancient buildings in the old town centres of cities because the form of buildings and the style of outside facades can not be modified as watched over by town planning legislation. In these cases the planner must turn his attention to indoor constructional elements to try to obtain improvements both in energy consumption and in aesthetic features of building.
The Authors believe that a good key to obtain both previous objectives is to utilise new techniques for the design of heating and cooling systems of buildings.
In the traditional heating and cooling systems the supply of necessary heat flux (positive or negative) is calculated by method of convective heat exchange and by this way the thermovector fluid works with remarkable level of enthalpy.
On the contrary, if the supply is obtained by radiative heat exchange, and in accord with O. Fanger's theories, it is possible to utilise thermovector fluid with low levels of enthalpy.
The achievement of second objective, that is improvements of indoor aesthetic features of building, is obtained since the radiative heat exchange do not needs of canalizations , fan-coil and so on in view as "fitting" and radiative elements are placed inside the walls of building which act as radiative elements themselves.
On the ground of previous theories people built an experimental heating and cooling plant for a flat of an ancient building in the old town of Catania city (south Italy) to the aim to verify:

- the feasibility of such kind of plant in the case of "cooling"
- the amount of saving energy in comparison with that used by convective plant
- the respect of indoor comfort parameters (ASHRAE 55/UNI-EN-ISO 7726; ISO 7730)
- the architectural indoor aesthetic improvements.

Conference Topic: Traditional solutions in sustainable perspective

Keywords: energy, comfort

1. HEAT EXCHANGE, ENERGETIC BALANCE AND THERMOHYGROMETRIC COMFORT

As shown in (e.g.Fig.1) there are different percentages of heat exchanged by human body in state of rest in indoor environment (50% of R.H. and T_a =293,15 K) and the most of exchange happens for sensible heat irradiation. This kind of heat exchange is governed by Stephan-Boltzmann laws [1] and to study radiative process people must referred in real case to "integral emissivity".
"Comfort" can be defined that psychophysical status of man in which he expresses "satisfaction" to indoor microclimate. As shown in (e.g.Fig 2) the status of comfort depends by many factors:

- kind of process of thermal dissipation of human body
- physiological factors
- thermohygrometric features and quality of indoor air
- Thermal insulation of human body (clothes).

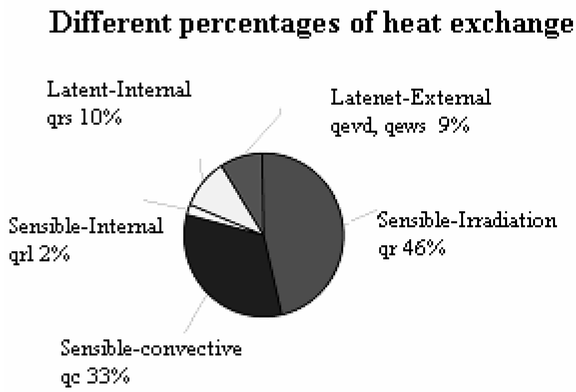


Figure 1: Different percentages of heat exchange

With reference to "standardization", the thermal indoor environments can be classified in function of their peculiarities as "hot environments","cold environments" and "mitigated environments": in function of this classification there are different rules to be respected to achive the comfort status.
The case studied can be classified as "mitigated environments" and it shows homogeneous environmental conditions , with short variability of the mean parameters running the time and lack of significant and localized thermal exchange between "human body" and indoor environment such as to have big influence to comprehensive thermal balance. The indoor living people trains moderate physic activity and has a substantial sameness as regard body thermal insulation of body (clothes).

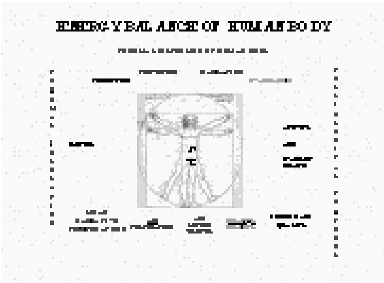


Figure 2: Energy balance of Human body

Under all previous conditions, the comfort criteria in the case of "mitigated environment" are based on parameters as like: Operating Temperature and New Operating Temperature (e.g.Fig 3) [2], Predicted Mean Vote (PMV) and Predicted Percentage of Dissatsfied (PPD), in accord with P.O. Fanger theories [3].

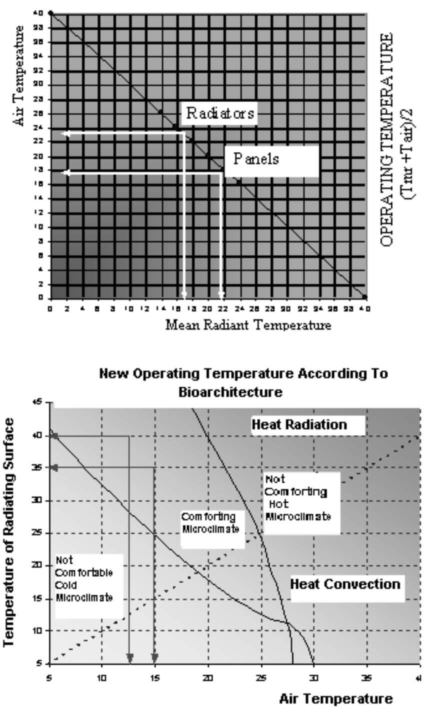


Figure 3: Operating Temperature and New Operating Temperature

The PMV value is given by :
$PMV=[0,303 \cdot e^{(-0,036M)}+0,028\ L]$ (1)
and the PPD is given by :
$PPD = 100 - 95 \cdot e^{(0,003353 \cdot PMV^4 + 0,2179 \cdot PMV^2)}$ (2)
The graphical correlation between PPD and PMV is shown in figure (e.g.Fig 4): PMV=0, it means to have the optimum of indoor comfort condition (not hot, not cold). By the trend of the graph it is possible to notice that for PMV=0 there is about ±5% of people dissatisfied by indoor microclimate . It means too that the method considers there is comfort condition of microclimate even if there are 10% of dissatisfied people.

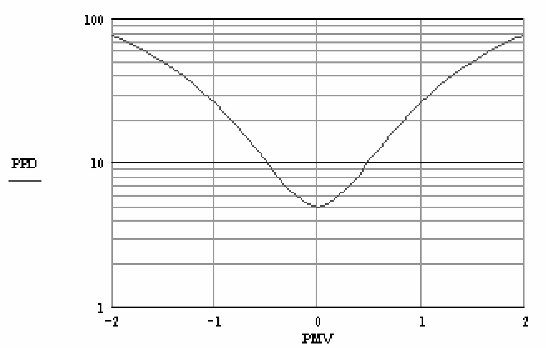


Figure 4: graphical correlation between PPD and PM

With reference to regulations it is possible to notice that:

- ISO 7730 allows $-0,5 \leq PMV \leq 0,5$ (10% of dissatisfied)
- ASHRAE 55 allows $-0,85\ PMV \leq 0,85$ (20% of dissatisfied)

Both in the case of "heating" and "cooling" the inner side of wall containing radiating panels will be at different temperature with reference to other walls of room and this situation causes an unsymmetrical heat radiative exchange with human body. Both ISO 7730 and ASHRAE 55 allow the 5% of dissatisfied people owing to this phenomenon of asymmetry.
Moreover, the effects of further parameters as average velocity of air motion (v_a) , air temperature (T_a) and air turbulence (T_u), have big influence on indoor comfort. To consider previous effects UNI-EN-ISO 7730 determined the up limit (15%) of a further index that indicates the percentage of dissatisfied for turbolent motion of air (DR) by which it is possible to correlate the effects of whole previous parameters with the formula :
$DR=(34-T_a) \cdot (v_a-0,05)^{0,62} \cdot (0,37 v_a \cdot T_u+3,15)$ (3)**.** ·
In our investigation T_a and v_a have been measured, whilst the T_u value has been drawn from technical bibliography (0,40 for our indoor environment conditions).
The regulations utilized with reference to experimental campaign of measurement are: UNI-EN-ISO 7726 (UNI 2002), UNI-EN-ISO 7730 and the European regulation ENV 1752, as in CEN 1996 recommendations, regarding "ventilation for building-design criteria for indoor environment". The investigated parameters have been: T_a=air

temperature [°C], V_a=air velocity [m/s], p_a=air pressure [kPa] and T_r=radiative temperature [°C].
The aim of measurements has been to verify both the “stationariness “and the “homogeneity” of indoor environment during the “cooling” period and then the values of PPD, PMV e DR.
The sample room in 3D grid is shown in figure (e.g. Fig 5) while the successive figure shows the natural view (e,g.Fig.6).
People chose the coordinates of the nodes of 3D grid (were have been carried out the measures) in the way to discover the trend of investigated parameters both in the case of “sitting person” (0,60m=eight of body barycentre and 1,1m=eight of neek) and “standing up person” (1,1m=eight of body barycentre and 1,7m=eight of neek).

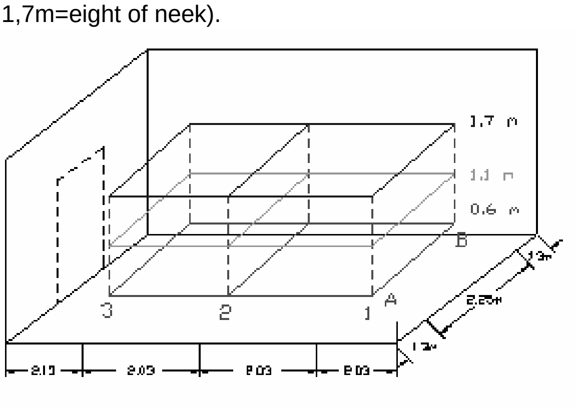


Figure 5: 3D grid utilized for the measures

Figure 6: Two photos of the room, with indications of location of dehumidifier and hygrometer

For each node of the grid it have been done tabulation of measured parameters running the time, of arithmetic mean and both of the lower and the upper limits to verify if each of one of measured value was included inside the interval of admissible fluctuation.
People interpreted the UNI-ISO 7726 in the way that “stationariness” must be “condicio sine qua non” to have comfort in indoor environment. In the same way people operated to verify the “homogeneity”.
The outdoor climate conditions during the surveying have been T_a=27°C, RH=71%.
Exempla of the calculus are shown in (Table I), (Table II).
The last table refers to the general features both of situs and of building (see Table III).
An exemplum of 3d trend T_a, v_a, RH, PMV and PPD.is shown in figure (e.g. Fig.7).

Table I: “Stationariness” in A2 point
Measure Point A2 – eight 1,7m – Room n.1

Time	ta (°C)	va (m/s)	pa (kPa)	tr (°C)
20.36.24	24,50	0,000	1,82	24,83
20.36.36	24,50	0,000	1,81	24,83
20.36.48	24,50	0,020	1,81	24,83
20.37.00	24,54	0,000	1,82	24,82
20.37.12	24,54	0,010	1,82	24,82
20.37.24	24,50	0,000	1,82	24,83
20.37.36	24,50	0,000	1,82	24,83
20.37.48	24,54	0,000	1,82	24,82
20.38.00	24,57	0,000	1,83	24,86
20.38.12	24,57	0,000	1,83	24,86
20.38.24	24,57	0,000	1,82	24,86
20.38.36	24,54	0,000	1,82	24,87
20.38.48	24,54	0,000	1,82	24,87
20.39.00	24,50	0,000	1,81	24,88
20.39.12	24,50	0,000	1,81	24,88
20.39.24	24,50	0,000	1,81	24,88
20.39.36	24,50	0,000	1,81	24,88
20.39.48	24,50	0,000	1,81	24,88
20.40.00	24,54	0,000	1,81	24,87
Mean Value	24,52	0,002	1,82	24,85
Min. value	24,50	0,000	1,81	24,82
Max. value	24,57	0,020	1,83	24,88
Δ_{max}	1,50	0,100	0,30	4,00
Inferior Limit	23,02	0,000	1,52	20,85
Superior Limit	26,02	0,102	2,12	28,85

Verifying Stationariness	
Minimum value >	Inferior limit
Maximum value <	Superior limit

Table II

	RH (%)	to (°C)	PMV ()	PPD (%)	DR (%)
	59,30	24,67	0,26	6,43	0,00
	59,00	24,67	0,26	6,41	0,00
	59,00	24,67	0,26	6,41	0,00
	59,10	24,68	0,27	6,47	0,00
	59,10	24,68	0,27	6,47	0,00
	59,30	24,67	0,26	6,43	0,00
	59,30	24,67	0,26	6,43	0,00
	59,10	24,68	0,27	6,47	0,00
	59,10	24,72	0,28	6,59	0,00
	59,10	24,72	0,28	6,59	0,00
	58,80	24,72	0,27	6,56	0,00
	59,10	24,71	0,27	6,55	0,00
	59,10	24,71	0,27	6,55	0,00
	59,00	24,69	0,27	6,48	0,00
	59,00	24,69	0,27	6,48	0,00
	59,00	24,69	0,27	6,48	0,00
	59,00	24,69	0,27	6,48	0,00
	59,00	24,69	0,27	6,48	0,00
	58,80	24,71	0,27	6,52	0,00
average	59,06	24,69	0,27	6,49	0,00
Min.	58,80	24,67	0,26	6,41	0,00
Max.	59,30	24,72	0,28	6,59	0,00

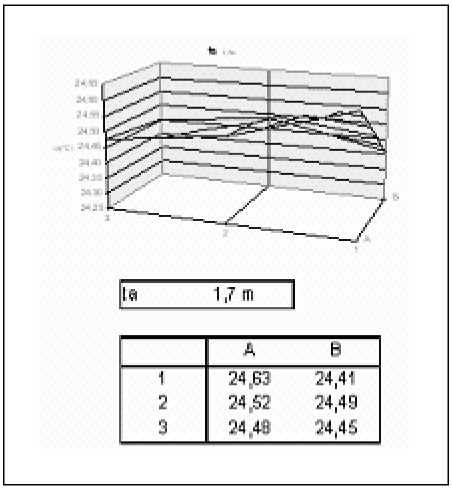
Day work of Plant : from 10:00 hr- ore 20:00 hr							
Thermoigrometric conditions of outdoor air (UNI 10349–tableXVI)							
T_{max} [°C]	33,6	The highest day temperature of outdoor air					
ΔT_{max}[°C]	10	The highest day temperature range					
φ_e [%]	65	Average of Day Relative Humidity of outdoor air					
Day Distribution of temperature of outdoor air (UNI 10349)							
$T_e = T_{max} - F(t) \Delta T_{max}$							
	Sun hour						
	6	8	10	12	14	16	18
F(t)	0,98	0,84	0,5	0,23	0,03	0,03	0,21
T_e [°C]	23,8	25,2	28	31,3	33,3	33,3	31,5
T_e-T_i [°C]	-2,2	-0,8	2	5,3	7,3	7,3	5,5

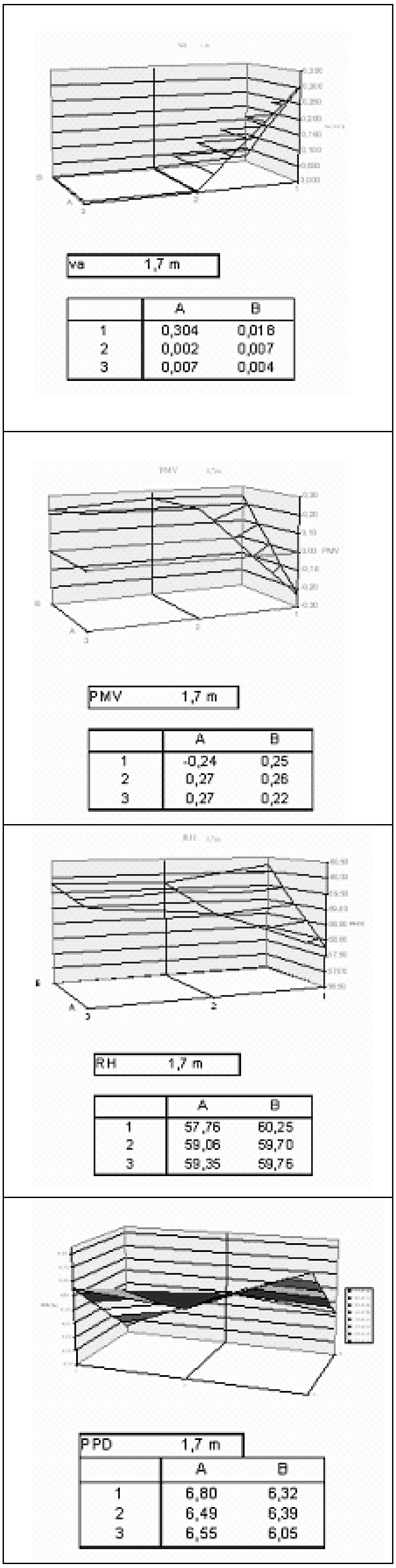
Situs Peculiarity

Kind of utization	Occupancy at full time
Class (DPR 26 Aug.1993)	E1 (appendix A UNI 10379
Total surface of flat	150 m^2 (room 1 40,4 m^2)
Total volume of flat = eight x surface	3.30 x 150= 495 m3.

Table III: General features both of situs and of building

Climate data of catania city Working Data of plant		
House building in Catania city		
Altitude on s.l.	7	[m]
Latitude	37°30'	
Longitude	15°3'	
Daily Degree	833	[°C g]
Climate Zone	B	
Wind Zone	3	
Correcttive coefficient	1	
Wind Velocity	4,4 [m/s]	
Prevalent Blowing Direction	West	
Plant Heating Period	1 December to 1 March	
Plant Cooling Period	1 June - 30 September	





	A	B
1	0,304	0,018
2	0,002	0,007
3	0,007	0,004

	A	B
1	-0,24	0,25
2	0,27	0,26
3	0,27	0,22

	A	B
1	57,76	60,25
2	59,06	59,70
3	59,35	59,76

	A	B
1	6,80	6,32
2	6,49	6,39
3	6,55	6,05

Figure 7: 3d trend of: T_a,V_a, RH, PMV and PPD.

2.THE MEASURING EQUIPMENTS

The surveying of indoor thermohygrometric parameters has been done by indoor climate analyser (BABUC A/M) equipped with sensor-probe (dry bulb temperature), glob thermometric-probe (mean radiant temperature), psychometric sensor-probe (wet bulb temperature) and hot wire anemometer sensor probe (air velocity). All of them are shown in (e.g. Fig. 8).

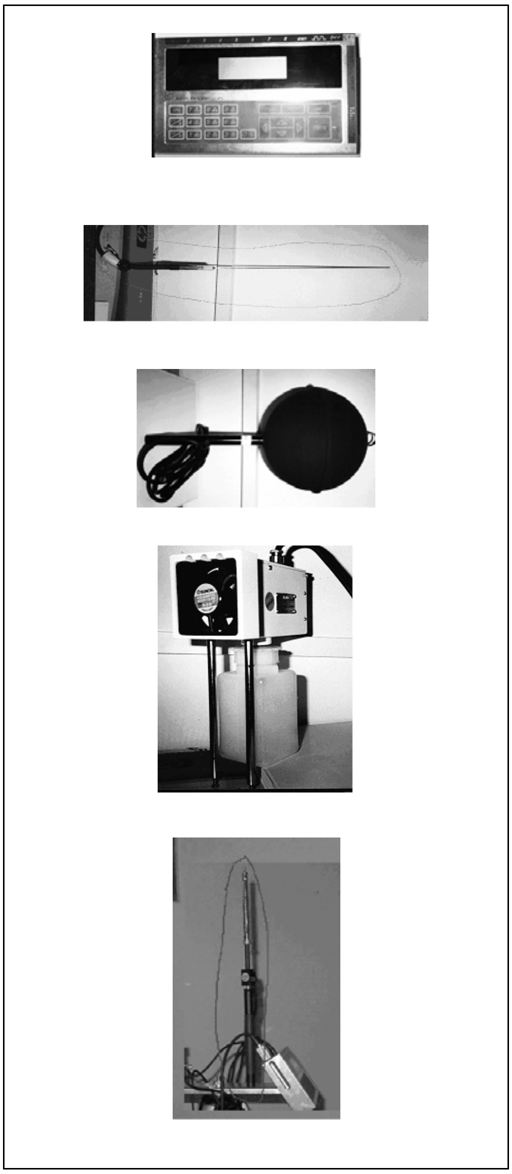


Figure 8: Measuring equipments

3.THE PLANT

For room reason people must summarize the description of plant utilizing the figures. The experimental test has been carried out in a flat located at the first floor of three floors building situated in old town centre of Catania City (Italy).

Radiant panels have been inserted in opportune zones of boundary walls. The plant has been equipped with one dehumidifier too. The radiative panels are fed by one heat pump which takes over 1,4 kW of electrical power producing 4 kW of refrigeration output and takes over 1,3 kW of electrical power producing 3,4 kW of heat output.

A heat storing up tank provides to maintain the temperature of water feeding the panels at about 313 K during heating period and at about 288 K during cooling period. In figure is shown the plan of panels inside the walls (e.g. Fig.9).

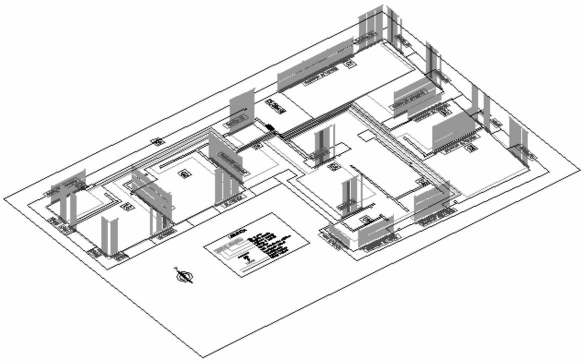


Figure 9: The plan of panels inside the walls

4.COMPARISON BETWEEN "EXERGETIC" EFFICIENCY OF CONVECTIVE AND RADIATIVE HEATING PLANTS

As the Italian laws on "energy saving" (L 373/76 and L .10/91) fix not up to T_i=293,15 K the limit of "hot" temperature to keep in indoor house environment, it is possible to compare the exergetic efficiency of both types of heat exchange (convective and radiative ones) taking in account welll known formula of Exergia, Exergetic Efficiency and First Principium of Thermodynaic [4]**,** that is:

$Ex= Q\cdot(1- T_a/T)$; $\eta_{ex}= (1-T_a/T_2)/(1-T_a/T_1)$, $Q=Q_c=Q_r$ were:

Q=thermal losses of indoor environment toward outdoor environment

Q_r=thermal flux by radative exchange able to maintain the required indoor temperature

Q_c=thermal flux by convective exchange able to maintain the required indoor temperature

T_a= outdoor air average temperature (278 K in our case)

T_1=thermovector hot fluid temperature (T_1=353K in convective case and T_1=313 K in radiative case).

T_2=indoor air temperature (293 K in our case).

The computation takes to η_{ex}=0,46 in the case of radiative and η_{ex} = 0,24 in the case of convective one. It means a better use of thermal energy in the case of radiating plant.

5.GENERAL RESULTS

- In each point of the grid the "stationariness" and the "homogeneity" have been verified with positive results
- The vertical distribution of temperature (ta) takes to one ΔT max= 0,19°C, less than ΔTmax = 1,5°C prescribed by the UNI-EN-ISO 7730 to classify "comfort condition".
- The velocity of air is very small, v_{max} = 0,08 m/s
- The RH values fluctuate around 60%, a little more up of optimum value that is 50%, but inside the admissible interval prescribed by UNI-EN-ISO 7730, that is 30÷70%.
- With reference to local and global comfort
  - Maximum value of PMV found: +0,27 (point A3, eight 1,1m)
  - Minimum value of PMV found: -0,24 (point A1, eight 1,7m).

  Both values compatible with limits (-0,5÷+0,5).
- By energetic data coming from heat pump it is possible to notice that a very low electrical power (1,4 kW) allows to have comfort conditions for a flat of about 150 m^2 of surface, whilst for the same flat and conditions the precedent cooling system (convective cooling) need of about 24000 btu/h that is about 7,0 kW.
- The thermal analysis takes an improvement of exergetic efficiency (from η_{ex}=0,24 to η_{ex}=0,46).

CONCLUSION

On the ground of previous experimental results it is possible to assert:

- The radiative panels plant is able in cooling period and for outdoor air conditions of T=27°C and RH=71% to maintain indoor the comfort conditions indicated by Regulation with Ta=20°C and RH=60%.
- The radiating plant obtains a reduction of need of electrical power in comparison with convective one.
- There is a better utilization of thermal energy because of an improvement of exergetic efficiency.
- The aesthetical features of indoor space increase as there are not in view the presence of cooling euipments and idraulic connections.
- The research is in progress to verify the situation of this kind of plant in the case of "heating period" (future paper).

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