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ZERO EMISSION TEMPORARY HABITATION: ANALYSIS OF A PASSIVE CONTAINER HOUSING SYSTEM ACCLIMATIZED BY GEOTHERMAL WATER

Prof. Antonio Dumas Phd.
Università di Modena e Reggio Emilia,
Di.S.M.I. - Reggio Emilia, 42122, Italy
antonio.dumas@unimore.it

Dr. Michele Trancossi Phd.
Università di Modena e Reggio Emilia,
Di.S.M.I. - Reggio Emilia, 42122, Italy
michele.trancossi@unimore.it

Dr. Mauro Madonia
Università di Modena e Reggio Emilia,
Di.S.M.I. - Reggio Emilia, 42122, Italy
mauro.madonia@unimore.it

Prof. Rinaldo Garziera Phd.
Università degli Studi di Parma,
D.I.I. - Parma, 43124, Parma, Italy
rinaldo.garziera@unipr.it

Prof. Luca Piancastelli Phd.
Università di Bologna,
D.I.E.M. - Bologna, 40136, Italy
luca.piancastelli@unibo.it

Prof. Alessandro Pirondi Phd.
Università degli Studi di Parma,
D.I.I. - Parma, 43124 Parma
alessandro.pirondi@unipr.it

Dr. Leonardo Frizziero Phd.
Università di Bologna,
D.I.E.M. - Bologna, 40136, Italy
leonardo.frizziero@unibo.it

ABSTRACT

This paper presents a novel concept of container mobile housing system denominated ZETHa (Zero Energy Temporary Habitation). It is based on the LESP (Low Exergy Structured Panel) concept, in which the acclimatization is realized by water recirculation inside the external walls of the building and the ZEBRA concept (Zero Energy Consumption Building totally Renewable Addicted). A general plant and building design has been produced with the aim to minimize the presence of thermal bridges. The calculations of energy dispersion have been performed both in the wall and in the whole building. The energetic contribution of renewable energy plants has been evaluated to obtain a totally passive

building. This evaluation will also consider energy needs by appliances.

NOMENCLATURE

ZETHa	Zero Energy Temporary Habitation;
ZEBRA	Zero Energy consumption Building totally Renewable Addicted;
LESP	Low Exergy Structured Panel;
A	Area [m^2];
Q	Heat [W];
q	Heat Flux [kW/m^2]:
U	Thermal transmittance [kW/m^2 K];
T	Temperature [T];
s	Thickness [m]
h	Thermal conductivity [W/mK]
λ	Thermal conductivity [W/mK]
α	Thermal adduttance [W/mK]
c	Thermal capacity [J/kgK]
H	internal heat production rate of an occupant per unit area [W/m]
L	energy loss from body [W/m]
M	metabolic rate per unit area [W/m^2].
PMV	Predicted Mean Vote Index
PPD	Predicted Percentage Dissatisfied index

INTRODUCTION

ZEBRA means "Zero Energy Consumption Building totally Renewable Addicted". It is a new concept of building with null energy consumption from fossil fuels in order to maintain the comfort conditions both during the summer and during the winter climatic cycle. It has been developed starting from a patent by Antonio Dumas [1]. The concept below this patent, even if presented at the end of the 70s, has been recently updated leading to the LESP (Low Exergy Structured Panel) adiabatic panel concept.

It has been presented with a preceding paper [20].

With the revitalization of the economy and the oil crisis and the worsening energy problems of today studies begun in 70's and 80's, and then abandoned in the subsequent period characterized by the illusion of energy supply at low cost, have been taken into account as the basis of novel studies and projects.

It is well known that wellness conditions inside a building mostly depend on the thermo-physical envelope of the buildings and its thermal quality. It is also known that walls can be insulated by the presence of air cavities but also the acclimatization by using radiant floor and wall. In particular, several techniques are known and used for increasing energy efficiency of a building and the comfort conditions for occupants:

1) prefabricated cladding for thermal insulation;
2) ventilated facades;
3) thermally insulating materials to decrease the heat losses to the surroundings.

The following applications are also of common utilization:

1) the so-called solar plants with the ability of capturing the solar radiation;
2) the use of radiant "floor" or "ceiling" for internal heating which operates using low temperature energetic sources (33 ÷ 45 °C).

It 'also known that low temperature energy supply is less expensive on an economic and exegetical point of view than a high temperature energy supply and the relations between the use of radiant heating system and human comfort conditions [2-5].
In particular it is well known to adopt different systems to increase the wellness conditions mixed together with the exigency of increasing the general thermal efficiency of the system. In particular two technologies can be cited:

1) Ventilated facades: they increase the climatic insulation of walls through the use of air cavities with circulating air in communication with interior environment or exterior (Fig. 1).

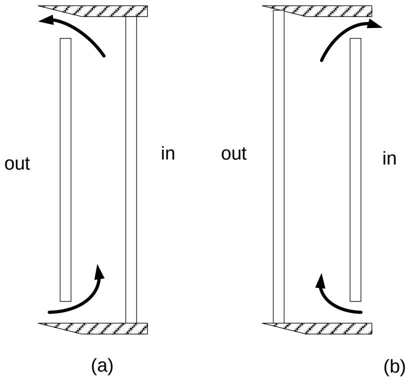

Figure 1 – Ventilated façade: (a) summer case; (b) winter case.

2) Radiant acclimatization: in many buildings related applications radiant floors and walls are used, which permits the use of low temperature water [Fig.2] for heating purposes (33-45 °C).

High energy efficiency and passive building concepts have been developed to meet very advanced energy performance requirements:

1) demand for useful energy for heating less than 15 kWh / m² per year
2) no thermal bridges
3) total primary energy demand less than 120 kWh / m² per year,
4) percentage of days with temperature of the air you less than 25 ° C under 10%.

CALCULATION METHODOLOGY

The energy efficiency and dispersion evaluation presented in the paper needs a certified calculation method, in order to produce comparable results. They are realized using the methodologies related to European and Italian Standards [6-16].

In particular the energetic evaluation has been defined by using the general framework of Italian standardization [1, 6, 7, 9, 10, 13, 14, 15 and 16].

THE LESP WALL

The idea of ZEBRA building can be considered a further development of the above basic concepts, in order to produce a dynamic building envelope with a level of energetic dispersion much lower than any other system known today. It uses a novel thermal cut by circulating water which is presented in detail in the following paragraph.

The purpose of the LESP panel concept is to create a complete building envelope system able to minimize overall building heat loss and ensure an enhanced comfort for occupants. In particular the novel dynamic building concept can use low level energy sources and renewable energy sources. The main objective of this concept is to maintain the thermo-hygrometric levels of well-being constant within the building, regardless of external weather conditions, without the need 'type of energy supply from fossil fuels.

The novel feature of this system lies primarily in the renewed approach to the global problem of the building design, which starts from the need to achieve the highest level of comfort while minimizing energy consumption.

The zero energy consumption for this purpose becomes a target not only possible but absolutely not resolved using insulation and traditional plants. Instead by design and optimization of the very conception of the building and mathematical optimization of dynamic physical parameters can be reached by using the LESP wall concept.

The building envelope consists of two essential parts:

1) a circuit designed to create a thermal barrier thermally stabilized by exchanges in the soil, which can be guaranteed to have a source temperature not far from groundwater temperature all over the year, considering that a thermal contribution can be ensured by the excess of solar thermal energy for hot water production.
2) Solar systems that provide two functions: water heating and photovoltaic production.

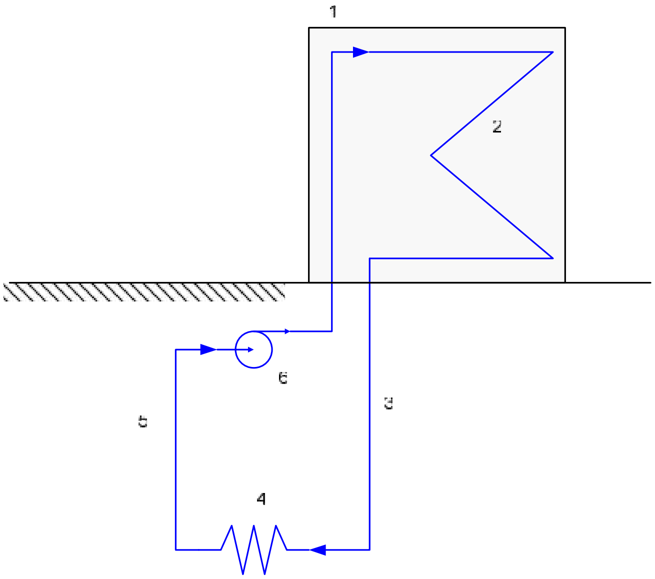

Figure 2 – Original LESP wall and building plant schema.

Referring to Fig. 2 it can be identified the following plant components:

1) building wall;
2) internal coil for the dynamic insulation of the wall;
3) return pipe;
4) geothermal heat exchanger;
5) discharge pipe;
6) circulation pump.

The purpose of the LESP system is to create a barrier able to minimize building heat loss and ensure an increased sense of comfort with the unique contribution of internal energy of low-level or derived from renewable sources. In particular this project aims to maintain constant thermo-hygrometric levels of wellness within the building, regardless of external weather conditions, without the need of energy supplies from fossil fuels.

The project aims to achieve objectives Zebra far more ambitious than those associated with the passive house concept:

This solution even if has some difficulties for the use into large buildings presents interesting benefits in terms of energy consumption of the building itself. In most cases it cannot need any energy source except the necessary pumping system for the water.

This solution is being studied in the case of insertion into a traditional concrete prefabricated panel [17] producing the ZEBRA building model [Fig. 3].

By this study also different panel architectures seem possible and even in terms of design. One of these solutions is related to the use of a container building, which can be interesting both in terms of performances and of building simplicity.

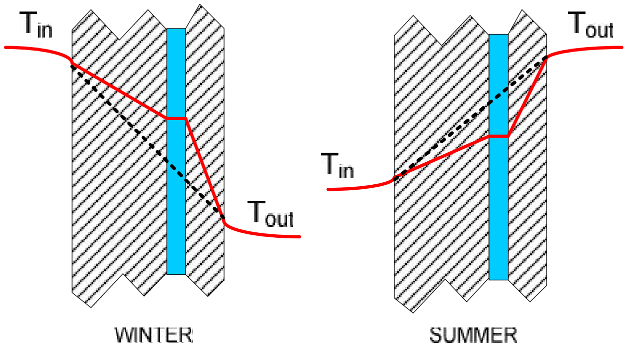

Figure 3 – Seasonal behaviour of the proposed wall.

TRADITIONAL WALL MODEL

The traditional wall model is well known and can be simply modelled by electrical analogy [Fig. 4]. It is constituted by more layers of different material both in terms of nature and thermal properties.

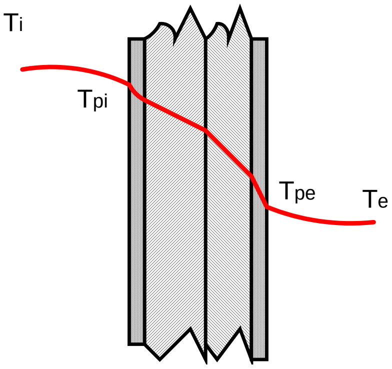

Figure 4 – Traditional wall schema and internal thermal profile (red line).

In order to quantify the losses must be considered the heat flow between the interior and exterior environment. The steady - state flow of heat from the inside of the surrounding is given by:

$$\frac{Q}{A} = \frac{(T_i - T_e)}{\frac{1}{\sim_i} + \sum_i \frac{s_i}{\mathrm{a}_i} + \frac{1}{\sim_e}} = \frac{(T_i - T_e)}{\frac{1}{\sim_i} + \frac{s_{eq}}{\mathrm{a}_{eq}} + \frac{1}{\sim_e}} \qquad (1)$$

where

- $\left(\frac{s}{\mathrm{a}}\right)_{eq} = \sum_i \frac{s_i}{\mathrm{a}_i}$
  is the thermal resistance of the wall;
- $\sim_e = h_{conv,e} + h_{irr,e}$
  $\sim_i = h_{conv,i} + h_{irr,i}$
  is the representation of the external and internal adductive coefficient?

ZETHA WALL MODEL

The ZETHa wall model presents an increased complexity when compared to traditional insulated walls.

The introduction of a coil in which water flows at T_0 reduces the heat loss from the internal environment of the surroundings. In particular the internal thermal profile is different from the one of traditional wall because of the presence of a thermal discontinuity generated by circulating water at almost constant temperature shown in Fig 5.

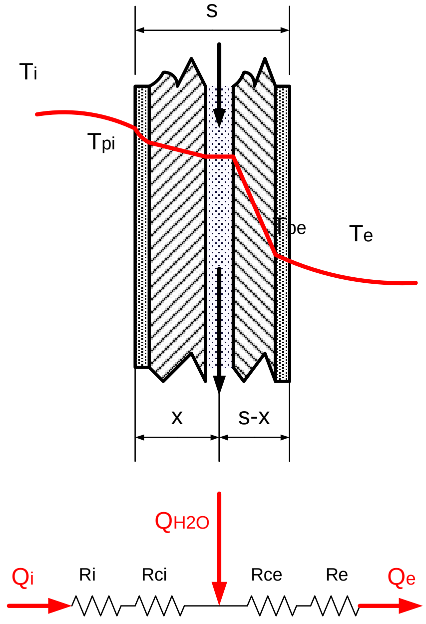

Figure 5 – LESP wall schema

The following equation can be used to model the Zebra wall behaviour:

$$\dot{q}_i = \frac{Q_i^{'}}{A} = \frac{(T_i - T_0)}{\frac{1}{\sim_i} - \left(\frac{x}{\mathrm{a}}\right)_{eq}} \qquad (2)$$

the waste of heat from this new configuration and

$$q_e^{'} = \frac{Q_e^{'}}{A} = \frac{(T_0 - T_e)}{\left(\frac{(s-x)}{\mathrm{a}}\right)_{eq} + \frac{1}{\sim_e}} \qquad (3)$$

the corresponding new amount of flow assigned outside, these are obviously to be determined depending on the distance *x* from the inner wall of the plate.

Consequently, the amount of energy needed to reverse the net flow of heat through the wall is given by:

$$q_{tot} = q_i - q_e \qquad (4)$$

where the subscript t indicated the amount of heat subtracted to the ground.

This concept is nearly similar to what happens in heating systems with heat pump. The benefit of this solution and 'that the waste heat from the walls and' provided almost entirely by land and / or a water table, possibly surface.

Based on these reports, the wall thickness can be calculated on the basis of reports presented in such a way as to allow optimum sizing of the heat shield according to materials used and the climate zone in which the building is placed.

In particular, a careful design of the system allows achieving levels of heat loss from the inner wall and serpentine arbitrarily low, only through the appropriate assessment of the variable x feature of the system. In particular, the overall functioning of the system parameters can then be adjusted according to different water temperature in the soil after the exchange.

This dynamic system provides a novel model of insulation which can arbitrarily lower heat loss by varying the only dimensional parameters. The algorithms for positioning and design have been produced by the working group and being about to be published up to now the subject of a standard confidentiality.

CONTAINER SIZING

Containers are strongly standardized in terms of size. Since American standards could only be applied with difficulty to conditions in Europe and other countries, an agreement was eventually reached with the Americans after painstaking negotiations.

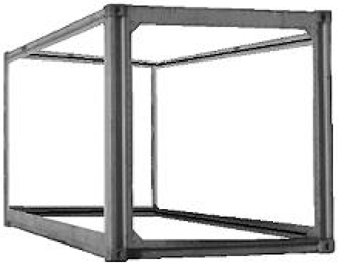

Figure 6 – Container Frame

The resulting ISO standards provide lengths of 10', 20', 30' and 40'. The width was fixed at 8' and the height at 8' and 8' 6". For land transport within Europe, an agreement was reached on a 2.50 m wide inland container, which is mainly used in combined road/rail transport operations.
Fig. 6 represents a typical container frame.

SYSTEM CONSTRUCTION

The system construction can be analysed to easy the assemblies and to reduce the times for mounting operations. It is certainly true that the realization of a circuit with circulating water.

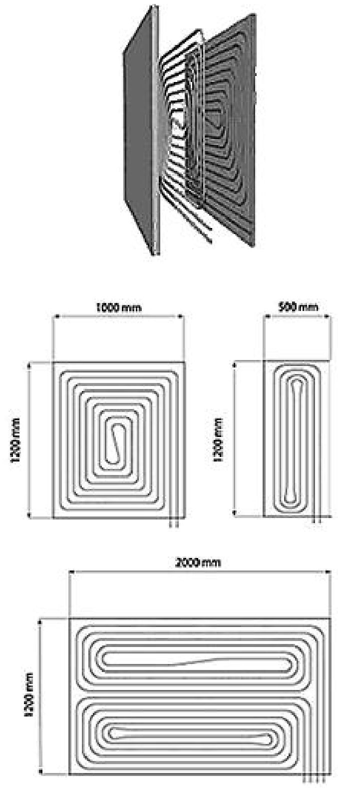

Figure 7 – Plasterboard panel assembly and design

In particular the design of the walls of the system is optimized to minimize the presence of thermal bridges and irregular conduction zones to minimize the energetic dispersions.

Radiating industrial preassembled thermal panels can be easily found on the market.

The design of the system can be designed to include thermal panels realized by plasterboard (Fig. 7) which can be derived by thermal radiating panels for heating. Their coupling is represented in Fig. 8 and represents the possible assembly of the thermal panels to minimize the presence of thermal bridges in the structure.

This architecture allows minimizing the presence of thermal bridges, except in the corners.

The general Container building layout is represented in ANNEX A.

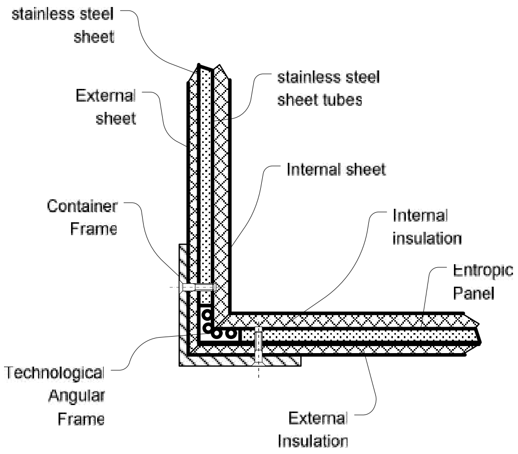

Figure 8 – Section detail

ENERGETIC EVALUATION

Climatic data

To realize an effective evaluation of the energetic performances of the above described container house it can be assumed that it is located in any effective location. In particular, because of the nationality of the authors it has been assumed that the container is located in northern Italy, in the town of Bologna. Climatic data are reported in ANNEX B.

Reference static temperature for determining the heat transmission of a building is defined by Italian and European standards:

- Internal Reference Temperature: Summer 26 °C; Winter 20 °C;
- External Reference Temperature: Summer 35 °C; Winter -5 °C.

Energy calculations can be performed by the assumption of the reported reference values.

Reference container

To ensure an effective level of comparison between both configurations the same wall structure has been assumed and traditional and water based thermal shield with circulating water.

By thermal calculation (Table 1) during winter the overall thermal transmittance $U_{wall} = 0.435$ that means a resistance of the reference container walls results about 2.29 W / m^2 K.

Table 1 – Material properties (MJ/m²)

n.	Material	s [mm]	ρ [kg/m^3]	k [W/mK]	α [W/mK]	c [J/kg K]
	External				25	
1	Steel	1	8000	17		500
2	Polyurethane	20	40	0.022		1600
3	Steel	1	8000	17		500
4	Internal Shield	42	900	0.21		1000
4	Steel	1	8000	17		500
5	Polyurethane	40	40	0.022		1600
6	Steel	1	8000	17		500
	Internal				7.7	

The calculations have been realized by a certified Italian (16) freeware (18) for the thermal resistance calculation. In particular it has been adopted TerMus-G, a software for the calculation of thermal transmittance and Glaser diagrams of walls, floors and window areas.

It has also assumed to use a 20 ft container represented in Annex A.

Windows have been assumed to have an overall thermal transmittance U = 1.8 kW/m^2 K (a common value on the southern European market).

By assuming the following reference data:

1) Gross external surface: 75.6 m^2
2) Usable area: 27.0 m^2
3) Gross heated volume: 73.0 m^3
4) Degree Days: 2259
5) Shape factor S/V: 1.04 m^{-1}
6) Indoor temperature: 20.0 ° C

The geometric data presented in Table 2 have been assumed.

Table 2 – Geometric Data and Thermal Properties

		NORD
Description	U (W/m²K)	Area (m²)
Wall not insulated container	0.435	30.0
		SUD
Wall not insulated container	0,435	20.4
Windows.	1.800	9.6
		WEST
Wall not insulated container	0.435	8.0
		EST
Wall not insulated container	0.435	8.0
Floor	0.450	29.5
Ceiling	0.435	29.5

The energetic performance can be calculated by energetic certification software DOCET 2.0 (freeware by CTI/ENEA) and monthly results are reported in Table 3 and 4.

Table 3 – Energy monthly balance (Winter)

	Heat dispersion from envelope kWh	Heat dispersion by ventilation kWh	Heat contributions by occupants kWh	Solar Heating kWh	Coefficient of Utilization -	Net Energy Needs kWh
January	933,2	87,3	98,2	196,5	1	725,9
February	732,5	67,8	88,7	247,3	1	465
March	576,4	51,7	98,2	312,5	0,98	226,2
April	165,4	13,7	47,5	136,3	0,86	21,4
October	168,7	13,6	53,9	167,3	0,77	11,5
November	590,9	53,3	95	213,1	1	337,3
December	840,4	78	98,2	187,9	1	632,3

Table 4 – Energy monthly balance (Summer)

	Heat dispersion from envelope kWh	Heat dispersion by ventilation kWh	Heat contributions by occupants kWh	Solar Heating kWh	Coefficient of Utilization -	Net Energy Needs kWh
May	236	20	60,2	204,3	1,86	34,1
June	209,3	15,2	95	338,6	2	210,2
July	103,6	4,5	98,2	363,8	2	353,8
August	136,2	7,8	98,2	351,5	2	305,8
September	306,9	25	95	366,2	1,97	142,4
October	45,8	4	9,5	36,4	1,8	3,3

The average annual energetic values for 1 m^2 of net plant area (Table 5) can be obtained.

Table 5 – Average annual energetic values for 1 m^2 of net plant area

		Winter	Summer
Heat dispersion from envelope	kWh/m^2	148,4	38,4
Heat dispersion by ventilation	kWh/m^2	13,5	2,8
Heat contributions by occupants	kWh/m^2	21,5	16,9
Solar Heating	kWh/m^2	54,1	61,5
Time Constant	h	84,6	84,6
Net Energy Needs	kWh/m^2	89,6	38,9

CONTAINER WITH LESP WALLS

The general model of the system is represented in Fig. 9. It presents a hydraulic circuit where water flows after an exchange of heat with the ground to ensure a thermal shield for the building. In particular the model of the real wall is represented in Fig. 9.

To ensure the best possible distribution of the temperature it can be inserted (on both sides of the adiabatic panels) two metal sheets which ensure the optimal distribution of temperature for this thermal cut.

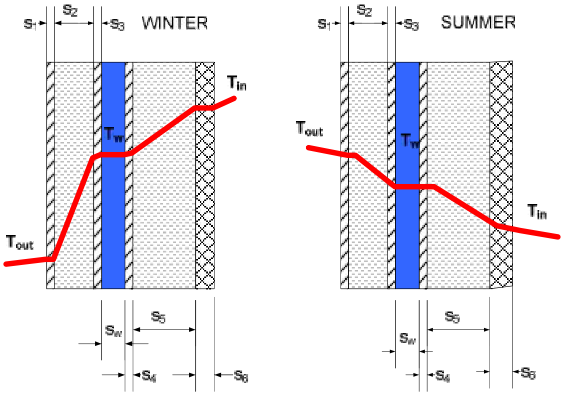

Figure 9 – Thermal model of the panel

It is possible to calculate the main thermodynamic parameters of the system by using the model expressed by equation 3 and 4.

It has been assumed that the thermal insulation by water acts on lateral surfaces and not on the ground floor. By assuming this envelope it has been modelled the system by assuming different values of the thermal barrier temperature.

It has been calculated the thermal conductivities of the external and internal wall.

The obtained values are reported below:

Internal wall: U = 0.7 W/ m^2 K

External wall: U = 1.32 W / m^2 K

The thermal barrier effect has been evaluated for tree different heat barrier average temperatures:

Winter: T_w = 10°C; 15°C, 17°C

Summer: T_s = 18°C, 16 °C, 12°C

Thermal distribution and Glaser diagram have been calculated in both configurations for the two wall parts.

In particular the following average exchanges between the interior and the exterior has been evaluated, assuming a thermal transfer coefficient between the thermal barrier and the interior are represented in Table 6.

Table 6 – Average annual energetic values for 1 m^2 of net plant area with Zebra walls

	Winter			Summer		
kWh/m2	12°C	14°C	20C	12°C	16°C	18°C
Heat dispersion from envelope	119,8	63,6	38,5	80,7	60,3	51,2
Heat dispersion by ventilation	13,5	13,5	13,5	14,4	14,4	14,4
Heat contributions by occupants	21,5	21,5	21,5	33,2	33,2	33,2
Solar Heating	42,3	42,3	42,3	36,5	36,5	36,5
Net Energy Needs	69,5	13,3	-11,8	25,4	5	-4,1

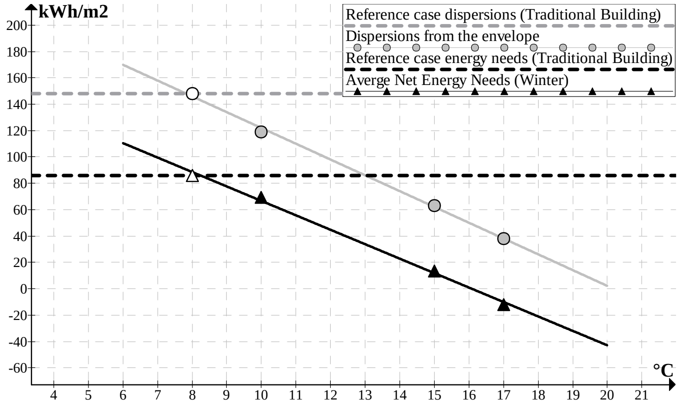

Figure 10 - Dispersions through an internal wall in different conditions and net energy needs during Winter

Fig. 10 represents the graphs of average seasonal heat dispersions from the building envelope and net energy needs by building in different conditions during winter time.

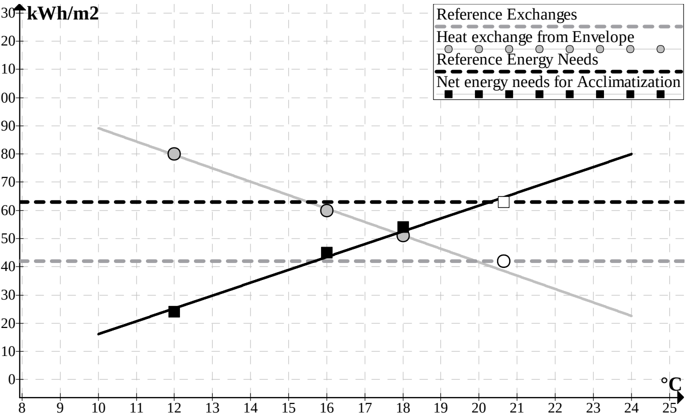

Figure 11 - Dispersions through internal wall in different conditions and net energy needs during Summer

The reference condition is supposed to be equal to the average temperature from October to April. Fig. 11 represents the same for summer building management.

External heat dispersions

Heat dispersions trough the exterior envelope of the acclimatized walls can be calculated by a simple energy balance. In this way it can be easily calculated the water mass flow (and speed in the coils) to produce the necessary thermal barrier.

It can be easily calculated and results are reported as a function of water average temperature in Table 7, both in winter and summer.

Table 7 – Energy dispersions by external walls.

	Winter			Summer		
kWh/m^2	10°C	15°C	17°C	12°C	16°C	18°C
Heat dispersion from Internal	119.8	63.6	38.5	51.2	60.3	80.7
Heat dispersion to the surrounding	38.8	229.8	306.2	22.1	29.5	33.2
Solar Contribution	42.3	42.3	42.3	60	60	60
Net Energy Needs	123.3	-123.9	-225.4	89.1	90.8	107.5

Table 7 can be understood by considering the sign convention adopted: minus means that water must be cooled, while plus means that it must be heated to maintain thermal equilibrium.

It can be interesting to envelope the south facade of the building as a solar thermal increasing the thermal efficiency of the system on one side and reducing solar heating during summer.

Optimal energetic conditions

Optimal energetic conditions are can be defined by some considerations.

In particular the most interesting configuration considered is the one which has an average exchange temperature of 12°C during winter and 18 °C during summer. In this case the water can be operated and exchange at groundwater temperature, by use of ground based exchangers, having a free energy contribution such as the one schematized in Fig. 3.

Assuming that the ground water temperature is 14° C, the maximum consented difference of temperature during winter is 1° C and the same during summer. It is evident that in the case of external average temperature between 12 and 18°C the system has a much reduced convenience. In particular the analysis of system convenience can be performed on the basis of the following schema (Table 8).

Table 8 – Operative Model

Month	Average Temperature °C	Operability Model	Traditional Building Net Energy Needs kWh	ZEBRA Building Net Energy Needs kWh
January	4.5	Water 12°C	935.0	595.5
February	7.9	Water 12°C	734.0	381.7
March	12.1	Water 12°C	577.6	185.4
April	17.3	Water	165.8	19.9
May	21	No Water	0	0
June	23.6	Water 16°C	-23.5	-12.5
July	25.6	Water 16°C	-235.3	-53.0
August	21	Water 16°C	-109.5	-45.0
September	15.4	No Water	0	0
October	9.9	Water 12°C	169.1	7.1
November	5.3	Water 12°C	592.1	260.6
December	4.1	Water 12°C	842.0	512.5

The comparison of annual thermal needs demonstrates the advantage of the thermal shield with water (Table 9).

Table 9 – Energetic comparison in defined operative conditions

	Traditional Building Net Energy Needs [KWh]	ZETHa Net Energy Needs [kWh]	Difference [kWh]
Summer	4015.6	1962.7	2052.9
Winter	368.3	110.5	257.8

To describe the wall behaviour an equivalent thermal transmittance can be defined (Eqn. 5).

$$U_{eq} = U_{wall} \cdot \frac{\dot{Q}_{ZEBRA}}{\dot{Q}_{wall}} \qquad (5)$$

In these operating conditions it has been evaluated as 0.342.

The energetic exchanges needed for the water thermal shield can be evaluated and water mass flow velocity can be defined. By assuming an efficiency of the heat exchange equal to 0.5 it can be evaluated the following data (Annex C). Pipes are assumed to have a diameter of 1” (24.5 mm) and operations are assumed to be 16 hours per day.

It can be verified that the required operating conditions are good and that water velocity in the defined operative conditions are good and ensures quiet operations.

Water pumping average power can be evaluated in about 0.18 kW assuming a conservative efficiency about 0.8.

It means that overall annual consumption for 16 hours of work a day it can be calculated the overall annual consumption for pumping (about 870 kWh/year).

Table 10 Air Conditioner Performance Table

Mass of treated air	m^3/min	9
Cooling Capacity	kW	3.5
Cooling Electric Consumption	kW	1.1
Heating Capacity	kW	4
Heating Electric Consumption	kW	1.1

Assuming to use an air heat pump conditioner with the following performance table (Table 10) for conditioning it can be determined an electric energy need for acclimatization of about 650 KWh.

OTHER ENERGY NEEDS

To ensure a complete satisfaction of users needs it has been evaluated on one side the necessary energy for acclimatization and the necessary energy for any other domestic use.

In particular the following consumption data have been evaluated for one occupant (Table 11).

Table 11 – Appliance consumptions

Appliances	Average Annual Energy Consumption [kWh/Year]
Refrigerator 350 l Energy Class A+++	340
Washer 7 kg Energy Class A+++	140
Dishwasher 7 kg Energy Class A+++	130
Vacuum Cart	70
TV LED 32"	120
Lightening	170
Electric Microwave/Grill Energy Class A+	230
Laptop Personal Computer	250
Other consumptions	300
Total	1700

Total consumptions including water pumping necessities and air treatment are about 3.25 MWh/year.

Hot water production consumption can be evaluated by European standards in about 0.800 MWh/year.

Energy Production

Energy production for sanitary use can be produced using solar heating modules which can be applied on the vertical façade with south orientation. A 6 m^2 solar thermal plant is expected to produce of about 1.800 MWh which is almost double.

Considering the above mentioned consumptions and the acclimatization consumptions it can be calculated the overall energy needs of living can be satisfied by renewable entirely stored on the ceiling of the container house. These conditions can be ensured together with other energy needs by a 3 kW photovoltaic plant (Table 12).

Table 12 Photovoltaic Performance

Photovoltaic		
Solar tracking mode	Fixed	
Slope	°	10.0
Azimuth	°	0.0
Type	Poly	
Power capacity	kW	4.00
Module Power	kW	250
Efficiency	%	15%
Number		12
Nominal operating cell temperature	°C	46
Temperature coefficient	% / °C	0.4%
Solar collector area	m²	20
Miscellaneous losses	%	3.0%
Inverter		
Efficiency	%	95.0%
Capacity	kW	2000.0
Miscellaneous losses	%	3.0%
Summary		
Capacity factor	%	12.9%
Electricity exported to the grid	MWh	3.5

Total photovoltaic production and the thermal production are more than the required needs and can be personalized for specific applications and deployment of the container house.

INTERNAL COMFORT

The obtained results show that the energetic behaviour of the proposed building with a thermal shield realized by circulating water is very interesting in terms of energy saving.

On the other side the new wall model presents also the advantage of increasing human comfort. It is well known that Macpherson [18] identified six factors that affect thermal sensation. These factors are air temperature, humidity, air speed, mean radiant temperature (MRT) [19], metabolic rate and clothing levels.

It is not sufficient for heat comfort only to heat the air on certain temperature. Feelings of heat or cold perception are more complex and are influenced by:

- temperatures of areas limiting the heated area;
- velocity of air in room (draught);
- personal activity and clothes.

A fundamental importance is assumed by the temperatures of areas limiting heated area e.g. walls, ceiling, floor and windows. Cold walls remove radiated heat from the exposed skin and clothes, ensuring a better perception by occupants.

In particular the proposed building system allows realizing an effective regulation of the indoor Mean Radiant Temperature which is usually regulated by enclosure performances.

During winter, as the quality of wall increases, the wall is also warmer and therefore higher the mean radiant temperature.

The ZETHa concept, which needs a further investigation and analysis, helps to maintain an effective balance between the operating temperature and the mean radiant temperature can create a more comfortable space.
The comfort level can be better than other conditioning systems because thermal loads are satisfied directly by the envelope. Only air ventilation is required for cooling and a very limited air heating is required during winter [21].
In this case the acceptable range of operative temperature for radiant cooling system is 18-26°C [22. 23].

Predicted Mean Vote Index

The thermal comfort is assessed by ASHRAE thermal sensation scale by using PMV. Predicted Mean Vote Index. In this way it is possible to assess thermal comfort in an occupied zone based on the conditions of temperature, mean radiant temperature, relative humidity, interior air velocity, metabolic rate, and thermal insulation of the subject's clothing. PMV values range from -3 (cold) to +3 (hot).

The equation proposed by Fanger [24] can be useful to define the PVM and is reported in eqn. (6):

$$PMV = \left(0.303 \cdot e^{-0.036M} + 0.028\right) \cdot (H - L) \text{ (6).}$$

where H is the internal heat production rate of an occupant per unit area [W/m^2], L includes all the modes of energy loss from body [W/m^2], M is the metabolic rate per unit area[W/m^2].

Predicted Percentage Dissatisfied index

The other fundamental wellness parameter is PPD (Predicted Percentage Dissatisfied index) which is a quantitative measure of the thermal comfort of a group of people at a particular thermal environment. PPD index considers that at least aprox. 5% of people in a group will be dissatisfied with the thermal climate - even with PMV = 0.

PPD index is calculated by the following expression:

$$PPD = 100 - 95 \cdot e^{\left(-0{,}03353 \cdot PMV^4 - 0.2179.\ PMV^2\right)} \text{ (7)}$$

Wellness indices calculation

On the basis of the above cited parameters it is possible to make an effective calculation of the expected wellness conditions. Calculation data are reported in Table 13.

Table 13 – Wellness indices calculation data

Parameter	*Unit*	*Winter*	*Summer*
Clothing	clo	1.80	0.80
Air temp.	°C	20.0	26.0
Mean radiant temp.	°C	17.0	22.0
Activity	met	1.0	1.0
Air speed	m/s	0.15	0.15
Relative humidity	%	50.0	50.0

PMV and PPD calculations have been done in both cases with very interesting results. They have been reported in Table 14.

Table 14 – PMV and PPD calculations

Parameter	*Winter*	*Summer*
Operating temp. °C	18.5	24
PMV	-0.1	-0.1
PPD	5.2	5.2

Wellness graphic PPD on PMV is reported in Fig 12 both in summer and winter conditions reporting the calculated values.

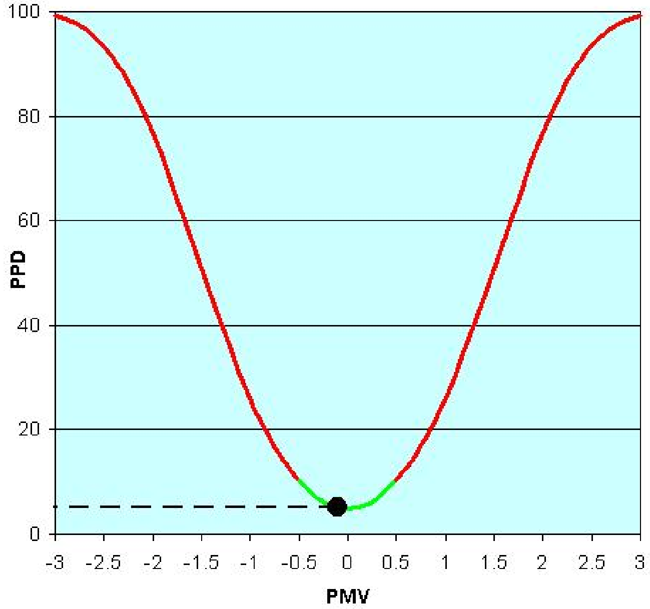

Figure 11 – Expected wellness conditions for ZETHa building concept

By the results reported in Table 14 and Fig. 12 it is possible to verify that the internal conditions are very good verifying initial expected evaluations about internal comfort.

CONCLUSIONS

The proposed building model presents an effective reduction of the thermal needs by using the water circulation LESP wall. In particular these applications regulating the temperature of the internal walls with a negligible energy need can increase the radiant comfort for occupants, maximizing internal wellness.

It also defines a low cost and easily mobile solution for a comfortable life in any situation of temporary needs of a structured environment with the maximum comfort.

It has been demonstrated that the considered configuration of the building leads to excellent condition of comfort.

The building concept presents also the advantages of being more than auto sufficient energetically and can be personalized in terms of renewable production using any climatic reference. Further studies are also necessary to produce an effective optimization of the container house in terms of wall composition and of plant optimization.

By demonstrating the energetic feasibility and some technical features related to this building concept the authors aim to promote an international group of study comprising research institutions and companies which could lead to the optimization of this building concept, its personalization for different operative scenarios and to its industrialization.

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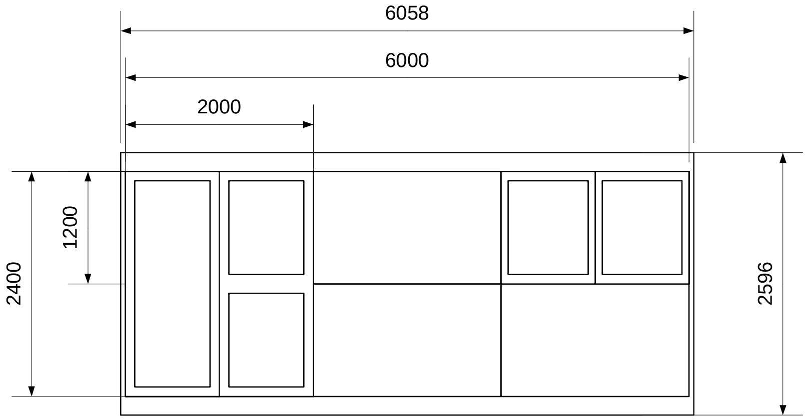
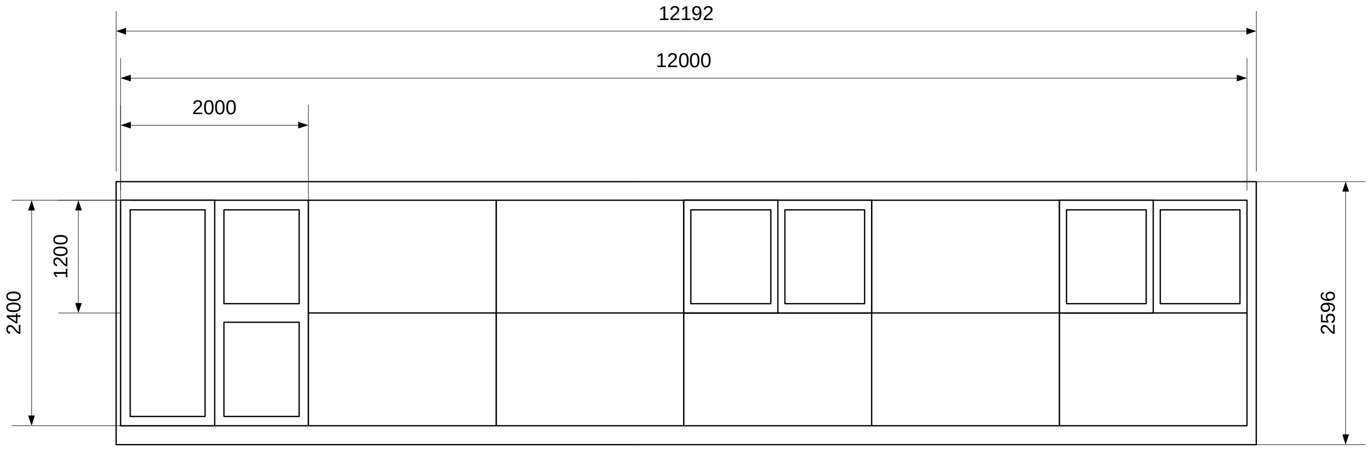
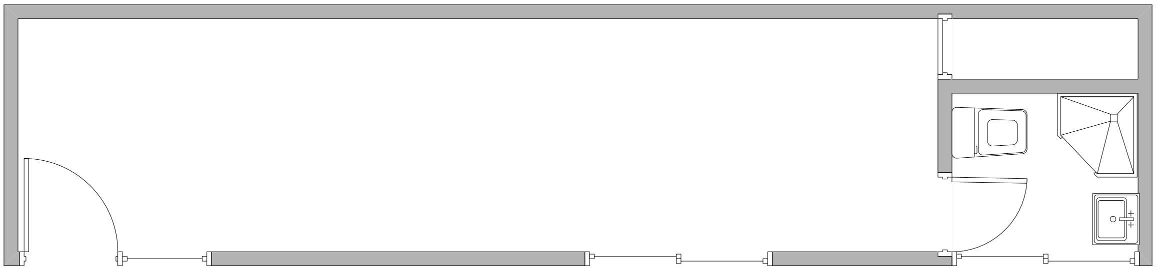
ANNEX A

BUILDING SCHEMATICS







ANNEX B

CLIMATIC DATA

Table B.1 – Climatic Data (Bologna. Italy)

Month	Air Temperature	Relative humidity	Daily solar radiation horizontal	Atmospheric pressure	Wind speed	Earth Surface temperature	Heating degree-days	Cooling degree-days
	°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	2.5	82.0%	1.22	98.8	1.7	3.2	481	0
February	4.4	75.2%	1.91	98.7	1.9	4.5	381	0
March	9.2	70.0%	3.12	98.5	2.4	9.1	273	0
April	12.9	70.8%	4.38	98.1	2.6	13.2	153	87
May	18.2	68.0%	5.45	98.3	2.5	19.2	0	254
June	22.3	65.5%	6.08	98.4	2.6	23.1	0	369
July	25.1	63.4%	6.15	98.4	2.5	26.0	0	468
August	24.6	66.0%	5.26	98.4	2.4	25.7	0	453
September	20.2	70.6%	4.04	98.5	2.2	21.2	0	306
October	14.7	80.3%	2.55	98.6	1.8	15.4	102	146
November	8.2	83.9%	1.39	98.5	1.7	8.8	294	0
December	3.8	83.0%	1.05	98.7	1.8	4.6	440	0
Annual	13.9	73.2%	3.56	98.5	2.2	14.6	2.124	2.083
Measured at	m				10.0	0.0		

Table B.2 – Solar radiation in Bologna (MJ/m²)

	ORIZZ	NE	EST	SE	SUD	SO	OVEST	NO	NORD
January	4.5	1.8	3.5	5.8	7.4	5.8	3.5	1.8	1.7
February	7.9	3.2	6.1	9	10.7	9	6.1	3.2	2.6
March	12.1	5.4	8.8	11	11.6	11	8.8	5.4	3.8
April	17.3	8.5	11.9	12.6	11.2	12.6	11.9	8.5	5.5
May	21	11.1	13.8	12.7	10.2	12.7	13.8	11.1	7.9
June	23.6	12.8	15.2	13.1	10	13.1	15.2	12.8	9.7
July	25.6	13.6	16.8	14.7	11.1	14.7	16.8	13.6	9.5
August	21	10.5	14.3	14.3	12	14.3	14.3	10.5	6.6
September	15.4	7	11.1	13.1	12.9	13.1	11.1	7	4.3
October	9.9	4.1	7.6	10.7	12.4	10.7	7.6	4.1	3
November	5.3	2.1	4.2	6.8	8.5	6.8	4.2	2.1	1.9
December	4.1	1.6	3.3	5.7	7.2	5.7	3.3	1.6	1.5

ANNEX C

CALCULATED DATA

Table C.1 – Operative evaluations

	Dissipations Through the External Envelope [kWh]	Dissipation From Building Interior [kWh]	Energy Needs By Water [kWh]	Necessary Water Circulation (l/day)	Necessary Water Circulation (l/s)	Water velocity (m/s)
January	2656.3	767	1889.3	903.69	0.52	1.11
February	2081.7	597.6	1484.1	709.87	0.41	0.87
March	1629.8	459.4	1170.4	559.83	0.32	0.69
April	462	124.4	337.6	161.48	0.09	0.20
May	0	0	0	0.00	0.00	0.00
June	-287.7	-85.6	-202.1	96.67	0.06	0.12
July	-269.5	-144.1	-125.4	59.98	0.03	0.07
August	-363.1	-51.8	-311.3	148.90	0.09	0.18
September	0	0	0	0.00	0.00	0.00
October	469.6	124.8	344.8	164.92	0.10	0.20
November	1672.5	473.1	1199.4	573.70	0.33	0.70
December	2389.1	686.9	1702.2	814.20	0.47	1.00