Acta Technica Napocensis: Civil Engineering & Architecture Vol. 56, No. 4 (2013)
Journal homepage: http://constructii.utcluj.ro/ActaCivilEng
Special Issue: International Conference Sustainable Solutions for Energy and Environment-EENVIRO 2013.

Ecological House with Green Energy

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(Accepted 11 October 2013; Published online 26 December 2013)

Abstract

This paper describes an ecological building with walls made of straw bales that use more than 80% renewable and geothermal energy for building requirements.The first section presents the importance of energy efficiency performance in housing industry. Buildings in general are responsible for about 38% of total energy consumption. Meanwhile, statistics show that the same buildings are responsible for 30% of greenhouse gases emissions. Following the energy policy objectives, the focus of this paper will be set on ecological and passive housing made of straw bales that could use more than 80% green energy. This type of building combines the advantages of low specific energy consumption with the significant reduction in greenhouse gases emissions. The second section presents the potential performance of a heat recovery system of the ground and groundwater. For the building heating is used a air / water heat pump that uses the air geo thermal energy potential with a Canadian well style system that works together with a groundwater potential recovery system. The heat pump is installed in dedicated equipment space and could deliver the liquid heating fluid at 40 to 50 deg C. The building ambient temperature set point being at approximately 20 deg C. The third section shall analyze the direct and diffuse solar radiation potential. This potential is capitalized for building heating through the glass surfaces and for electricity producing using a photovoltaic' of grid" unit. The fourth section shall analyze the specific energy consumption using the building heat balance equation. Of the total annual energy (heating, cooling, lighting, utilities) share electricity from the national grid is 18….20% heat recovery plant from the ground and ground water heat pump ensure 55...60 % and 20....24% solar energy.

1. Introduction

The straw bales have been used in thermal insulated living quarters since 1850 [1], when in America straw baler's machine was invented. The passive house concept see referance [8],[9] is also very well known and the energy crisis made it very popular.

The subject of this paper aims to combine these two concepts in order to obtain a house with an interior and exterior ergonomic design, high energy efficiency and the expected specific energy consumption lower than passive houses.

As building heating system, an air to water heat pump has been considered. The geo thermal potential used with a type "Canadian well" that works simultaneously with a recovery of ground water thermal energy potential. To ensure the air to water heat pump coefficient of performance COP more than 3, the heat pump was installed in a dedicated technological space.

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Figure 1 shows the house floor plan, the attic plan and 3D image of the house. The usable space area is about 200 m^2.

The building envelope was built using straw bales as building bricks, structural wood for framing and natural clay plaster with natural organic binders as walls exterior coating. This component configuration allowed use of 85% organic material. (straw bales, wood, natural clay)

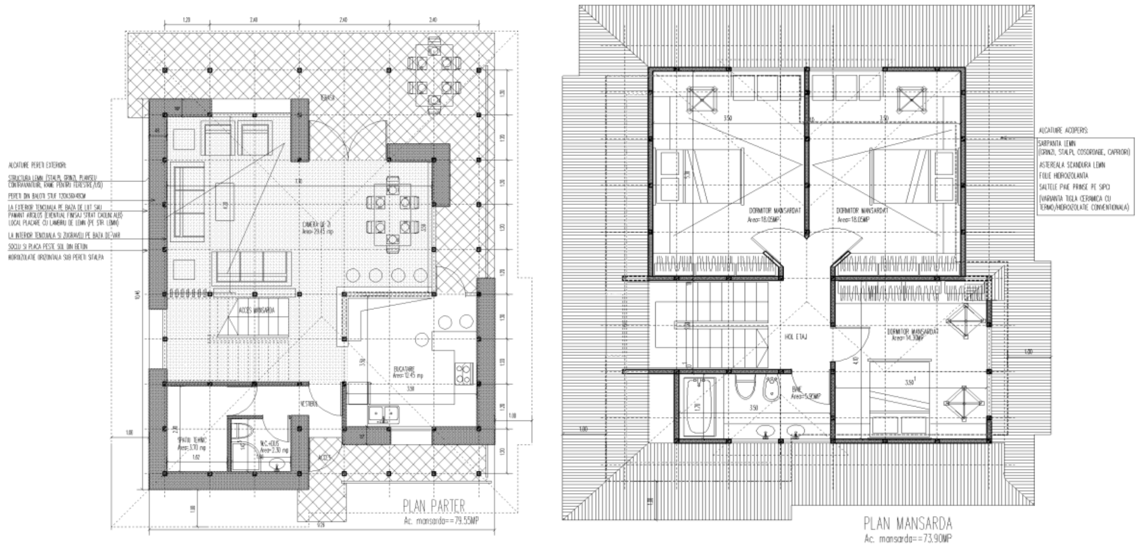
The clay mortars ensure healthy indoor climate with a constant relative air humidity of 45-55%. The clay has the ability to absorb moisture and was able to reduce the relative humidity ration inside the rooms, maintaining the air humidity at a comfortable level. The roof is made of bales of straw and reed fixed on a wood frame (Figure 1). The 45^0 roof angle ensures rapid discharge of rain water. On the roof section with southern orientation are installed 12 solar collectors capable to produce up to 24 % of the necessary power required by the house.

The exterior wall thickness is 500 mm and has a heat resistance of 11 m2 * K / W. The walls thickness allows the installation of two rows of windows that are fitted with insulating glass panes having low emittance coatings that help reduce the heat loss through the glass surfaces. The thermal resistance of the glazed surfaces is exceeding 1.25 m^2 * K / w.

The solar radiation share is 15 to 20% of the necessary heat of the house. The depth of window opening is adding partial shading capability without any additional components required.

The house roof architecture is designed with overhang to provide a high shading coefficient during the summer. In winter, when the sun angle is up to 60 degrees, it ensures a high solar radiation absorption and in summer, when the sun angle is up to 90 degrees, significantly reducing the direct radiation heat.

3D image of the house



House attic plan House floor plan

Figure 1

2. The potential soil and groundwater heat use

The heat recovery from ground and groundwater system is installed in a self-supporting annex construction made of wood framing and straw bales walls, fitted with two windows located in opposite directions to enhance the natural draft ventilation (Figure 2 Operating diagram for heating system and heat recovery).

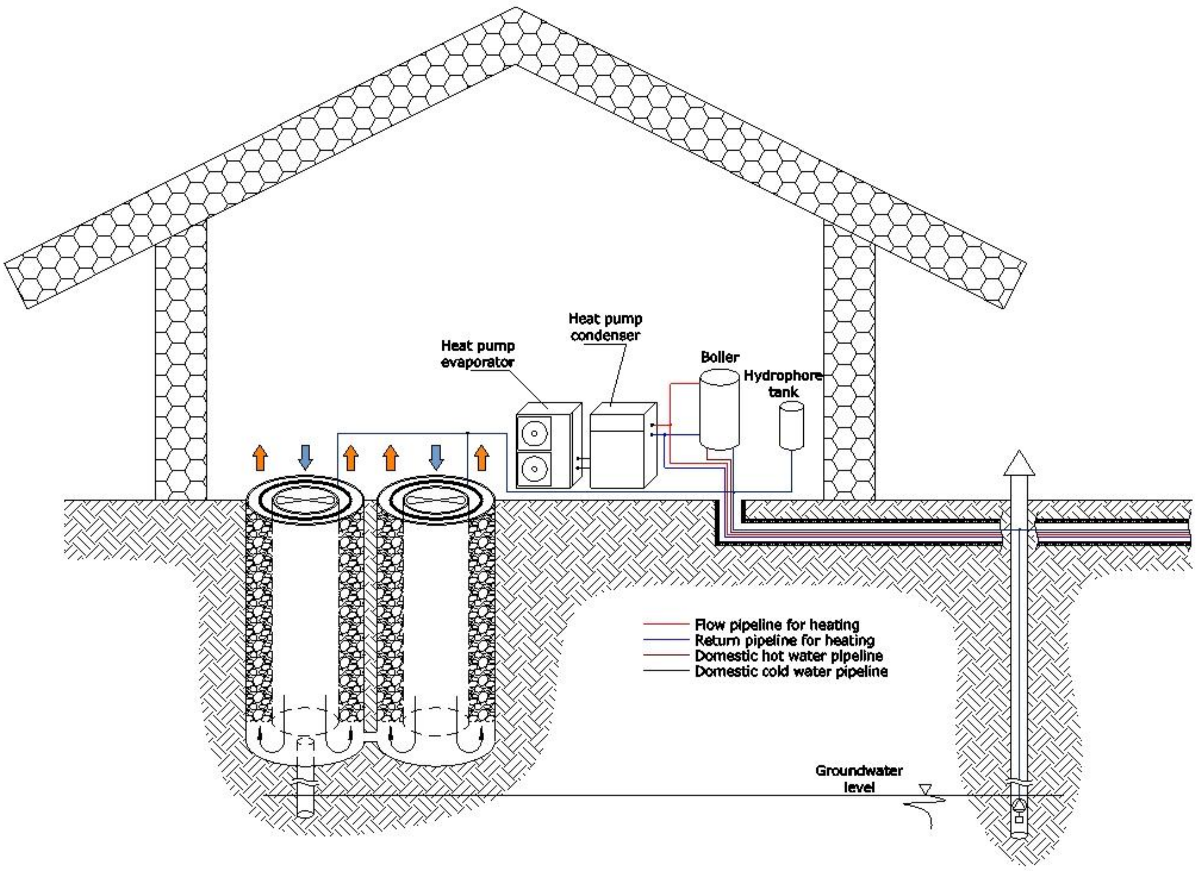


Figure 2 Operating diagram for heating system and heat recovery.

This structure could accommodate two vertical 6 m deep Canadian wells having the protective tube diameter of 1 m. In this two Canadian wells are installed inner tubes with 0.75 m outer diameter. The space between the two tubes is filled with honeycomb material used commonly in cooling towers. At the top of the inner tubes, two axial fans are fitted to provide forced air circulation from the room through the two Canadian wells.

This system represents the soil heat recovery potential system, well-known as "Canadian well". The novelty of this system is that it combines the heat recovery from the Canadian wells and from the ground water.

Ground water pumped from an external well is sprayed onto the honeycomb material and flows through the material. In this way there is a heat and mass transfer between the water that flows from top to bottom and air circulating from bottom to top. The heat and mass transfer is a characteristic polytrophic processes transfer, specific for cooling towers. Also, the annex construction accommodates the air/water heating pump that consists of an Inverter technology type pumping unit, a CFC heat exchanger and a CFC/ domestic water heat exchanger. The CFC/ water heat exchanger is connected to the house heating system and delivers heating agent with the right temperature for space heating, respectively $50^0C/40^0C$. The house heating system uses heating static bodies (type PURMO) designed for operation with low temperature heating agent. In these conditions the interior spaces of the house will be provided a minimum temperature of 20 ^0C

The heat recovery from the Canadian wells and from the ground water assures in the annex construction a temperature higher then zero degrees, during heat pump operation. Under these conditions, the conventional air / water heating pump works with a performance coefficient, COP > 3, even for extreme temperatures of -15 up to -20 ^0C, due to the heat recovery system. In winter days with positive temperature, the recovery unit automatically stops and heating pump works with the exterior air that is circulated through the two windows of the annex construction. The windows opening and closing is performed by an automatic control unit.

From the specialized literature, the recommended speed for air circulation through the Canadian well has to be between 1 and 3 m/s see referance [2]. For the heat recovery unit described above, it has chosen a speed of 1.2 m/s. The simplified equation for heat thermal transfer from the ground and groundwater is:

$$Q_{drilling\ hour} = Q_{Canadian\ well} + Q_{water} \quad (1)$$

where:

$Q_{drilling}$- is the total energy that is possible to be recovered from the well, in an hour,

$Q_{Canadian\ well}$ –is the energy possible to be extracted from ground using vertical wells, for well inner of $S_{drill} = 37\ m^2$; P_{minim}=30Wh/m^2 see reference [4]

$$Q_{Canadian\ well} = S_{drill} * P_{minim} = 1130\ Wh \quad (2)$$

Q_{water} is the heat intake from ground water with temperatures of 8 - 10 ^0C, calculated with the Wittorf Rasch method for polytrophic transfer see reference [3] (Figure 3 Air treatment process using groundwater).

$$Q_{water} = G_{air} * \rho * cp * m * (T_{B1}-T_{B2}) \quad (3)$$

where

G_{air} - is the air flow that is circulated through the honeycomb material located between the wells tubes;

ρ - is the air density, at a temperature of 5 ^0C;

c_p -; air specific heat, for a temperature of de 5 ^0C;

m - is the spraying coefficient, m = 1 kg_{apa}/kg_{aer};

T_{B1} - is the ground water temperature at the honeycomb material input point, see Figure 3 (the upper part of the well);

T_{B2} - - is the ground water temperature at the honeycomb material output point, see Figure 3 (the lower part of the well);

Q_{water} = 2323,5 Wh

Check the amount of heat air extracted from groundwater

$Q_{air} = Q_{water} = G_{air} * \rho * cp*(T_B-T_A)$ (4)

where

G_{air} , ρ , cp have the same significances with (3 formula)

T_B – is the air temperature coming out from Canadian Well

T_A – is the initial temperature from the annex construction coming in Canadian Well

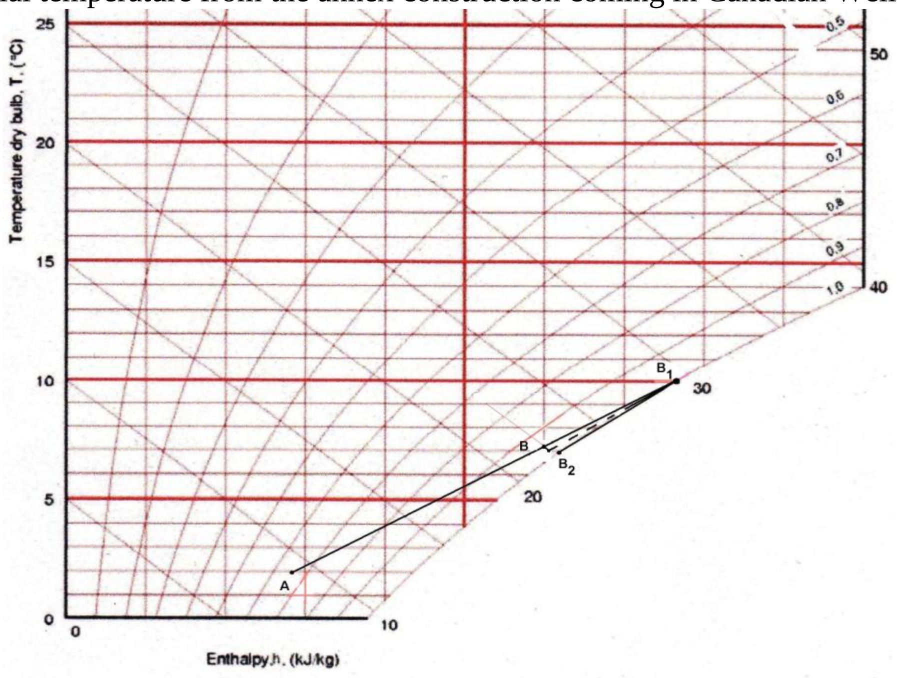


Figure 3. Air treatment process using groundwater

$Q_{Canadian\ well}$ = 1130 Wh

Q_{water} = 2323,5 Wh

$Q_{drilling\ hour}$ = 3453 Wh

The total energy that is possible to be recovered from the well all heating season can be calculate with :

$Q_{maximum\ drilling\ season} = Q_{drilling\ hour}$ * 24 hours * No. of operating days (5)

where:

No. of operating days - is the number of days for heating season calculated with Normative C 107-2005

No. of operating days=184 days: $Q_{maximum\ drilling\ season}$ = 15248 kwh/season

3. The global solar radiation heating potential use. Solar radiation heating potential use

The house architecture is very well adapted to its purpose (building passive), house eaves providing a great shading coefficient during the summer. In winter, when the sun is at an angle of up to 60 degrees, a high absorption of solar radiation is ensured while in summer, when the sun is at an angle of up to 90 degrees, the heat from direct radiation is significantly reduced.

The heat gain due to solar radiation calculation during winter was done for the conditions under which all the available global radiation at the glazed surfaces is taken into account.

3.1 Solar radiation gain through the glazed surfaces

From the meteorological measurements on the daily global solar radiation for Bucharest (for the winter months), the average solar radiation is calculated (using solar radiation on m^2 day, vertical wall) for the 184 days representing the last heating season for Bucharest.

Average daily global solar radiation intensity for vertical glass surface is taken from: http://solarelectricityhandbook.com/solar-irradiance.html

$$Q_{solar\ glass} = (Q_{Jan} + Q_{Feb} + Q_{March} + Q_{Oct} + Q_{Nov} + Q_{Dec}) * 30\ days \qquad (6)$$

where:

$Q_{solar\ glass}$ - is the average solar radiation for heating season (6 month)

Q_{Jan} …. Q_{Dec} - is the daily solar radiation for January, February, March, October, November , December (from Table A)

Table A. Solar radiation to a vertical surface for Bucharest

	Ian.	Feb.	March.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
KWh/m^2day	2,85	3,05	3,15	2,83	2,78	2,71	2,82	3,12	3,34	3,12	2,52	2,08
KWh/m^2month	88,3	88,4	97,6							96,7	75,6	64,5

Using the formula (4) solar useful energy “ $Q_{solar\ useful\ energy}$ “for heating season is calculated (useful energy that reaches through glass surfaces in the house) see reference [5]

$$Q_{solar\ useful\ energy} = c_1 * c_2 * c_3 * m * Q_{solar\ glass} * S_{glazed}\ ] \qquad (7)$$

where:

c_1 = window quality coefficient, $c_1 = 0,8$

c_2 = shielding factor, $c_2 = 1$

c_3 = window total area per glazed surface ratio = 0.8

m = accumulation coefficient in boundry elements = 0.3

S_{glazed} = windows total area

Useful energy that reaches into the house through the glazed surfaces:

$$Q_{solar\ useful\ energy} = 1586,1\ {kWh}/{heating.season}$$

3.2 Solar radiation (direct and diffuse) gain using the photovoltaic unit

The house photovoltaic unit has 12 photovoltaic panels installed on the southern face of roof and having a collecting area of 1.5 m^2 per panel and total collecting area is 18 m^2. The solar photovoltaic system is "of grid" type and has batteries and a sinusoidal inverter for house aplliancesess that requires 230 V ac. During the summer when electricity production is higher than the house energy requirements, the unit can use an "on grid" type inverter that delivers electricity into the national network.

The available power calculation of during the heating season is done with the formula:

$$E_{fotovoltaic\ month} = \eta_p * \eta_i * I_{solar} * S_{solar\ colecting\ area} * NR._{day} \qquad (8)$$

where:

η_p – is the energy conversion efficiency for a POLICRISTALIN type solar panel, $\eta_p = 0,15$

η_i - is the solar unit efficiency (with storage batteries) η_i=0,8

I_{solar} – is the solar radiation, in KWh/m^2day (from Table B)

$S_{solar\ colecting\ area}$ – is the collecting area installed on the house

The average daily global solar radiation intensity for 44˚ angle to the horizontal is taken from: http://solarelectricityhandbook.com/solar-irradiance.html

$S_{captare}$ – is the collecting area installed on the house

Table B. Solar radiation at 44° for Bucharest

	Ian.	Feb.	Mar ch.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
KWh/m^2day	2,85	3,48	4,15	4,44	5,05	5,21	5,33	5,32	4,72	3,71	2,67	2,12
KWh/m^2 month	88,3	101	128,6							115	80,1	65,7
$E_{solar\ electric\ 6}$ month 18mp	190,6	218	277,7							248,3	172,9	141,8

Using the data presented in Table B, the maximum monthly energy which can be used during the heating season is calculated..

Using data from Table B, the useful electric energy delivered by the photovoltaic unit, during the heating season, can be calculated, taking into account the efficiency of photovoltaic unit $E_{electric\ month\ 18mp}$

$$E_{solar\ electric\ season\ 6\ month} = E_{ian}+E_{feb}+E_{march}+E_{oct}+E_{nov}+E_{dec} \quad (9)$$

$$E_{solar\ electric\ season\ 6\ month} = 1249 \text{ kwh/heating season (184 days)}$$

4. The house specific energy consumption assessment

In order o calculate the house specific energy consumption of it is necessary to calculate the heating pump number of functioning hours, using this equation:

$$Q_{necessary\ season\ heating} + Q_{hot\ water} = Q_{heating\ and\ hot\ water} + Q_{solar\ useful\ energy} \quad (10)$$

where :

$Q_{necessary\ annual\ heating}$ - is the house heat necessary calculated according to the technical specification C 107 – 2005, for an inside temperature of, $t_i = 20\ ^0C$ $Q_{necessary\ annual\ heating}$=6761 Kwh/an

$Q_{hot\ water}$ - is the heat need for domestic hot water, calculated according to the technical specification I 9-2009 $Q_{hot\ water}$ =1711 Kwh/an

$Q_{solar\ useful\ energy}$ - useful heat gained from solar radiation, due to to glazed surfaces

$Q_{solar\ useful\ energy} = 1586{,}1\ {kWh}/{heating.season}$

$Q_{heating\ and\ hot\ water}$ - is the heat gain from Heat Pump using ground thermal potential and groundwater potential for covering the house heat need (domestic hot water and heating)

$$Q_{heating\ and\ hot\ water} = Q_{heat\ pump} * 24h * \text{No. of functioning days} \quad (11)$$

where

$Q_{heat\ pump}$ – is the nominal Heating Power provided be Heat Pump in an hour

Using the formula specific to Heat Pumps we can evaluate the electrical power input for the Heat Pump:

$$E_{power\ input} = \frac{Q_{heat\ pump}}{COP} \quad (12)$$

From equations 10 and 11 result the number of days required for a heating pump unit used for heating and domestic hot water.

The chosen Heat Pump that assures the house heating and the domestic hot water is a Carrier type ESTIA 803H-E pump with central heating unit and a domestic hot water unit, having the following characteristics:

$Q_{heating\ power}$ = 8,00 kW,
$Q_{cooling\ power}$ = 6,00 kW,
$E_{power\ input}$ = 2,07 kW

COP = 4,25

To ensure the building's heating requirements are calculated number of days of operation of the pump in the heating season No. of functioning days

$Q_{heat\ pump}$ * 24h * No. of functioning days = $Q_{necessary\ season\ heating} + Q_{hot\ water} - Q_{solar\ useful\ energy}$

$$\text{No. of functioning days} = \frac{Q_{necessary\ season\ heating} + Q_{hot\ water} - Q_{solar\ useful\ energy}}{Q_{heat\ pump} * 24h} \quad (13)$$

No. of functioning days =36 days (864 hours/heating season)

If is considered an average coefficient of performance for the heating pump COP = 3.3, it results using formula 10 that the electricity necessary for the pump functioning, during the heating season is:

$$E_{electric\ HP\ heating\ season} = \frac{Q_{heat\ pump}}{COP} 24h * \text{No. of functioning days} =$$

$$= \frac{Q_{necessary\ season\ heating} + Q_{hot\ water} - Q_{solar\ useful\ energy}}{COP} \quad (14)$$

$E_{electric\ HP\ heating\ season}$ = 2087 Kwh

To ensure that the pump works with good coefficient COP it is necessary that heat recovered from the Canadian wells and from the ground water (1) to be greater than the amount of heat recovered $Q_{recovered\ HP}$ with the Heat Pump working at detrimental condition at 90% load and air temperature in the technological. room is 2^0C. In these conditions the Heat Pump has the following characteristics:

$Q_{heating\ power}$ = 5,22 kW,
$E_{power\ input}$ = 2,07 kW
COP = 2,52

$$Q_{recovered\ HP} = Q_{heating\ power} - E_{power\ input} < Q_{drilling\ haur} \quad (15)$$

3,15 Kwh < 3,453 kWh

Other electricity consumers who are supplied from photovoltaic unit and optionally from the national network are:

- groundwater pump $E_{pomp\ water}$ = 0.35 kwh
- heat recovery fans E_{fans} = 0.16kwh
- air/air recoverers $E_{rec\ air}$ = 0.018kwh
- LED light unit E_{light} = 0.150kwh

The electric energy consumption for all the consumers in the heating season is calculated using the formula:

$E_{electrical\ consumers} = (E_{water\ pump} + E_{ventilators})$* No. of functioning days *24 h + ($E_{lighting}$ *10h* + +$E_{recovery\ air}$ *24h)*$Nr_{day\ heating\ season}$

$E_{electrical\ consumers}$ = 1079.7 kWh

The biggest consumer of electricity in this house is the heating pump. $E_{power\ input}$ = 2,07 kW Power supply of the house is made of photovoltaic installation and the national electricity grid, the power balance equation, resulting the consumption of electricity from the national grid:

$$E_{photovoltaic\ heating\ season} + E_{national\ grid} = E_{electrical\ consumers} + E_{electric\ HP\ heating\ season} \quad (16)$$

$E_{national\ grid} = E_{electrical\ consumers} + E_{electric\ HP\ heating\ season} - E_{photovoltaic\ heating\ season}$

$E_{national\ grid}$ = 1079,7+ 2087kWh - 1249 kWh = 1917,7 kWh

For a home useable aria $S_{useable}$ = 200 m^2 results a specific energetic consumption for the heating season:

$$q = \frac{E_{national\ grid}}{S_{usable}} \quad (17)$$

$$q = 9.6\ {kWh}/{m^2 an}$$

For the hot season (summer), the electricity supplied by the photovoltaic unit is greater than the energy needs of the house even when cooling is needed inside the hot summer days.

5. Conclusions

The innovative nature of the project is generated by the combination of two concepts whose separate implementation has been the focus of research endeavours of the past years: the concept of low-energy passive house and the concept of ecological house, using ecological materials (wood, straw, ecological binders etc.).

The originality contribution of the project proposal are generated by the solutions adopted for the indoor heating system and air conditioning. The heating system uses an air/water heat pump using the thermal potential of the ground, with a “Canadian wall” system which operates simultaneously with a system that uses the energy potential of underground water. The heat pump is installed in a technology room and the heating system may deliver the thermal agent used for indoor heating at temperatures of 50^0C/40^0C.

The most important findings of our theoretical research is the specific energetic consummation for heatig season q = 9.6 kWh/m^2an . We evaluate that this is a very good index taking in to account the price the house.

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