Small Cogeneration by Biomass Gasification on the Decentralized Energy Production

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Abstract. This work consists on the development of a technical and economical energy model, related to the use of a renewable energy source: biomass, for combined cooling heating and power production (CCHP). All system is integrated as a hybrid and autonomous model with e.g. solar PV panels, i.e., implement an environment friendly process, aiming the reduction of energy demand, costs and emissions, on a small hotel.

Also a new standard about energy electrical and thermal demands efficiency consumption of this building, with the biomass gasification cogeneration technology, for self electricity production and to be thermal behaviour certify, to satisfy the new national thermal buildings legislation are distinct goals to achieve.

This system is a good contribution to the sustainable and decentralized energy production, as for local biomass trade development and a way for new profits for the hotel owners by selling electricity and hot water to the neighbour.

Keywords

Energy Efficiency, Renewable Energy, Biomass, Thermal Regulations, Small CCHP.

1. Introduction

Our interest is concerned to the use of biomass: pellets or wood chips as a combustible and simultaneously with other energy supply systems, such as solar PV panels and cold air circuit for heat, cold and electricity production - trigeneration concept or combined cooling heating and power production - CCHP, see fig. 1.

This energy model must be one hybrid and/or autonomous mode in small scale for the fossil energy demand reduction, in one small hotel building. This model will be a way for to reach the eco-efficiency concept and the integrated management consumptions of all energies sources on the building and the waste (liquid and solid) [1].

Also to achieve the certification from national thermal regulations (SCE/RSECE/RCCTE) and a new energy efficiency parameter is another objective. For to reach this goal the thermograph analysis of the building is one methodology use and the forecast calculations of the different energy parameters.

2. Methodology

The national legislation implementation in Portugal about Energy Performance Buildings [2], determines the Buildings Energy Certification, after 2009 to fulfil the European Directive 2002/91/EC. The directive imposes the necessity to measure the energy, to prepare the sanitary hot water and all other important consumption, in order to introduce more deeply the solar systems or other renewable source energy.

The production by cogeneration only will be profitable if the thermal part will be simultaneously usefully with the electricity production. So the laundry timetable that consumes, the main part of electric energy must work, at the same time, the main consumption of sanitary hot water for showers and heating demands.

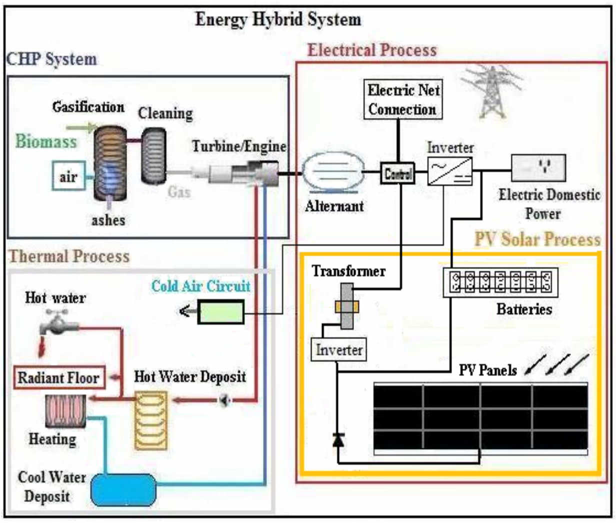

Figure 1 - Energy Model Proposed

The proposed energy model is been applied to one hotel building (Hotel/Albergaria El-Rei Dom Manuel, Marvão-Portugal) and the use of biomass as primary energy source is one way to achieve best building energy performance and also an relevant contribution for the building energy certification.

A. Energy Consumption Forecast Methodology

The simulation method for predicting the energy consumption in our case-study follows SCE, RSECE, and RCCTE [3], guidelines and meets WHO, ISO and CEN standards. We consider the following fundamentals elements:

a) Thermal building features, exterior walls, internal measures divisions.
b) Heating installations, sanitary hot water distributions, insulation features.
c) Air conditioning installations.
d) Mechanical and natural ventilation.
e) Artificial lighting.
f) Building orientation, position and exterior climatic conditions.
g) Passive solar gains and protection.
h) Desired ambient conditions.

We calculate the hourly heat flux through transparent surfaces such as windows and skylight, as well as heat gains through opaque surfaces; however, we exclude small services buildings such as supermarkets, swimming pool covering less than 500m^2, industrial storage buildings, churches, monuments and other buildings exempt from the Portuguese regulations. Total energy needs for heating and cooling, Q_{hc} is calculated as in (1).

$$Qhc = Qv + Qw + Qem + Qg \quad [W] \qquad (1)$$

Qv - Gain/loss corresponding to air removal
Qw - Gain/loss corresponding to heat flow through transparent glass window.
Qem - Gain/loss corresponding to heat flow through opaque surfaces in the absences of solar radiation effect.
Qg - Gains from occupants, mechanical components, radiation, and lighting.

The heat transference through opaque surface in the presence of solar radiation is calculated by (2):

$$Qopaque = U \times A \times (T_{air\text{-}sun} - Ti) \quad [W] \qquad (2)$$

U - Thermal transmission coefficient.
A - Surface area.
$T_{air\text{-}sun}$ - Temperature air- sun.
T_i - Reference temperature.

To determine thermal conduction and verify regulatory parameters for independent units of large or small scale buildings, we collect electricity, fossil fuel and water consumption of the past several years and measure interior and exterior walls and pavements.
The main parameters are:
- Annual Nominal Energy Needs:

Nic - Heating	[kWh/m^2]
Nvc - Cooling	[kWh/m^2]
Nac - SHW production	[kWh/m^2]
Ntc - Global Primary Energy	[kgep/m^2]

The complementary parameters are:
- Building Features: Thermal Transmission Coefficients, Thermal Bridges, Solar Factors, and Insulation Elements.
- Solar Energy Systems.
- Air Evacuation (0.6 units/hour) in compliance with regulatory parameters.
-Thermal Inertia Classes of independent units and small buildings.

To guarantee interior thermal comfort, air quality, reduced CO_2 emissions and needed SHW (sanitary hot water) production, we use the calculation scheme described in Annex A to determine the main and complementary parameters. We divided the country into winter and summer climatic zones.
To determine the maximum nominal energy to produce SHW, we need the following parameters, see (3).

$$Na = (0{,}08x\ M_{SHW}\ x\ nd) / Ap \quad [kWh/\ m^2.year] \quad (3)$$

Na - Maximum limit value for needed energy to produce SHW.
M_{SHW} - Diary medium consumption (40 liters/person).
nd - Days of consumption.
Ap - Shed pavement useful area.

Nominal primary energy needs of independent units and individual buildings are referenced by the global indicator *Ntc*, see (4).

$$Ntc = 0{,}1x(Nic/\eta i)xFpui + 0{,}1x(Nvc/\eta v)xFpuv + Nac\ x\ Fpua \quad [kgep/m^2.year] \qquad (4)$$

Nic - Annual nominal energy needed for heating.
ηi - Heating equipment nominal efficiency.
$Fpui$ - Conversion factor from delivered energy to primary energy for heating.
Nvc - Annual nominal energy needed for cooling.
ηv - Cooling equipment nominal efficiency.
$Fpuv$ - Conversion factor from delivered energy to primary energy for cooling.
Nac - Annual nominal energy needed for SHW.
$Fpua$ - Conversion factor from delivered energy to primary energy for SHW production.

The *Ntc* value of each independent unit or individual building cannot exceed its maximum nominal primary energy value *Nt*, which is calculated in correlation with the *Ni, Nv, Na* values as (5):

$$Nt = 0{,}9(0{,}01\ Ni + 0{,}01.\ Nv + 0.15.\ Na) \quad [kgep/m^2.year] \quad (5)$$

Ni - Delivered or maximum nominal energy for heating.
Nv - Delivered or maximum nominal energy for cooling.

Na - Delivered or maximum nominal energy for production SHW.

B. Heating, Cooling and SHW Needs Calculations

To maintain a constant indoor air temperature at 20°C throughout the whole heating season, the nominal energy needed is determined by the formula (6):

$$Nic = (Qt + Qv + Qgu) / Ap \qquad (6)$$

Qt - Dissipated heat losses.
Qv - Heat losses from air renewal.
Qgu - Delivered heat gains.
Ap - Shed pavement useful area.

Conditions required by the regulations are Nic < Ni. If this value is greater than or equal to the former, the building must be renovated.
To maintain a constant indoor air temperature at 25°C and 50% humidity, throughout the whole cooling season (June to September mouths or 122 days) the nominal energy needed is determined by the formula (7):

$$Nvc = Qg.\ (1 - \eta) / Ap \qquad (7)$$

Qg - Building gross gains of independent unit
η - Gains factor
Ap - Useful paved storage area

Conditions required by regulations require Nvc < Nv. If the latter value is greater than or equal to the former, building alteration need to be make in order to comply with the energy efficiency regulations.
The nominal needs for the production of sanitary hot water, *Nac* are calculated by the expression (8):

$$Nac = (Qa / \eta a - Esolar - Eren) / Ap \qquad (8)$$

Qa - Delivered energy to produce SHW with current systems.
ηa - Conversion efficiency.
Esolar - Solar systems contribution for SHW.
Eren - Solar photovoltaic, biomass or other renewable energy source to produce SHW.
Ap - Shed pavement useful area.

Preliminary calculations for our case-study reveal Nic ≤ Ni. Moreover, the existence of structural deficiencies and the lack of any renewable source energy, lead us to a negative conclusion for the winter season.

To comply with the regulations during the summer season, our energy parameters must satisfy Nvc ≤ Nv. If this condition is not met, improvements can be obtained with the introduction of curtains and correctly implemented natural air ventilation.

C. Thermography for Best Efficience and Consumptions.

One thermograph analysis, see fig. 2 was done along the building as a way to detect thermal leak and isolate walls, windows and door or install new equipment with higher thermal levels.
The wide spread of combined heat and power (CHP) presents a substantial potential for increased energy efficiency and reduced environmental impacts [4]. It is considered to be a priority area for many member states on EU.

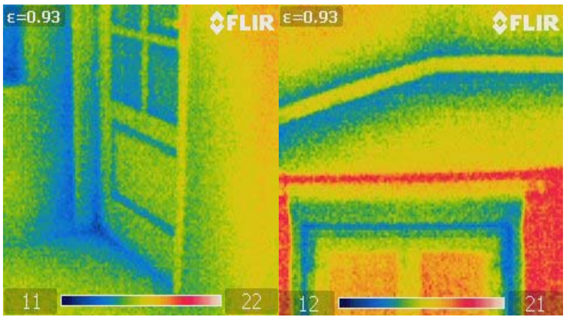

Figure 2 - Door, Ceiling and Window Thermal Leaks.

The gathering of electricity values was already done to conceive the diary load graph, see fig. 3. Also the loads graphs of the higher consumptions equipments on the laundry area, the dryer machine fig. 4 and the ironing maid equipment for sheets fig. 5 was already conceived, in order to understand the best hour for to the equipment operate without electrical consumption peaks [5].
The electrical peaks on the load graph is not a best energy efficience practice. The electrical consymption must be distributed along the day.
Other electrical data consumptions should be knowning and the more relevant are on the services area (kitchen, restaurant, bar), Table I.
These equipments are operate by the employers and should be well done for a best efficiency performance.

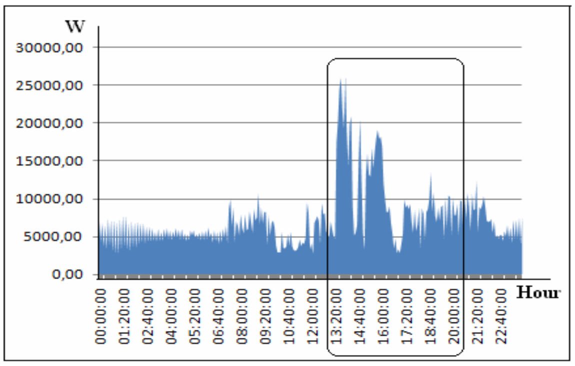

Figure 3 - Electricity Diary Load Graph and Higher Period Comsunption Hours.

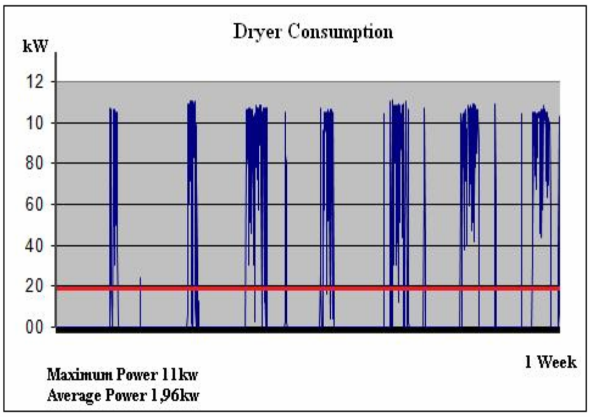

Figure 4 - Electricity Dryer Load Graph During One Week.

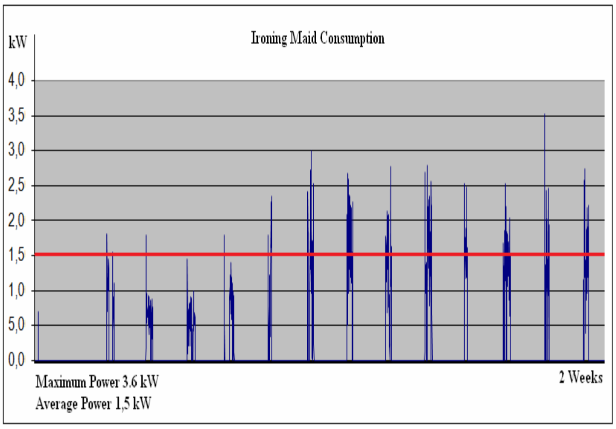

Figure 5 - Electricity Ironing Maid for Sheets Load Graph During Two Weeks.

TABLE I - Equipments Operated by Employers.

Electricity Consumption on the Services (Kitchen, Restaurant, Bar)		
Equipments	**Consumption Monthly Average (kWh)**	**%**
Dryer	425	11,6%
Elevator	350	9,5%
Ventilator	170	4,6%
Dishing Washer (kitchen)	165	4,5%
Ironing maid	120	3,3%
Kitchen Ilumination	90	2,5%
Clothes Washer	75	2,0%
Dishing Washer (Bar)	60	1,6%
Dinning Room Ilumination	45	1,2%
Ironer	40	1,1%
Totaly	42%	

d. Cogeneration System Features.

The down-draft gasifier is the main component of the small modular cogeneration system Fig. 6, integrated with an engine/generator that produce electric power/hour 20kW/h and thermal power/hour 87,8 kWt/h [6]. Also it uses variety of local forest biomass such as pellets or wood chips, Table II.

TABLE II - Power Features by Biomass: Wood Chips & Pellets.

Calorific power biomass - wood chips 13800kJ/kg	*Calorific power biomass - pellets 18900kJ/kg*
Maximum biomass kWh/day 480kWh	*Maximum biomass kWh/day 480kWh*
Wood chips/kWh 1,5kg	*Pellets/kWh 1,102kg*
Max. wood chips/day 720kg	*Max. pellets/day 529,3kg*

This cogeneration process has a relevant overall efficiency associated to the electrical generator equipment for the best performance of this energy model. Next we calculate the efficiency having as reference the minimum values proposed, but taking away 1% taking into consideration a round up case. And the following results will be obtained:

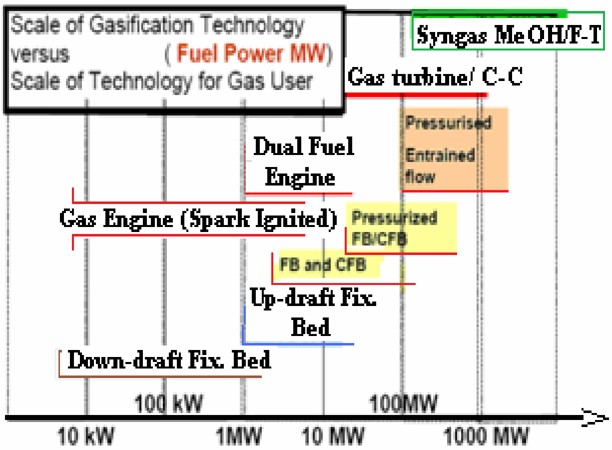

Figure 6 - Gasification Technology Models *versus* Power Generation for each Model [7].

Establishing:

$$\eta_{electrical} = [Electrical\_Energy(kWhe) / Biomass\_Energy(kWhtb)] = 0,25 \quad (11)$$

Inverting this relation comes:

$$[Biomass\_Energy(kWhtb) / Electrical\_Energy(kWhe)] = (1 \div 0,25) = 4 \text{ kWhtbiomass} \quad (12)$$

This means that by each 1kWhe generated we need 1,5kg biomass/wood chips or 1,2kg of biomass/pellets, which is equivalent to 4kWh of biomass and that 1,96kWhthermal.

$$\eta_{total} = (Electrical\_Energy\ Obtained + Thermal\_Energy\ Obtained) \div (Total\ \_Biomass\ Energy) = 0,74 \quad (13)$$

Rate:
(Thermal_Energy Obtained ÷ Electrical_Energy Obtained)
= 0,49÷0,25 = 1,96 (14)

ηthermal = ηtotal - ηelectrical
= 0,74 - 0,25 = 0,49 (15)

After having made calculations, we obtain the average daily power demands for the study case:

143,2kWhelectrical/day *correspond to* 314,52kWhthermal/day

The maximum thermal power generated daily:

Maximun_Thermal_Energy = (Maximun_daily_wood chips ÷ kg de wood chips per kWh) x (Thermal_Energy ÷ Electrical_Energy)
= (720kg ÷ 1,5kg) x1.96
= 940,8kWht (16)

This value surpasses the necessary daily thermal demands. Therefore one should control the amount of biomass consumed. This must only satisfy the daily thermal and power demands.
The downdraft fixed bed gasifier model is the technology use on this energy hybrid system because small kW power will be necessary to produce.
The main function of a gasifier system is the conversion of a solid fuel such as: pellets, wood, wood chips, paddy husk or coal to a gaseous fuel.
This gas is called syngas or producer gas. The combustible components of syngas are mainly (~20% each) hydrogen and carbon monoxide.
Same features of gaseous fuels are better than to solid fuels as they have good combustion performances.
Syngas consists of H_2 and CO, which can easily be ignited by a small spark.
The gaseous fuels can be transported via pipelines from the point of generation / storage to where it is consumed as opposed to solid fuels where they have to be transported via conveyors or trucks! Well one main drawback of using gaseous fuels is that it must be handled safely [8].
Some advantages of gasification uses can be described as follow:
- Produces gas synthesis for more versatile application in power generation.
- Potential for higher efficiency conversion using integrated gasifier combined cycles compared with micro turbines systems.
- Reduce heavy volatilization.
- Compared to combustion systems lower volume of gas requiring treatment to reduce NOx and Sox emissions.
- This system typically produces lower temperatures than direct combustion, so thus decreases potential alkali volatilization, fouling and bed agglomeration/fluidized beds.
- The main applications are for power generation at smaller scales, than direct combustion systems although gas cleaning is expensive.

Another potential to develop is the occasional excesses distribution electricity production, to a neighborhood grid mandates the notion micro grids. The idea of passive energy consumers is being replaced by that of active energy producers.
Also the low costs of energy transportation and distribution, as well as protection of generalized wipe out, make micro grids of several and similar smaller scales systems very competitive.
The desire to distribute occasional excesses in electricity production to a neighborhood grid mandates the notion micro grids [9] and the decentralized energy process will be a reality.
Like conventional energy grids, losses in micro grids increase when congestion is high – at critical periods can be up to 20% [10]. High efficient systems of small cogeneration are available; they usually use thermal power to meet electrical demands [11].

3. Results

To satisfy the electrical consumption peaks at this development stage, it is necessary to buy this small electrical amount to the electrical net company installed. But if the system as an additional solar PV panels and a storage batteries group, these electrical consumption peaks will be supplied, by them and also a percentage of electrical electricity produce can be sell to the electrical company. With the actual tariff prices, for the PV electricity production prices, the payback investment value period is between 7 or 8 years.
This hotel building is inside a castle, than a historic place with restricting architecture. This is a condition for to have only about 19m2 to implant the PV panels. A remain production CHP system time below 20kW will be for to satisfy the demands of the hotel and storage energy.
The electrical energy PV production process is considered as one support module of the cogeneration system and it will be for the electrical peaks hours for self consumption. On the remains hours all the electrical PV production will be for to sell, because the tariff for PV production is very competitive: 0.65euros/kWh.
The simulation done and the local solar conditions, Fig. 7 gave us an annual average PV production for the electrical building consumption about 7,22%, but on the summer mouths it can be higher about 8,23%.
On the figure 7 the value E(sist) = 3780kWh is the variable Eren on equation (8) addition with the contribution of biomass production as primary energy, so the regulations parameters as Nac≤Na and Ntc≤Nt will be satisfy and the building can be certified.
If the efficiency on the PV panels will be better the value 3780kWh will be greater.
The fig. 8 represents the comparative graphic for payback period between wood chips and pellets. For wood chips [12] this payback are 3.14 and 4.68 years and it is the best option and for pellets 8.25 and 12.1 years it is the worst solution for the CHP system economic viability.

Concelho de Marvão
Latitude 39,4°N (nominal) - Longitude 7,4°W (nominal)
TRY para RCCTE/STE e SOLTERM
Fonte: INETI - versão 2004
Obstruções do horizonte: Marvão_10grausObst_Horizonte

Balanço energético mensal e anual

	E(rad) kWh	E(PV) kWh	E(sist) kWh
Janeiro	1990	244	230
Fevereiro	2129	256	241
Março	2837	337	316
Abril	3071	360	339
Maio	3466	396	372
Junho	3538	396	372
Julho	3971	431	406
Agosto	4030	438	411
Setembro	3273	363	341
Outubro	2745	317	298
Novembro	2109	252	237
Dezembro	1888	231	217
Anual	35048	4021	3780

Rendimento global: 10,8%
Produtividade: 1399,8 kWh/Wp

E(rad): energia solar incidente no painel fotovoltaico
E(pv): energia eléctrica convertida pelo painel fotovoltaico
E(sist): energia eléctrica fornecida pelo sistema

N.B. 'E(sist)' é designado 'E solar' nos Regulamentos Energéticos (DLs 78,79,80/06)

Figure 7 - Simulation Results of the PV Production [13].

Finally the maximum cool consumption in summer is 6,4kW for a medium value of 1,6kW. So a refrigerator machine with a compression cycle is the best option feed by the electrical energy produce by the CHP (trigeneration notion) [14].

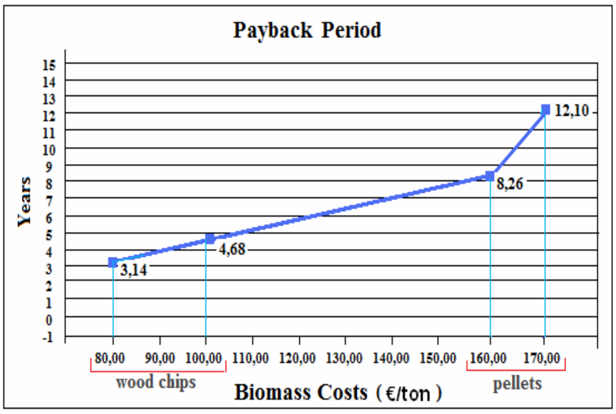

Figure 8 - Payback Period CHP System: WChips/Pellets.

4. Conclusions

After an accurate diagnosis to an hotel energy consumption needs and building structure, few isolated problems were found, in spite of the existing building which has only nine years. The energy necessities for heating, cooling, sanitary heating water and primary energy should respect the thermal comfort buildings regulations to achieve the energetic certification.

We propose one integrated solution based on a hybrid energetic system, with several renewable energetic sources for this case study.

It is a way for the buildings to be certified in agreement to the regulations and lead the buildings proprieties to choose, that renewable energy systems rise the efficiency, with very low emissions and reduce the economic costs, should be a reality on this hotel.

We also want to expand to other similar applications like bakeries, laundries and also for small places where the hot, electricity power and cool are necessary, such as isolate houses.

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