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ESTABLISHMENT OF ENERGY DEMANDS FOR A RESIDENTIAL BUILDING IN JOÃO PESSOA, NORTHEAST BRAZIL

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Abstract. *The idea of sustainability in the residential sector has been spreading with the objective of this sector to improve its environmental performance. The residential sector is a consumer of both electricity and thermal energy (cold and heat). The quantity of each type of energy demanded is influenced by the income of the consumer, the prices of the products that demand electricity, the quantity of people consuming these utilities, the loads inserted in the environment, among others. These demands can be met in a conventional way, consuming electricity directly from the grid, or in an unusual way, through the simultaneous production of two or more utilities (cogeneration), which can result in economic and environmental benefits for the sector. An optimization study is indicated whenever there is the possibility of producing two or more types of energy, in order to meet the energy demands with minimum cost, for example. The optimization depends on the energy demands of the building, electricity tariffs and other energy utilities, and legal regulations. The objective of this work was to obtain the energy demands (electricity, hot water, and refrigeration) for a residential building, for later application in an optimization of the energy supply. EnergyPlus software was used for calculations, a specific tool for thermoenergetic performance of buildings. The building has 20 floors with two apartments of 92 m² on each floor, located in the city of João Pessoa, latitude -7.11 ° and longitude -34.86 °. The final energy demands were 170 MWh / year of electricity, 83 MWh / year of hot water and 242 MWh / year of cooling.*

Keywords: *Energy demands, optimization, electric power, heat, refrigeration, residential*.

1. INTRODUCTION

Residential electricity consumption in Brazil has an average annual growth of 4.7% and consumption has increased more in recent years (Castro and Montini, 2010). This fact is caused by the increase in the number of consumers, increase in income coupled with the growth of the sale of household appliances as well as the higher average consumption per family. Figure 1 presents a Sankey diagram presented by the National Energy Balance 2015 (EPE, 2015), which shows the residential sector as the second largest responsible for Brazil's electricity consumption in 2015.

IEA (2012), mentioned that electricity will account for 65% of energy consumption in Brazilian buildings in 2050 (49% more than in 2012), due to the increase in the consumption of household appliances and small appliances and the proliferation of electrical and electronic equipment. As a result, the decarbonisation of the electricity sector will play an important role in reducing greenhouse effect gas emissions. Improvements in energy efficiency and replacement of fuels will help contribute 47% of emissions reductions, for example (IEA, 2012). The buildings of the residential, commercial and public power classes represent a large part of the share of electric energy consumption in Brazil, currently around 50%, and much of this energy is consumed to provide users with environmental comfort (INMETRO, 2014).

The energy demands associated with the operation of residential buildings are electric energy to power the electrical equipment, thermal energy (heat) for heating the water used in the baths and environmental comfort, and (cold) cooling to air-conditioning the environment (environmental comfort). Energy demands vary widely according to geographic location, type of building, and consumer habits, for example. According to Castro and Montini (2010), the demand for electric energy is influenced by the average tariff of the consumption class in question, by the income of the consumer, by the price of the products that consume electricity and by the prices of a source or well substitute to the electric energy. The demands of thermal energy and cooling will depend on the number of people consuming these utilities, the loads inserted in the environment, the size of the space in question to heat or cool, the location of the building and the materials of the walls of that building.

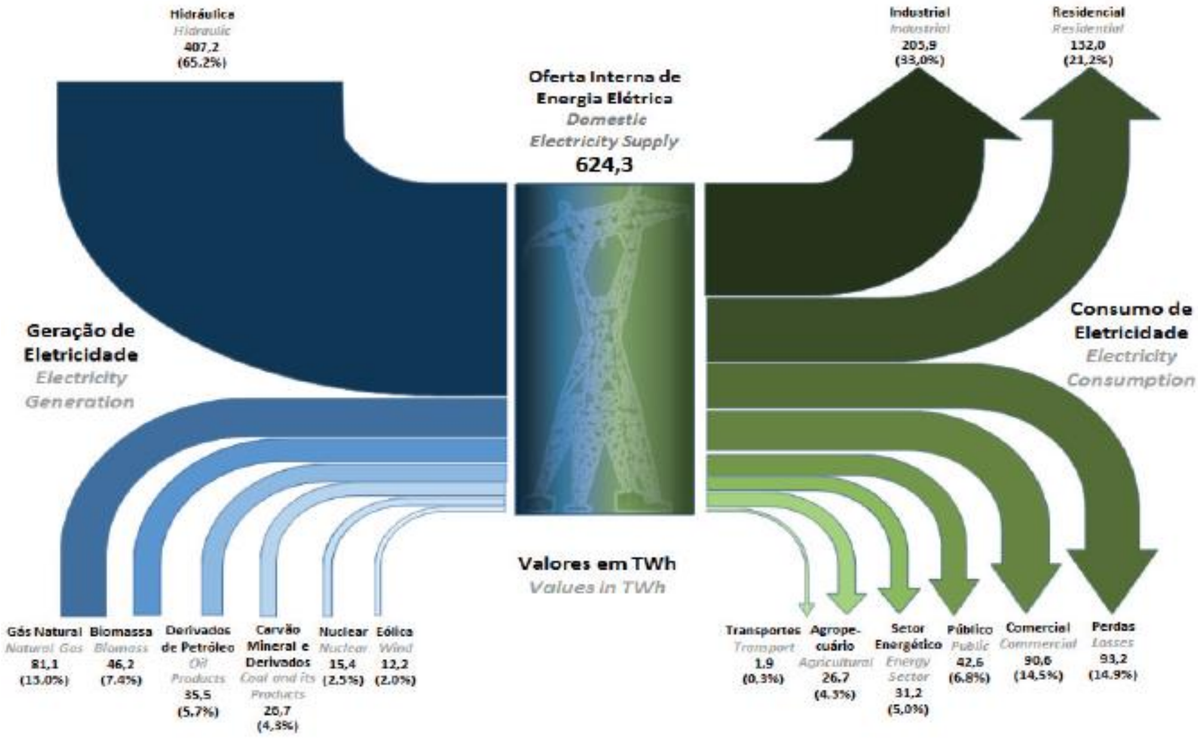

Figure 1: Electricity flow, source: EPE, 2015.

Besides the importance of residential buildings in the energy sector, Garcia (2006), says that the construction industry has a poor tradition in energy analysis and it is often quite complicated to integrate a team of architects and engineers working together in the project of a building. The absence of energy studies in buildings can bring unsatisfactory results for a long time when considering the life time of buildings. Due to these factors, an energy study in this sector is very convenient.

The quest for a more sustainable standard of living is discussed worldwide, in the media, in schools, in magazines and in scientific conferences (Garcia, 2006). The industrial and commercial sectors have already been under pressure to improve their energetic (and environmental) performance and this position has been spreading to the residential sector, which, as previously mentioned, is a sector that has a significant share of electricity consumption (Melo and Carvalho, 2016).

There are several ways to meet the energy demands of a building: in the usual way, from the electricity grid or unconventionally, for example, from the simultaneous production of two or more energy needs (cogeneration).By combining the concept of cogeneration with energy integration in an optimization model, we obtain an optimized configuration of equipment that operates in an optimized way, satisfying the energy demands with lower costs (if the objective is to minimize the cost). As a result, there is a greater use of energy resources, and as a consequence, reduction of costs and emissions. However, the implementation of a more complex system must be questioned if it is justified economically, or how it would be the best way to implement among the various possibilities to meet these energy demands. To answer these questions, an optimization of the energy system must be performed.

In the case of energy optimization, hospitals were optimized in Spain from an economic point of view (Lozano, *et al*., 2009; Carvalho, 2013), and from environmental perspectives (Carvalho, Serra and Lozano, 2011a; Carvalho, Serra and Lozano, 2011b), or considering both perspectives (Carvalho, Lozano and Serra 2012). The concepts were extended and adapted to a hospital in Canada (Romero, Carvalho and Millar, 2014), and even to Canadian mines (Romero, Carvalho and Millar, 2016; Carvalho, *et al*., 2014; Millar, Carvalho and Levesque, 2014). Brazilian hospitals were optimized based on mixed integer linear programming (PLIM), with objective economic function (Delgado, *et al*,. 2015; Carvalho, Romero and Millar, 2014), and environmental (Carvalho, Delgado and Chacartegui, 2015; Carvalho, Abrаão and Delgado 2016).

The residential sector was the focus of the work of (Melo and Carvalho, 2016), where tools were discussed to achieve sustainability in the residential environment. The objective of this work is to facilitate the expansion of the

application of mathematical models based on PLIM for the optimization of energy systems applied to the residential sector.
However, an optimization study is related to an in-depth study, considering all the equipment used for the energy supply and conversion, considering the variations of the consumption throughout the day and the year and considering the energy tariffs (Carvalho and Millar, 2012). A study of energy optimization and better use of resources often departs or depends on the energetic demands of building.

The energy optimization of processes means minimizing and improving energy use and, consequently, lower operating costs and increased energy efficiency. The energy demands of a residential building can be calculated in some ways, such as done by (Achão, 2003) which determined the energy consumption from data collected from the national energy balance, household appliance survey and consumption habits, family budget research, Demographic census and communication with the concessionaires. Rahde and Kaehler (2000) characterized the sector's electricity load curve based on studies carried out on the agents involved in the electric system (consumers and concessionaire), in order to explain and identify the behavior of the curve. De Souza (2010), determined load curves through an algorithm implemented in Matlab and Java.

This work presents the detailed procedures to calculate the energy demands of a residential building with 20 floors, with two apartments in each floor, to assist the studies of optimization in the supply of energy in the residential sector, contributing in the decision making of the resources that will be used to meet these demands.

2. COMPUTATIONAL PROCEDURE

The software used to simulate the residential building and determination of the energy demands was the Energyplus (DOE and BTO, 2017). A residential building was simulated, with its chosen location for the city of João Pessoa, latitude -7.11 ° and longitude -34.86 , With 20 floors, each floor with two apartments of 92 m^2, with the objective of obtaining the thermal and electric energy demands.

The size and internal divisions of the apartments were chosen based on apartments used by the middle class of João Pessoa-Paraiba.

In order to carry out this simulation, we used climatic data from the municipality of João Pessoa, produced by the National Association of Built Environment Technology (ANTAC), based on data recorded by INMET climatological stations (Roriz, 2012).

EnergyPlus is a computer program, created from the BLAST and DOE-2 programs and distributed by the United States Department of Energy, being widely used by researchers or designers who want to evaluate the thermal energy performance of buildings. Energyplus (DOE and BTO, 2017) analyzes the performance of the building from several chosen options, such as materials used in construction, architectural design, period of use of electrical equipment and air conditioning. EnergyPlus calculates the energy required to cool or heat the building, using a variety of systems and power source. Electrical loads can be inserted into the building and the software outputs reports with user-readable variables at defined time intervals. The solution technique of Energyplus is based on energy balances, allowing the simultaneous calculation of radiant and convective effects on the inner and outer surfaces for each time interval.

An output file dxf is generated as a result of building the walls, doors and windows in the program. Figure 2 shows a modification of the generated dxf file.

Figure 2 represents the floor plan of a floor. The building materials of the walls, doors and windows were, respectively, concrete, wood and glass. It was necessary to insert in the software the specific conductivity, density and heat of these materials. These properties were inserted according to NBR 15220 - Thermal Performance of Buildings (ABNT, 2005), as shown in Table 1. The density of concrete and wood was chosen as an intermediate value to the values presented in the table.

The cooling load is calculated by the software from the insertion of a maximum temperature in the thermostat of the refrigeration system and the identification of the zones that will be acclimatized by the system. The chosen temperature was 22 ° C and the zones chosen were zones 2, 5, 6, 11, 13 and 14 (rooms and suites). That is, in these environments, during the operating period of the system, from 00:00 to 09:00 h, the maximum temperature is 22 ° C. The internal loads, lights and electrical equipment were inserted into the Energyplus according to Table 2.

The amount of these equipment presented are only for one apartment. Only the most used equipment with the highest electrical power was considered. It was not considered electrical equipment used to meet other energy purposes such as air conditioning and electric shower which are used to cool the environment and heat the water. Despite the great power of these equipments, their use will depend on the result of the optimum configuration of the system.

Energyplus provided the total electrical consumption and the thermal energy withdrawn from the internal (cold) environment by the cooling system in a period of one year. By year, the total demanded was 614.2 GJ of electric energy and 870.8 GJ of refrigeration. The software allows the output of variables such as temperature, electrical energy and thermal energy per environment at determined intervals of time, during all days of the year.

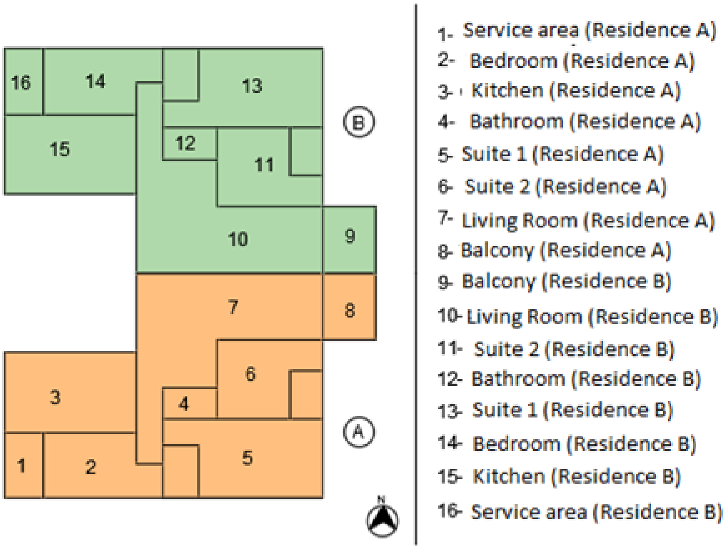

Figure 2: Scheme of a generic floor of the building.

Table 1: Properties of the building materials for the walls, doors and windows.

Material	ρ (kg/m³)	λ (W/mK)	c (kJ/kgK)
Normal Concrete	2200-2400	1,75	1,00
Wood With High Mass Density	800 – 1000	0,29	1,34
Common Glass	2500	1,00	0,84

Table 2: Equipment and lighting usage data

---	Lighting	Television	Refrigerator	Washing machine	Dishwasher
Amount	-	3	1	1	1
Power	5 W/m²	90 W	200 W	450 W	1500 W
Operation	Daily	Daily	Daily	Daily	Daily
Use	25%	30%	50%	100%	100%
Start of Operation	17:00 h	10:00 h	00:00 h	09:00 h	20:00
End of Operation	18:00 h	14:00 h	00:00 h	16:00 h	22:00
Use	100%	100%	-	-	-
Start of Operation	18:00 h	18:00 h	-	-	--
Start of Operation	00:00 h	00:00 h	-	-	-

The heat used for heating the shower water was calculated by establishing a desirable temperature for the water. According to Bohn (2008), the temperature for personal use and baths should be between 35 and 50°C. 45°C was chosen as the desired temperature for the water. The external air temperature of the building was obtained by the simulation of the building in Energyplus and was adopted as the temperature of the water, considering that the water is in thermal equilibrium with the air. According to Bohn (2008), the daily consumption of hot water in apartments is 60 liters per person per day. Considering that each apartment of the building has 4 people (being a family with a couple and two children), there is a consumption of 240 liters daily or 0,24m³ of water per day. According to Wylen, Sonntag and Borgnakke (2004), the specific mass of water is 997kg / m³ and its specific heat is 4,184kJ / kg.K, which results in 239.28kg of water in each apartment per day. A hot water consumption of two hours per day in the bath period was considered from 7:00 to 8:00 and from 21:00 to 22:00, and with these data a water flow of 0,03323 kg / sec. Applying the First Law of Thermodynamics, considering a permanent regime and neglecting the variations of kinetic and potential energy, one can arrive at Equation 1 that allows calculating the heat flux for each day of the year.

$$\dot{Q} = \dot{m}.c.\Delta T \qquad (1)$$

Where m˙ is the mass flow (kg / s), c is the specific heat (kJ / kgK), andΔT is the temperature variation of the water.

The demand for electricity can be given hourly, through the loads inserted into the environment (Table 5). It was considered that refrigeration was used for 9 hours per day from 24:00 to 09:00 h, using the maximum reference temperature as 22 ° C.

In this way, it was possible to obtain the result of the demands of electricity, heat (hot water) and refrigeration for each day of the year, hour by hour.

3. RESULTS AND DISCUSSION

The simulation in Energyplus provided the demands of electricity and cooling for the entire building, based on the considerations made. Heat demands were calculated from equation (1). Figures 3, 4 and 5 show the result of the energy demands of the entire building. The left side represents the first business day or the first weekday of each month. The first weekend of each month is being represented by the right side of the figures. It can be observed that the demands of electric energy between the days of week and between the weekends are always constant. This is because the equipment considered does not vary its use throughout the year.

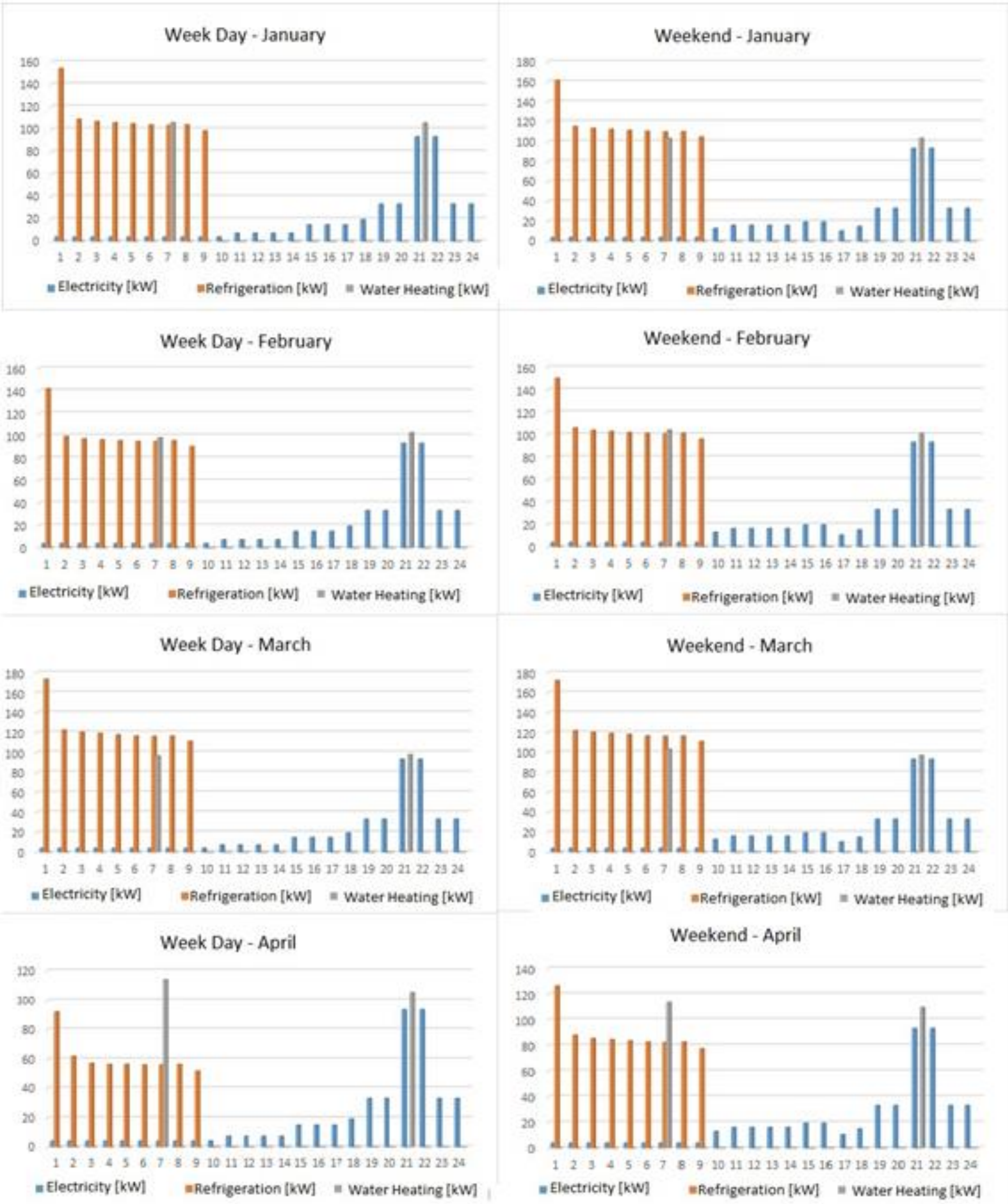

Figure 3: Energy demands from January to April with the weekdays on the left side and the weekends on the right side.

There is only a variation in the demand for electricity between weekdays and weekends, since it was considered that the washing machine is only used on Saturdays. As the climate of João Pessoa does not require heat for environmental comfort, the heat demand was made to only attend the heating of the water for use in the baths that varies in each day, depending on the external air temperature in thermal equilibrium with the water, which varies according to the time of year. The demand for refrigeration varies every day, depending on the external air temperature that varies according to the time of year. This result can also be seen in Table 3, which shows the energy consumed in kWh during the first working day of each month and the first weekend of each month in all months of the year. This table also shows the total energy consumption, in MWh / year. One can observe the difference in demand between electricity, heat and refrigeration. The demand for heat is very low when compared to the demand for electric energy and refrigeration, due to the climate of João Pessoa does not require heat for heating the environment and there is no other application of this utility in a residential environment.

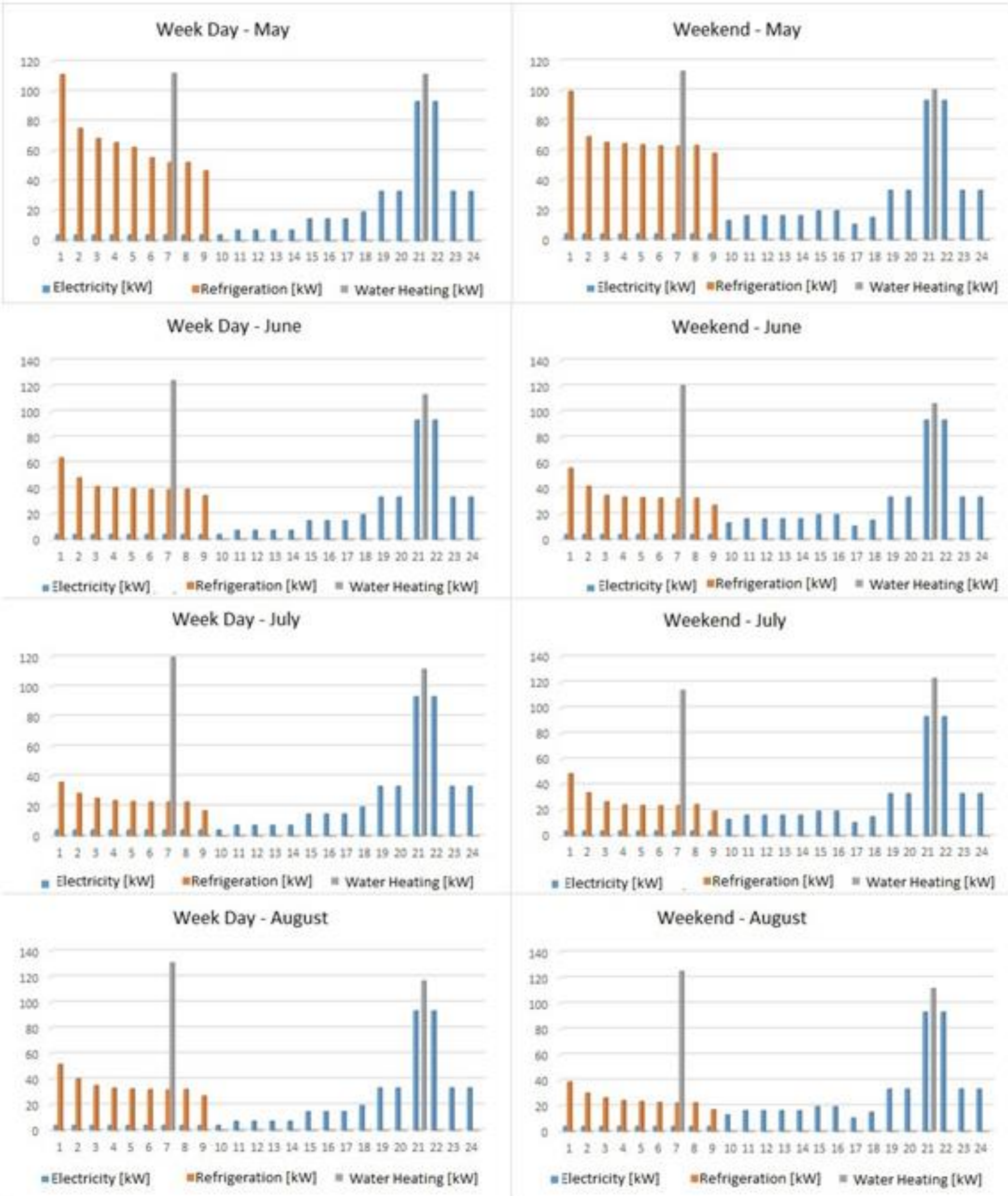

Figure 4: Energy demands from May to August with the weekdays on the left side and the weekends on the right side.

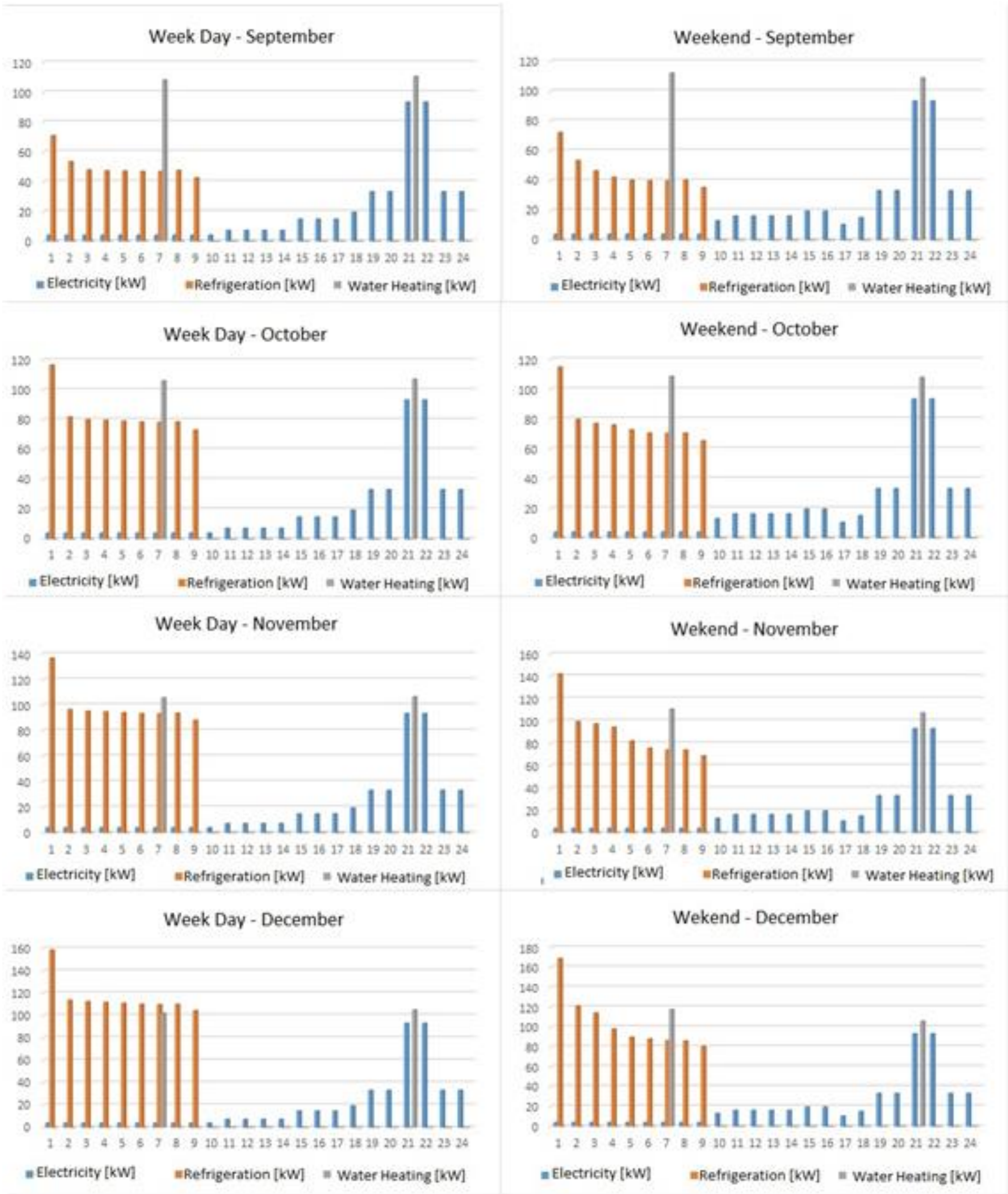

Figure 5: Energy demands from September to December with the weekdays on the left side and the weekends on the right side.

The electricity demand presented considers only the basic equipment, listed in table 2, composing the electric consumption. By inserting other equipment such as air conditioning to meet the demand for refrigeration and electric shower to meet hot water demand, this demand will increase considerably. As Energyplus performs its simulations using heat transfer theories, the demand for cooling can vary if we consider different construction materials, different geographic positions and different architectural designs. The demands obtained in this study will be the starting point for an economic optimization of the power supply to this residential building.

Although the behavior of the demands presented in Figures 3,4 and 5 are inherent to the considerations made herein, they are very similar to the curves of electric charges standard for the residential sector presented by Souza et al. (2010). The electricity load curve of a residential consumer is expected to exhibit relatively uniform consumption behavior during the day and, during the peak period, consumption will increase considerably (Souza et al., 2010).

Table 3: Energy demands for each representative day.

Month Representative Day	n_d (days/yea)	Electricity Total kWh/day	Hot Water Total kWh/day	Cooling Total kWh/day
Jan w	20	451.96	211.19	989.12
Jan f	11	497.68	206.60	1047.63
Febw	19	451.96	200.84	905.26
Feb f	9	497.68	205.08	963.21
Mar w	20	451.96	194.44	1112.81
Mar f	11	497.68	200.35	1111.51
Aprw	20	451.96	219.05	542.76
Aprf	10	497.68	223.22	793.03
Mayw	20	451.96	223.29	590.77
Mayf	11	497.68	212.93	607.82
Junw	19	451.96	236.98	385.45
Jun f	11	497.68	226.00	321.20
Julw	20	451.96	231.00	221.92
Jul f	11	497.68	236.57	249.04
Augw	20	451.96	247.34	314.79
Aug f	11	497.68	236.57	226.80
Sepw	21	451.96	218.56	449.82
Sepf	9	497.68	220.72	409.47
Octw	20	451.96	213.21	745.91
Octf	11	497.68	215.99	695.51
Novw	20	451.96	211.96	889.70
Nov f	10	497.68	217.73	807.72
Decw	20	451.96	207.37	1042.32
Decf	11	497.68	223.43	931.92
Σ		MWh/year	MWh/year	MWh/year
Year	365	171	83	242

The study presented herein reached successfully its objective of calculating the energy demands of a residential building located in João Pessoa (Northeast Brazil). The results presented herein are the first step towards more complex energy supply and conversion optimization studies, which begin with the definition of the consumer center and calculation of its energy demands. The optimization methodology followed by the authors then requires the creation of a energy superstructure that must include all possible processes and connections. Equipment models and their connectivity, along with operational constraints, are incorporated into a mathematical model, where the objective function is specified. Once the system is optimized, this superstructure is reduced to an optimal configuration.

4. CONCLUSIONS

Knowledge on the energy demands and behavior of energy consumption associated with a residential building can contribute to achieving better energy efficiency, either through better use of electrical equipment or even through an optimization of energy supply, using cogeneration and energy integration techniques. Optimization can be more complicated and challenging, but provides the best results, specifying the configuration of the system (type and size of equipment) as well as its operation. Energy demands were calculated herein with the aid of software Energyplus, which proved to be a very useful tool.

The energy demands for the building were 171 MWh / year, 83 MWh / year and 242 MWh / year for electricity, hot water and cooling, respectively. As the building is located in Northeast Brazil, in João Pessoa, which presents hot and humid climate, heat was only considered for the production of hot water (shower/bath water) in the residential building. This fact justifies the final low demands for heat, almost half the value of the electricity demand. The high demand for refrigeration (air conditioning) was also a result of climate conditions. The energy demands obtained herein are a consequence of the considerations made during the modeling, but these demands should vary if the location of the building, the consumption habits, constructive characteristics, or the number of people living in the apartments is changed. However, the behavior and seasonality of energy demand curves across Brazil is very similar.

Future work by the authors include economic optimization of the energy supply and conversion system, considering commercially available equipment and Brazilian legal and economic scenarios. Resilience analyses will also follow.

5. ACKNOWLEDGMENTS

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6. REFERENCES

ABNT (Brazilian Association of Technical Standards), 2005. NBR 15220: Desempenho térmico de edificações – Parte 2: Método de cálculo da transmitância térmica, da capacidade térmica, do atraso térmico e do fator solar de elementos e componentes de edificações. Rio de Janeiro.

Achão, 2003. Carla da Costa Lopes. Análise da estrutura de consumo de energia pelo setor residencial brasileiro. PhD Thesis, Universidade Federal do Rio de Janeiro.

Bohn, A. R, 2008. Instalações Prediais de Àgua Quente. Florianópolis: UFCS.

Castro, J. B.; Montini, A. A., 2010. Previsão Do Consumo Residencial De Energia Elétrica No Brasil: Aplicação Do Modelo Arx. Future Studies Research Journal: Trends and Strategies. São Paulo.

Carvalho, M.; Romero, A. ; Millar, D. L. 2014. Biomassa e energia solar térmica na síntese e otimização de um sistema de poligeração. In: V Congresso Brasileiro de Energia Solar, Recife.

Carvalho, M.; Delgado, D. B. M. ; Chacartegui, R. 2015. Life cycle analysis as a decision criterion for the implementation of solar photovoltaic panels in a northeast brazil hospital. In: Global Conference on Global Warming, Greece.

Carvalho, M.; Abrahao, R. ; Delgado, D. B. M. 2016. Energía solar térmica en la síntesis y optimización ambiental de un sistema de suministro energético. In: X Congreso Internacional de Refrigeración, Climatización y Energías Renovables, La Havana.

Carvalho, M.; Millar, D. L. 2012. Concept development of optimal mine site energy supply. Energies, v. 5, n. 11, p. 4726-4745.

Carvalho, M. et al. 2013. Synthesis of trigeneration systems: Sensitivity analyses and resilience. The Scientific World Journal.

Carvalho, M.; Serra, L. M.; Lozano, M. A. 2011a. Geographic evaluation of trigeneration systems in the tertiary sector. Effect of climatic and electricity supply conditions. Energy, v. 36, n. 4, p. 1931-1939.

Carvalho, M.; Serra, L. M.; Lozano, M. A. 2011b. Optimal synthesis of trigeneration systems subject to environmental constraints. Energy, v. 36, n. 6, p. 3779-3790.

Carvalho, M.; Lozano, M. A.; Serra, L. M. 2012. Multicriteria synthesis of trigeneration systems considering economic and environmental aspects. Applied Energy, v. 91, n. 1, p. 245-254.

Carvalho, M. et al. 2014. Optimal synthesis of energy supply systems for remote open pit mines. Applied Thermal Engineering, v. 64, n. 1, p. 315-330.

Carvalho, M.; Freire, R. S. ; Brito, A. M. V. G. 2016 . Promotion of Sustainability by Quantifying and Reducing the Carbon Footprint: New Practices for Organizations. In: Panagiotis Grammelis. (Org.). Energy, transportation and global warming. 1ed.: Springer International Publishing, v. 1, p. 61-76.

Delgado, D. B. M. ; Carvalho, M. ; Chacartegui, R. ; Coelho Junior, L. M. 2015. Optimization of energy supply and conversion in a northeast brazil hospital: use of photovoltaic panels. In: ABCM International Congress of Mechanical Engineering, 23. Rio de Janeiro.

DOE; BTO. 2017. "Energyplus. Versão 8.7.0." 26 may 2017 <https://energyplus.net/>.

Empresa De Pesquisa Energética (EPE). 2015 "Balanço Energético Nacional 2015." 17 Sep 2017. <https://ben.epe.gov.br/BENRelatorioSintese.aspx?anoColeta=2015&anoFimColeta=2014>.

GARCIA, X. 2006. Analysis of building energy regulation and certification in Europe. Their role, limitations and differences, Energy and Buildings, vol. 38, pp. 381-392.

IEA - International Energy Agency. Energy Technology Perspectives - Scenarios & Strategies to 2050.2012. Available at: <https://www.iea.org/publications/freepublications/publication/ETP2012_free.pdf> Access 17 Sep 2017.

INMETRO. 2014. "Manual para etiquetagem de edificações públicas." 17 Sep 2017 <http://www.comprasgovernamentais.gov.br/arquivos/sustentabilidade/manual_etiquet_edific_publicas_20141010.pdf >.

LOZANO, M. A. et al. 2009. Structure optimization of energy supply systems in tertiary sector buildings. Energy and Buildings, v. 41, n. 10, p. 1063-1075.

Melo, F. M. ; Carvalho, M. 2016. Cogeração Como Ferramenta Para Alcançar A Sustentabilidade Energética No Ambiente Residencial. In: II Congresso Luso-Brasileiro de Materiais de Construção Sustentáveis, 2016, João Pessoa. Anais do II Congresso Luso-Brasileiro de Materiais de Construção Sustentáveis.

Melo, A. P.; Westphal, F. M.; Matos, M. 2009. Apostila do Curso Básico do Energyplus. Florianópolis: UFCS.

Millar, D. L. ; Romero, A. ; Carvalho, M. ; Levesque, M. Y. 2014. Optimal Mine Site Energy Supply. In: Helen Muga; Michelle Eggart. (Org.). Responsible Mining: Case Studies in Managing Social & Environmental Risks in the Developed World. 1ed. Englewood: Society for Mining, Metallurgy, and Exploration (SME). v. 1, p. 389-430.

Rahde, S. B.; Kaehler, J.W. 2000. Modelagem da curva de carga das faixas de consumo de energia elétrica residencial a partir da aplicação de um programa de Gerenciamento de Energia pelo Lado da Demanda. In: BRAZILIAN CONGRESS OF THERMAL SCIENCES AND ENGINEERING, 8. Porto Alegre.

Romero, A.; Carvalho, M.; Millar, D. L. 2014. Application of a polygeneration optimization technique for a hospital in northern Ontario. Transactions of the Canadian Society for Mechanical Engineering, v. 38, n. 1, p. 45.

Romero, A.; Carvalho, M.; Millar, D. L. 2016. Optimal design and control of wind-diesel hybrid energy systems for remote Arctic mines. Journal of Energy Resources Technology, v. 138, n. 6, p. 06.

Roriz, M. 2012. "Arquivos Climáticos de Municípios Brasileiros. São Paulo: ANTAC, 2012". 17 Sep 2017 <http://www.roriz.eng.br/epw_9.html>.

Souza, A. N. et al. 2010. Algoritmos para estimar curvas de cargas a partir de padrões de Hábitos de Consumo. In: BRAZILIAN CONFERENCE ON DYNAMICS, CONTROL, AND THEIR APPLICATIONS, 9. Serra Negra.

Wylen, G. J. V.; Sonntag, R. R.; Borgnakke, C.. 2004. Fundamentos da Termodinâmica. 6. ed. Editora Edgard Blucher.

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