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THERMOECONOMIC METHODOLOGY FOR DISTRICT COOLING SYSTEMS ANALYSIS

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Abstract. *The constant development of urban areas and increased energy consumption for thermal comfort encourage studies that formulate a methodology for thermoeconomic analysis of district cooling systems. The main objective is to describe a thermoeconomic methodology related to the implementation of district systems in Brazil. The secondary objective is to apply the methodology in the state of São Paulo, analyzing the premises used in the methodology. At first, an overview and literature review of district heating and cooling systems was presented, indicating their advantages and disadvantages, just as the various applications and challenges for their implementation. Applications on the world stage have been introduced and analyzed, demonstrating that their use in several countries extends for decades. The main advantages observed in the existing applications are related to global energy and exergy efficiency, reduction in greenhouse gases and reliability of the systems. Finally, the applied methodology is presented in five steps in an orderly manner based on the steps of a district system project. Its result is based on routines, process simulations and optimization procedures, as well as application of energy indicators. At the end of the steps and their mathematical development, a preliminary study of the feasibility of the implantation of a district system is obtained. The present case study applies the methodology for the city of São Paulo and describes in detail the premises and steps.*

Keywords: *district cooling system, energy simulation, exergy analysis, thermoeconomic analysis.*

1. INTRODUCTION

1.1 Overview

The development of urban areas is increasing year after year. According to The United Nations (UN), currently 54% of the world's population lives in urban areas and this value is expected to increase to 66% by 2050. In Brazil, it is no different, according to UN-Habitat report, by 2050 more than 90% of the Brazilian population would be living in urban areas. (UNRIC, 2014)

The growth of urban areas leads to increase the energy demand. The Ministry of Mines and Energy carried out a projection of energy consumption between the years 2013 and 2022. The study points out that energy consumption is expected to increase 5.8% per year for commercial class and 4.3% per year for residential class. The increase is due both to the growth in the number of consumers and to the increase in per capita demand. (EPE, 2012)

In countries with a primarily tropical and equatorial climate, such as Brazil, a large proportion of the energy demand is for thermal comfort. Nowadays, the United States of America has the highest global demand for air conditioning equipment, however it is estimated that Brazil will exceed this demand by up to two times in the coming years and countries like India by up to 14 times. (SIVAK, 2013)

This scenario spurs consumers to search for more efficient and reliable solutions. For this purpose, central chilled water systems for HVAC are widely used in large buildings, as they reduce operating and maintenance costs in relation to individual systems. However, there are certain disadvantages in the use of central systems; these include the space required for installation, high initial cost and limitations of the power source. (ASHRAE, 2008)

Among the various alternatives that can be adopted to handle with the increase in Brazilian energy demand for heating and cooling systems is the implementation of district cooling and heating system (DCS – District Cooling System; DHS – District Heating System).

1.2 District Systems - Background

According to a report by the National Research Council (NRC, 1985) - a scientific organization and a division of the National Academy of Sciences (NAS) founded in 1916 - district heating and cooling systems constitute a network of pipelines that distribute hot water, chilled water or steam through insulated pipes, attending the demand for heating, cooling and industrial processes of commercial buildings, residences, institutions, universities, military bases and/or industries. The energy produced by the district power stations can be commercialized similarly to the sale of fuels or electric energy.

District heating and cooling systems have been in use for more than a century and their technology is known worldwide but is largely unknown to the public in part because of the variety of nominations for the same technology.

For example, in the United States of America (USA), district cooling and heating systems (DCS / DHS) are also known as: central plant heating; cooling and steam; municipal heat, cooling, power and steam; campus heating; total energy system; municipal integrated utility systems; total integrated or community energy systems. On the other hand, in Europe the most common terms are: distance heating; urban heating; block central systems. (NRC, 1985)

Nowadays, there are numerous district systems in operation in the USA, Europe and Japan. Most of these systems have district heating as their priority, so the demand for steam and hot water is the main concern. In countries with a mostly tropical climate, DCS is the most common district system and consequently the central point of this research. However, the history of DHS and its evolution helps to understand the possible issues and solutions to invest in DCS in tropical countries that do not have spur for its development. Figure 1 presents the number of the district energy systems in the USA and part of Canada in 2017.



Figure 1 – District energy systems in United states and part of Canada in 2017. (IDEA, 2017)

Historically, two major types of DHS have developed in the USA. The first one is named as urban systems and consists of heated steam systems developed in the late 19th century to serve urban areas. Many of these systems were operated by local power companies. With the advent of large power plants away from urban centers, the low cost of oil and gas (replacing coal as fuel) and the development of individual boilers have led to decline this type of DHS in recent decades. The second type is used for institutional buildings. These include universities, military bases, industrial parks, closed condominiums, offices and commercial complexes. In contrast to the urban system, institutional systems have been growing in the last three decades in the United States. Recently, a third type of district cooling and heating is growing in the US. This type is administered by the municipalities or by the users themselves reusing old systems abandoned by power companies. This new way of administering is encouraged and sponsored by US government departments - U.S. Departments of Housing and Urban Development (HUD) and Energy (DOE), consisting of one of the government's strategies for developing the community and economy of cities. (NRC, 1985)

In Brazil, the development of DCS is inexistent and there is not district system managed by energy companies. One of the possible reasons is that Brazilian public policies do not make feasible the implantation of district cooling systems. The main problems of viability are related to the commercialization of electricity, incentives for cogeneration, structure of the natural gas market, use of municipal public goods, public policy of hot water and chilled water distribution, among others (COGEN et al. 2013). On the other hand, institutional district cooling has some successful examples, such as the Globo Production Center - CGP (Projac) in Rio de Janeiro and the Rochaverá Corporate Towers building in São Paulo (COGEN et al. 2013). Both have cogeneration plants that use natural gas to supply the energetic demands of the complexes. Such systems are beneficial for the enterprise and for Brazil that has a limitation in the energy matrix. In this way, with the saturated Brazilian energy infrastructure and the constant growth of the demand, new opportunities arise for the development of DCS in Brazil.

2. METHODOLOGY

The applied methodology is presented in an orderly manner based on the development stages of a district system project. Each stage represents the development of mathematical models, process simulators, routines and process optimization, as well as the application of energy indicators. These models are applied to synthetic plants configurations that represent a set of processes studied.

2.1 Definition of the study area for feasibility analysis of the district system

A district constitutes a delimited area that has buildings and facilities with potential energy demand. A district can be described from the following parameters: location, limit of perimeter, number of buildings, and typical climate.

The choice of the region should consider information and criteria that benefit the implementation of a district system. The main factors influencing the viability of a DHCS, according to ASHRAE (2008), are: high thermal load and high annual load factor, in other words, high energy consumption collaborative with a uniform demand during the year.

Since the initial district determination is made a priori with no quantitative, the selection is based on a qualitative decision matrix analysis, reporting the main factors that influence the viability of a DHCS. This initial step directs the analysis to districts with greater potential; however, the implementation of the district is obtained after analyzing the demand data, not excluding the possibility of re-evaluating the decision matrix.

The main factors of selection are listed in Tab. 1. Each factor has an influence that can vary from 0 (zero) to 10 (ten), values closer to "10" represent a greater possibility of DHCS installation in the evaluated district.

Table 1 - Main factors for a decision matrix analysis.

Factor	Description
I	High thermal load.
II	Number of buildings/facilities.
III	Diversity of occupations.
IV	Available area.
V	Government incentive.

2.2 Determination of district energy demand

The district's energy demand consists of a curve with the month-to-month values of a typical year of electricity consumption in kWh and the total thermal load of buildings in tons of refrigeration (TR).

The data used to determine the typical annual energy demand curve are the actual consumption data and the thermal load of each building. These data are measured individually for each building over a period of more than two years and the thermal load is calculated for each thermal zone. So, the following surveys should be made:

- Survey of the real consumption of electrical energy of the buildings in a minimum period of two years;
- Survey of the actual consumption of electric energy destined to the air conditioning in a minimum period of two years;
- Calculation of the thermal load of all the thermal zones of each building;

However, most of the buildings have minimal data collected and archived from the consumption of electricity. In addition, the thermal load calculation of all zones becomes impracticable for a methodology that intends to obtain an initial analysis of the potential for implantation of a DHCS. Therefore, scenarios with different data is introduced and the procedures to determine the energy demand and the total thermal load of the district.

The total energy consumption of the district buildings is divided into two main parts:

- I) Consumption realized by the demand of lighting and equipment (light bulbs, computers, refrigeration, furnaces/ovens, resistances, etc);
- II) Consumption realized by the demand of HVAC systems (fans, chillers, fan coils, etc.).

The difficulty of obtaining the data related to part II prevents to survey the real consumption for HVAC systems. Therefore, the thermal load and the consumption of the thermal zones of each building must be calculated from a simulation in the program OpenStudio (OPENSTUDIO, 2016). This free modeling program uses a simple interface to model and simulate energy demands on buildings using the EnergyPlus program (ENERGYPLUS, 2013). Building modeling is done in three dimensions by an OpenStudio plug-in for the SketchUp program (SKETCHUP, 2016).

Computational simulations are based on typical values of occupancy, building materials, lighting and equipment load presented by ASHRAE 90.1 and available in OpenStudio libraries (OPENSTUDIO, 2016). Therefore, the buildings of the district should be classified in different typologies. The main typologies adopted are presented in Tab. 2.

Table 2 – Main typologies presented in OpenStudio libraries. (OPENSTUDIO, 2016)

Typologies	Occupation	Description
A	Schools	Schools, colleges, universities.
B	Residential	Horizontal condominiums, apartment buildings, single family houses.
C	Hospital	Hospitals, clinics, medical center.
D	Laboratory	Schools with research and laboratory activity.
E	Office	Commercial buildings, offices.
F	Hotel	Hotels, motels, hostels, guesthouse, flats, serviced residence, apart-hotel.
G	Shopping	Shopping centers, stores, outlets, commercial center.
H	House	Single family houses, small condominiums.

Each typology presented has the values in the library based on ASHRAE 90.1. However, the typologies of occupancy related to the patterns of operation at peak times, vacation periods, weekends, among others, should be adjusted for each building, regardless of the values already assigned by the OpenStudio library. These values can be easily modified by the program interface, adding for each typology daily typical values for a standard simulation year.

The modeling of different building patterns allows an energy simulation to be performed. The simulation is based on a typical climate of the region where DHCS will be implanted. EnergyPlus has an extensive library (WEATHER DATA, 2016) with typical climates from all regions of the globe. The simulation is performed "hour by hour" in a typical year for the region defined based on typical days (.DDY file).

The simulation by OpenStudio results in an extensive report with lots of information about the model. The consumption data are presented by the sum of the daily consumptions of each month. For this reason, the DHCS total energy demand data is presented monthly for the typical year considered.

The scenarios presented in the methodology are related to the availability of measured data:

- Measure data of power consumption of all buildings with lack of the proportion in relation to the HVAC consumption;
- Measure data of power consumption of part of the buildings with lack of the proportion in relation to the HVAC consumption;
- Lack of measure data of power consumption of the buildings and lack of the proportion in relation to the HVAC consumption.

2.3 Definition of district power plant models

After determining the district total energy demand, different models of district power plants should be evaluated and defined. The models must have all the necessary components to meet the district's energy demands, such as gas turbines, gas generators, power cycles, condensers, boilers, steam generators, pumps, heat exchangers and other components.

The defined models are presented in a simplified way, in other words, each component is presented in representative blocks with their respective input and output data. The data specific to each component can be taken from manufacturers' catalogs or estimated by mathematical models. Two examples of models are shown in Figure 10 and Figure 11.

The triage of settings should consider selection parameters, whether they are related to the components or to the operation:

- Fuel used in the plant (energy input): the definition of the fuel is fundamental for the selection of the generator components of the plant. The selection should be made using availability, cost, and reliability information;
- Number of power plants in the district: the number of power plants in the district can vary and different configurations along the district's distribution network should be analyzed.
- Energy and exergy efficiency: the efficiency data of each component can be obtained through catalogs or estimated by mathematical models;
- Total district demand: total district demand obtained in section 4.2;
- Possibility of commercializing electricity with the grid: the commercialization of energy for the grid is a fundamental parameter for the economic viability of a district system, therefore it must be evaluated for selection of the models;
- Operating system: determines which demand curve the plant will meet - FEL (Follow Electric Load) or FTL (Follow Thermal Load).
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The number of defined models should be sufficient to analyze and compare the implantation feasibility of DHCS.

2.4 Energy, exergy and thermoeconomic system analysis

In this section the models defined in section 2.3. are analyzed based on the first and second laws of Thermodynamics. The first law is applied to the plant performing an energy balance of the system. In conjunction with the second law of thermodynamics an exergy balance of the system is performed. With both analyzes realized, it is possible to determine the efficiency of each equipment and the overall efficiency. Finally, for the thermoeconomic analysis a cost balance is applied to each model.

The analysis will be implemented in the EES – Engineering Equation Solver (EES, 2017) and the values will be presented for each defined model.

2.4.1 Input parameters and hypotheses adopted

For the analysis of each power plant model it is necessary to obtain the input parameters of the states and/or the equipment. The input parameters used are based on typical values found in the literature for district systems, Tab. 3 and Tab. 4.

Table 3 – Input Parameters.

Isentropic efficiency	
η_{ise}	
Energy efficiency (coefficient of performance)	
η_{en}	COP_{ciclo}
Mechanical efficiency	
η_{mec}	
Input and output temperatures	
T_{ent}	T_{saida}
Thermal Load	
Q_e	
Chemical exergy (SZARGUT, 2007) and Lower Calorific Value	
\overline{bch}_{comb}	PCI_{comb}
Reference state (environment)	
T_o	P_o

Table 4 – Predefined states properties (Pressure, Temperature, Specific volume, Quality, Enthalpy and Exergy, respectively).

State 01							
P_1	T_1	v_1	x_1	h_1	s_1	b_1	
State 02							
P_2	T_2	v_2	x_2	h_2	s_2	b_2	
State 03							
P_3	T_3	v_3	x_3	h_3	s_3	b_3	
State n							
P_n	T_n	v_n	x_n	h_n	s_n	b_n	

2.4.2 Definition of thermodynamic states

The thermodynamic state of a system is defined by specifying values of a set of measurable properties sufficient to determine all other properties. For fluid systems, typical properties are pressure, volume and temperature. (BEJAN, 1988)

Obtaining the predefined states and the input parameters allows the determination of the thermodynamic states of the power plant model. Table 5 shows the thermodynamic states and their properties.

Table 5 – Example table of parameters.

	Mass Flow rate	P	T	x	h	s	b
State	kg/s	MPa	K	Dimensionless	kJ/kg	kJ/(kg.K)	kJ/kg

Reference	-	-	-	-	-	-	-
01	-	-	-	-	-	-	-
02	-	-	-	-	-	-	-
03	-	-	-	-	-	-	-
n	-	-	-	-	-	-	-

2.4.3 Energy analysis

The energy analysis is performed on each component of the models and the global energy efficiency is calculated.

The analysis is performed using the definition of energy balance of control volume systems in steady state (1st law of thermodynamics) and conservation of mass, Eq. 1 and Eq. 2.

$$Q_{v.c.} + \sum \dot{m}_e \left(h_e + \frac{V_e^2}{2} + z_e \cdot g \right) = \sum \dot{m}_s \left(h_s + \frac{V_s^2}{2} + z_s \cdot g \right) + W_{v.c.} \quad (1)$$

Where $Q_{v.c.}$ is the heat transfer rate; \dot{m}_e , \dot{m}_s are the input and output mass flow rates; h_e , h_s are the input, and output specific enthalpies; V_e , V_s are the input and output velocities; z_e , z_s are the input and output reference elevations; g is the gravitational acceleration; $W_{v.c.}$ is work transfer rate.

$$\sum \dot{m}_e = \sum \dot{m}_s \quad (2)$$

Eq. 1 and Eq. 2 are applied to each control volume, obtaining the work and heat rates of each component of the model.

The global energy efficiency ($\eta_{en, global}$) is obtained from Eq. 3, based on the values determined by the energy balance.

$$\eta_{en, global} = \frac{\text{useful work}}{\text{energy input}} \quad (3)$$

2.4.4 Exergy analysis

Exergy analysis is performed on each component of the models and the global exergy efficiency is calculated.

The analysis is performed using the definition of exergy balance for control volumes, Eq. 4.

$$\frac{dB}{dt} = \sum_j \left(1 - \frac{T_0}{T_j} \right) \cdot \dot{Q}_j - \sum W_{v.c.} + \sum_i \dot{m}_i (h_i - T_0 \cdot s_i) - \sum_e \dot{m}_e (h_e - T_0 \cdot s_e) - T_0 \cdot \dot{S}_{ger} \quad (4)$$

Where $\frac{dB}{dt}$ is the exergy variation rate; T_0 is the reference thermodynamic temperature; T is the temperature; $W_{v.c.}$ is work transfer rate; \dot{Q} is the heat transfer rate; h is the enthalpy; s is the entropy; \dot{S}_{ger} is the entropy generation rate;

The Eq. 4 is applied for each determined control volume, obtaining the exergy values of each component of the model.

The global exergy efficiency ($\eta_{ex, global}$) is obtained from Eq. 5 based on the values determined by the exergy balance.

$$\eta_{ex, global} = \frac{\text{useful work}}{\text{energy input}} \quad (5)$$

2.4.5 Thermoeconomic analysis

It is a method that combines exergy with conventional concepts from engineering economics to evaluate and optimize the design and performance of energy systems.

The thermoeconomic analysis is developed using the concepts of cost balance and average cost per a given quantity unit (C_p, c_p), Eq. 6.

$$c_p = \frac{C_p}{N_p} \quad (6)$$

Where N_p is the basis used (exergy rate, energy rate, etc).

To determine the costs involved in the process, the following categories of costs are defined:

A. Specific cost of inputs

Cost of the inputs used in the process (c_{p_m}). The Eq. 7 and Eq. 8 introduce the specific cost in energy ($c_{p_{en}}$) and exergy basis ($c_{p_{ex}}$), respectively.

$$c_{p_{en}} = \frac{c_{p_m}}{PCS} [R\$/kJ] \quad (7)$$

$$c_{p_{ex}} = \frac{c_{p_m}}{b_p} [R\$/kJ] \quad (8)$$

Where PCS is the higher heating value;

B. Equipment costs

The equipment costs are calculated considering the purchase and installation value of the equipment (C_{cap}), fixed and variable operating expenses (C_{omf}), maintenance expenses and depreciation factor of the invested capital (C_{omv}). Equation (9) presents all the parameters involved for the calculation.

$$C_p = C_{cap} + C_{omf} + FC \cdot C_{omv} = f_a \cdot I_c + f_{omf} \cdot I_c + FC \cdot f_{omv} \cdot I_c = I_c \cdot (f_a + f_{omf} + FC \cdot f_{omv}) [R\$/s] \quad (9)$$

Where FC is the load factor; f are the respective investments fraction; I_c is the investment; f_a is depreciation factor.

C. Output process cost

The output costs of the analyzed processes can be calculated by different methods. The output cost on energy and exergy basis are calculated for each of the following methods (if applicable):

C.1. Equality Cost Method: all products have the same exergy cost per unit;

C.2. Extraction method: in this method, the studied equipment or component has only one function and the product of this function is charged with its capital and operational an maintenance costs. In this way, the user of this product will pay the exergy rate spent as well as the capital, maintenance and other operational costs;

The result of the analysis introduces the total processes costs.

2.5 Comparison of results and definition of the district system

The results obtained for each analyzed model is compared to a reference. The reference used is a model with no district system. Therefore, the comparison is performed in relation to a conventional system that does not have a district central.

The decision criteria for the feasibility of DHCS implantation are economic and environmental. The criterion with greater influence and fundamental for the decision is the thermoeconomic one. Thus, the time of return of the investment is fundamental to make feasible the implantation of a district central.

In addition to the thermoeconomic aspects, environmental factors and availability of resources are also considered. The environmental factor used is the annual production of carbon dioxide. Table 6 introduces the comparison table for the decision-making of the system viability.

Table 6 – Example table presenting the criteria used for comparison of results.

Model	Energy input	Global energy efficiency	Global exergy efficiency	Initial investment	Return on investment	Annual carbon gas production
I	-	-	-	-	-	-
II	-	-	-	-	-	-
III	-	-	-	-	-	-
Reference	-	-	-	-	-	-

3. PRELIMINARY RESULTS

The chapters presented so far define the methodology in general without reporting results and numerical conclusions at each step of the thermoeconomic analysis. The next chapters are based on a case study, more specifically, applying the methodology demonstrated for the city of São Paulo.

The case study should apply the methodology as presented previously to evaluate the feasibility of a district system in the city of São Paulo from the definition of the district to the thermoeconomic analysis. For each step of the methodology the assumptions and parameters adopted are presented and discussed.

3.1. Definition of the study area for feasibility analysis of the district system

The decision matrix for determining the area to be evaluated is applied to the metropolitan area of São Paulo. São Paulo city has approximately 12 million inhabitants, the region has a total electric energy consumption of 27.4 TWh, according to the Annual of Energy by Municipality in the State of São Paulo 2016, with 10.9 TW for residences, 10.6 TWh for the commercial sector and 2.9 TWh for the industries. In addition, natural gas consumption is approximately 895 million m³ for the period, 261 million m³ for industry, 267 million m³ for thermogeneration, 174 million m³ for residences, 88 million m³ for the automotive sector and 97 million m³ for the commercial sector. (SECRETARIA DE ENERGIA E MINERAÇÃO, 2017)

The numbers of consumption and the absence of district systems in the region demonstrate a great potential to be evaluated, consequently, the decision matrix is applied to three possible districts: District A - Armando de Salles Oliveira University Campus (CUASO); District B - Region of the downtown (Paulista Avenue); District C - Commercial complexes.

Table 7 – Decision Matrix – DHCS implantation potential.

Goal: Determine the district with the highest potential for DHCS analysis.			
Criteria: District with the highest sum of the scores of each factor.			
Factor: Features with influence on DHCS implantation potential.			
Weight: Zero (0) – Low potential to ten (10) – High potential.			
Factor	CUASO	Downtown	Commercial complexes
High thermal load	9	10	8
Number of buildings/facilities	8	10	5
Diversity of occupations	8	10	6
Available area	10	5	7
Government incentive	6	4	10
Total	41	39	36

After qualitative analysis of the districts and application of the decision matrix, the area for implantation analysis of a district system is district A - CUASO.

The university campus has a high energy potential and a variety of buildings and occupations. Its buildings include educational and research buildings, cafeterias, libraries, hospital, administrative buildings, residential, sports centers and laboratories present in a total area of approximately 3,650,000 m² with an average daily circulation of 80,000 to 100,000 people (PUSP-C, 2018).

3.2. Determination of district energy demand

At this stage a survey of actual consumption data by building was carried out and data on the power consumption by building was presented. However, some of the buildings do not have a set of steady data with more than one year of measurement. This situation is described in the methodology and the estimated consumption is calculated from modeling on SketchUp (SKETCHUP, 2016) and OpenStudio (OPENSTUDIO, 2016) and simulation on EnergyPlus (ENERGYPLUS, 2013).

The consumptions of the buildings were measured between 2005 and 2011 and the following buildings are considered in the district analysis:

- Buildings with measure Power consumption data: Institute of Oceanography; Polytechnic School (biennium, metal engineering, electrical engineering, naval engineering); Faculty of Economics and Administration; School of Physical Education and Sport; University hospital; Institute of Biomedical Sciences (ICB 01 and ICB 02); Faculty of Veterinary Medicine and zootechny; Rectory building; Center of Sports.

- Buildings with estimated power consumption data: Polytechnic School (Mine Engineering, Civil Engineering, Administration); Institute of Psychology, School of Communication and Arts; Faculty of Philosophy, Letters and Human Sciences; Institute of Chemistry; Institute of Mathematics and Statistics; Faculty of Architecture and Urbanism; Institute of Physics; Institute of Astronomy, Geophysics and Atmospheric Sciences, Institute of Geosciences; Faculty of Education; Residential Complex (CRUSP); Faculty of odontology; Institute of Biomedical Sciences (ICB 04); Institute of biology.

Each unit presented above is divided into occupations with typology according to ASHRAE 90.1. The typologies used and units are:

Typology A – Schools: Institute of Oceanography; Polytechnic School (biennium, metal engineering, electrical engineering, naval engineering, Mine Engineering, Civil Engineering); Faculty of Economics and Administration; School of Physical Education and Sport; Institute of Psychology, School of Communication and Arts; Faculty of Philosophy, Letters and Human Sciences; Institute of Chemistry; Institute of Mathematics and Statistics; Faculty of Architecture and Urbanism; Institute of Physics; Institute of Astronomy, Geophysics and Atmospheric Sciences, Institute of Geosciences; Faculty of Education;

Typology B – Residential: Residential Complex (CRUSP);

Typology C – Hospital: University hospital;

Typology D – Laboratory: Faculty of odontology; Institute of Biomedical Sciences (ICB); Institute of biology; Faculty of Veterinary Medicine and Zootechnology;

Typology E – Office: Rectory building, Polytechnic School administration.

Note: Sports practice center is considering only electricity consumption (lighting) with none typology classified.

The power consumption of the buildings that do not have measured data was estimated using the indicator of active energy consumption, Eq. 10, based on the typologies that have consistent measure data.

$$Indicator_{active\ energy} = \frac{Total\ average\ consumption\ of\ the\ building\ [kWh]}{Total\ area\ of\ the\ building\ [m^2]} \quad (10)$$

For typologies that do not have measured data, the total consumption is estimated by simulation in Openstudio or using indicators from other literatures, Eq 11.

$$Indicator_{estimated\ consumption} = \frac{Total\ simulated\ energy\ consumption\ [kWh]}{Total\ model\ area\ [m^2]} \quad (11)$$

The simulation in Openstudio/EnergyPlus is performed using architectural models close to the reality of the buildings in SketchUp software. Figure 2, Figure 3 and Figure 4 present typology models A, B and C used in the evaluated district.

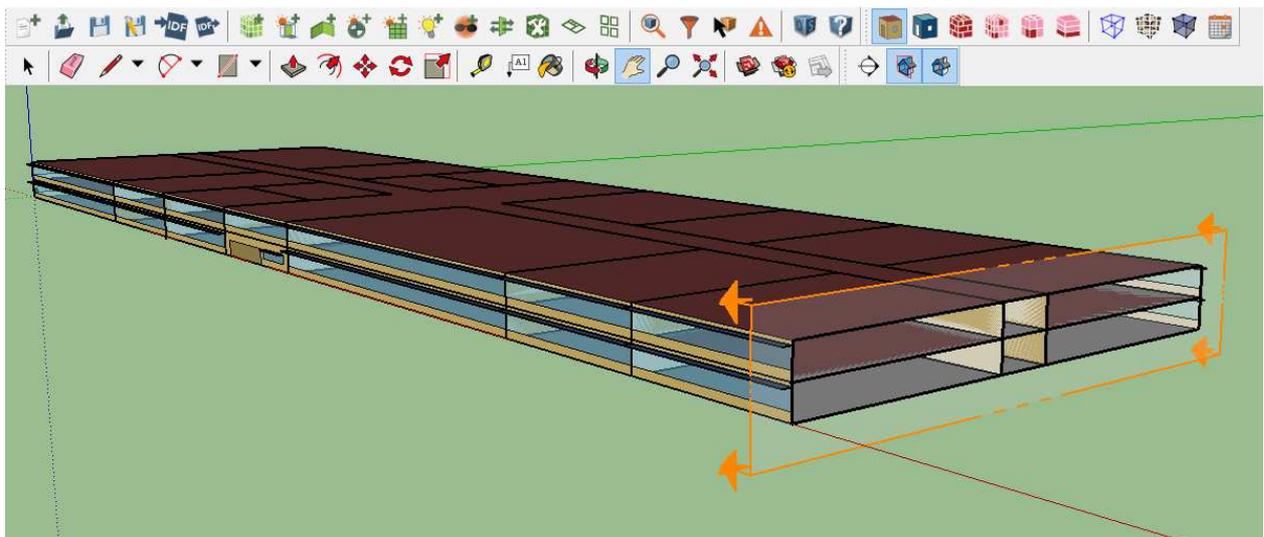


Figure 2 – Typology Model A – architecture of a typical school detected in CUASO.

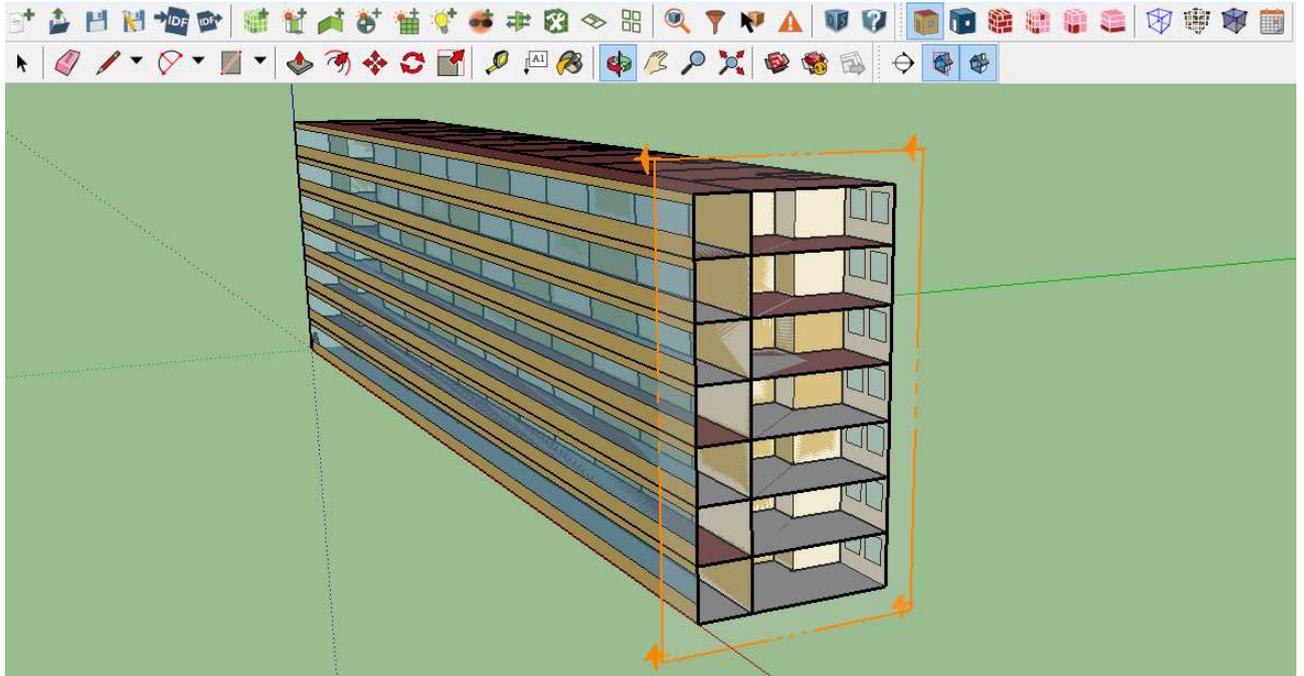


Figure 3 - Typology Model B – architecture of one unit of the Residential complex (CRUSP).

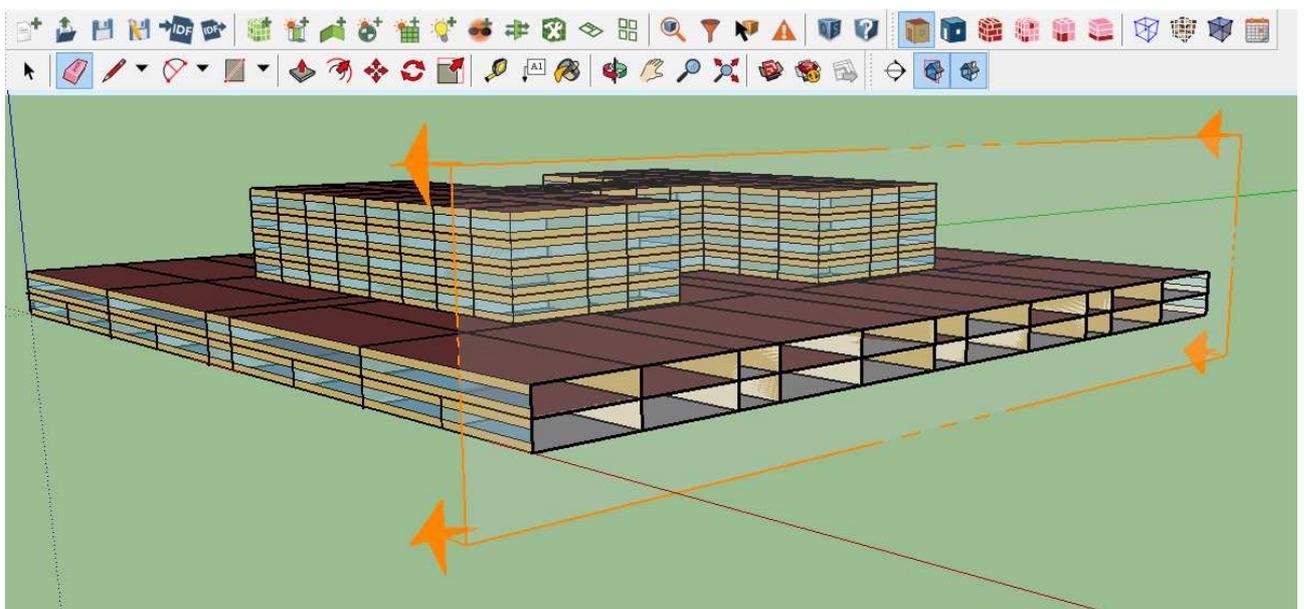


Figure 4 - Typology Model C – architecture of the University Hospital (HU).

After simulation of the models in Openstudio, the values of the power consumption and the HVAC consumption of the models are obtained. Therefore, the consumption of power energy/HVAC consumption ratio is calculated for each typology, Eq. 12.

$$Proportion_{HVAC} = \frac{HVAC \text{ consumption of the building [kWh]}}{Total \text{ model energy consumption [kWh]}} \quad (12)$$

It is worth mentioning that the simulation of HVAC consumption is based on unitary systems for typologies A, B, D and E. For typology C a cooling plant was simulated. This scenario is the closest to the present, where most of the buildings of USP do not have a cooling plant within them.

Finally, the thermal load is obtained from EnergyPlus and the indicator for each typology obtained by Eq. 13.

$$Indicator_{thermal\ load/area} = \frac{Total\ monthly\ thermal\ load\ [TR]}{Total\ Model\ area\ [m^2]} \quad (13)$$

All the values of each indicator can be checked in the complete work. After calculating all indicators and proportions, the consumption for each district unit is obtained. Thus, the summation calculation month by month obtained the district's annual energy demand, Figure 5.

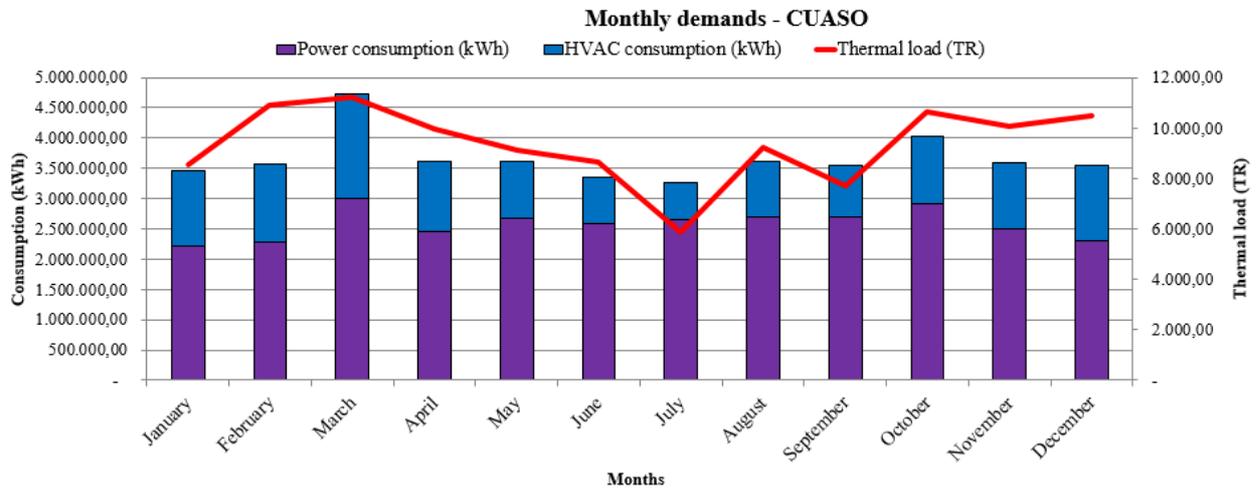


Figure 5 – CUASO annual energy demand.

4. CONCLUSIONS

This work assumed the primary objective of presenting a methodology for the economic analysis of district systems and a secondary objective of applying the methodology in the state of São Paulo, in order to exemplify the methodology, premises and results.

The methodology was presented in five distinct steps, based on the development stages of a district system project. Each step represented the development of mathematical models, process simulators, routines and optimization procedures, as well as the application of energy indicators.

The continuity of the work will be the application of the methodology in the state of São Paulo. The results obtained so far are related to the first two stages of the methodology – definition of the study area and determination of the district energy demand. As a preliminary result, the analyzed district is the University campus - CUASO. The total measured and simulated energy demand is approximately 43,96 GWh. It is worth pointing out that only one part of the existing campus buildings was considered in the calculation. For this demand, the highest monthly value of thermal load occurs in March - approximately 11.200 TR - and the month with the lowest monthly value occurs in July - approximately 5.900 TR.

The next steps are related to the definition of the power plant model and the implementation of the energy, exergy and thermoeconomic analysis in the EES software. Initially the plant will be modeled to meet the campus's thermal demand. The results of the thermoeconomic analysis of each defined model will be presented and a comparative study will be realized. Therefore, the feasibility of the analyzed DCS is defined.

Finally, the estimates used will be discussed and future investigations should lead to more accurate results.

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6. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.