1. INTRODUCTION

Directly related to sustainable development is the process of expansion and growth of cities. According to Rizwan, Dennis and Liu (2008) urbanization and industrialization represent improvements in the living conditions of people in cities in several aspects. However, this process also brought problems such as climate change, accumulation of solid waste and air compounds that affect the environmental balance. In the scenario of the current dynamics of life in cities, the tendency of this imbalance is increasing due to the increase in the urban population.

Urban planners are concerned with the typical development model of cities. It is necessary to think about a new model of the city, as well as were done by the architects and planners of the 19th and 20th centuries. Duarte (2012) summarizes three distinct references of contemporary cities: the North American vision of the movement called New Urbanism, the Asian reality of the previous dense cities of an unprecedented urban population growth and the scarcity of areas before the occupation and the reality of the much-consolidated compact cities.

The distribution of population in an urban area is variable in a city and its depend of the built environment, specially floor area ratio (FAR), which is the ratio of a building's total floor area to the area of the piece of land. The effects of density are complex and still an open field to researchers. Although it is well known that higher densities are associated to higher energy efficiencies in mobility in the cities, the impact on building energy demand is still unclear (SILVA; OLIVEIRA; LEAL, 2017).

This review is extremely relevant because studies focused on urban density are on the rise and need greater methodological definitions to cover all the complexity required by the urban scale.

2. OBJECTIVE

This study is a systematic review of previous articles with summarized results of the methodologies and measures of the impact of urban density on energy consumption in buildings.

3. METHOD

3.1. Search Strategy

The systematic review was implemented by exploring the following online databases: Google Scholar, Scopus, Periódicos Capes, and Science Direct. The search has started in November 2020, and updated in December 2020. The following terms and Boolean operators to include several combinations: "urban density" AND "energy efficiency" AND "operational energy". The Boolean operator chosen AND presents only the documents that contain all the terms.

The item 3.2 demonstrates the criteria of selection. After completing the search utilizing established criteria, the results were complemented by articles included from a personal library, in order to fulfill the research. These titles were added by screening the references of other studies.

Once with the articles selected, and using the Mendeley reference manager tool, a process of reading the titles and abstracts was carried out. By quickly analyzing the criteria and/or the subject of the material, it was possible to screening to the works that were truly related to the selection criteria. After the articles were chosen, the complete reading and selecting of potential information was accomplished. To simplify the work, a table was utilized as a tool of the main points of each article.

3.2. Inclusion and Exclusion criteria

The following inclusion criteria were applied: (1) being an original study; (2) being a publication in a peer-reviewed journals (although it is important, a few gray literature databases are available); (3) publication in English or Portuguese; (4) published between January 2015 and November 2020; (5) article that analyzed microclimate aspects that impact on energy efficiency in buildings; and (6) inclusion of residential and non-residential buildings. The following studies were not included: (1) reviews and (2) original studies that did not analyze the building performance.

4. PRELIMINARY RESULTS

Shown in Figure 1 are the stages of the systematic review. The database search obtained 484 studies in December 2020. After removing the duplicates and screening the title and abstract, an amount of 346 articles were screened from the search. Of these, 313 studies were excluded. Two articles were added from the personal library and reference list of other reviews. As a result, 14 articles were included in the present study. Thirteen studies were published in English and one in Portuguese.

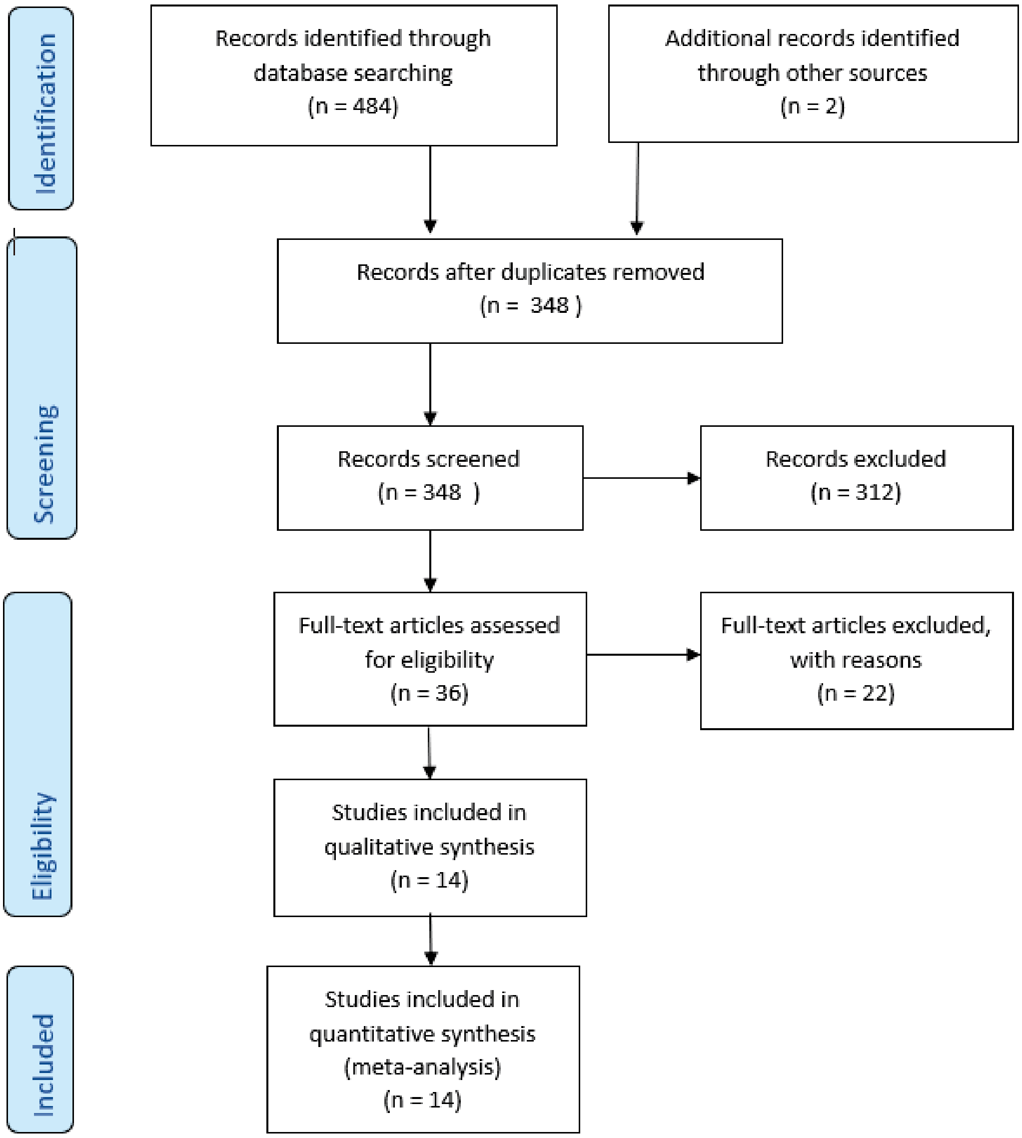

Figure 1 - PRISMA Flowchart of the study selection process.

Table 2 summarizes the characteristics of the studies about urban density and energy efficiency. The majority of studies focused on energy uses for cooling (21%) (CALCERANO; MARTINELLI, 2016; GROS *et al.*, 2016; LIAO; CHENG; HWANG, 2015) or both heating and cooling (79%)(AHMED; ALIPOUR, 2019; ASFOUR; ALSHAWAF, 2015; CUI *et al.* 2017; DU; WOOD; STEPHENS, 2016; GUATTARI; EVANGELISTI; BALARAS, 2018; LI; SONG; KAZA, 2018; LIMA *et al.* 2017; OSORIO *et al.* 2016; PALME *et al.* 2017; SHEN *et al*. 2019; ZINZI, CARNIELO; MATTONI, 2018).

Urban density is a critical aspect to be considered in urban planning. To study the urban microclimate, different assumptions of urban density have been discussed in the reviewed studies. It can be classified in three types: density, Land Use and Land Cover (LULC) and geometry.

Table 2: Characteristics of the studies about urban density and energy efficiency.

Article	Climatic context	Buildings function	Urban factors	Simulation tool	Period of analysis	Validated instrument?	Program/ project
Asfour and Alshawaf (2015)	Cold winters and hot summers	Residential	Urban configuration (single detached, semi-detached, low-rise and high-rise) and density (dwelling unit/m²)	Ecotect program and Design Builder	Annual	Unknown	No
Liao, Cheng and Hwang (2015)	Predominantly hot weather	Residential	Building density, underlying surface of bared ground, roads, and green area.	EnergyPlus	One season	Unknown	No
Ahmed and Alipour (2019)	Predominantly hot weather	Residential	Floor Area Ratio	Grasshoper and Rhino	Annual	Unknown	Centre-Based Interdisciplinary Grant Program, Emirates Center of Energy and Environment Reasearch
Shen *et al.* (2019)	Cold winters and hot summers	Residential and non-residencial	Number of floors, orientation and space between buildings	EnergyPlus and CFD	One specific day	Yes	National Key R&D Program of China
Osorio *et al.* (2016)	Predominantly cold weather	Residential	Surface area (km²), domestic buildings (m²), density of household spaces (hh/km²) and population density (prs./km²)	Simple metric	Annual	Unknown	No
Gros et al. (2016)	Predominantly cold weather	Residential and non-residential	Floor Area Ratio	EnviBatE and SOLENE-Microclimate simulation tools	One week	Unknown	IRSTV
Calcerano and Martinelli (2016)	Cold winters and hot summers	Residential	Shading effect of trees	EnergyPlus, Rhinoceros GrasshopperTM and the plug-ins HoneybeeTMand LadybugTM	Summer	Unknown	No
Guattari, Evangelisti and Balaras (2018)	Cold winters and hot summers	Residential	Not analysed	TRNSYS	2 Years	Unkown	No
Cui *et al.* (2017)	Cold winters and hot summers	Non-Residential	Not analysed	DeST software	Annual	Unkown	No
Li, Song and Kaza (2018)	Cold winters and hot summers	Residential	Housing unit: single-family house, slab apartment, or tower Apartment.Neighborhood level: floor area ratio and street configuration		Annual, Summer, Winter	Yes	Urban Scale Building Energy Efficiency and Renewable Energy
Zinzi, Carnielo, and Mattoni (2018)	Cold winters and hot summers	Residential and non-residential	Urban density and Urban Form	TRNSYS	3 Years	Unkown	No
Du, Wood and Stephens (2016)	Cold winters and hot summers	Residential	Downtown High-Rise x Suburban Low-Rise	SurveyGizmo	Annual	Unkown	No
Lima *et al.* (2017)	Predominantly hot weather	Non-Residential	Different material reflectance values	EnergyPlus v.8.5 software JEPlus v.1.7	Annual	No	CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior)
Palme *et al.* (2017)	Predominantly hot weather	Residential	Built-up area, green area and the facade to site area ratio	TRNSYS	Annual	Unkown	FONDECYT 11140578, DIUV53/2013 and DIUV 52/2013 (Chile) Prometeo 006-2015 (Ecuador)

4.1. Density

It is well known that the effect of the UHI (Urban Heat Island) on building energy consumption is not negligible and, in many cases, it is still not considered in building simulations. The effects of the UHI on the energy consumption of buildings have been widely investigated and this phenomenon clearly affects the energy performance of buildings.

Several studies demonstrate a significant increase of the cooling loads and electricity consumption in the buildings due to UHI (CUI et al. 2017; GUATTARI; EVANGELISTI; BALARAS, 2018; ZINZI; CARNIELO; MATTONI, 2018). On the other hand, the overheating of the city results in lower heating demand in the dense built zones (GUATTARI; EVANGELISTI; BALARAS, 2018; ZINZI; CARNIELO; MATTONI, 2018).

The urban density is basic to understand the complexity of the cities that result from demographic, social, economic, cultural, geographical and/or political dynamics. Among the measures, the most common are density of household spaces and population density (dwelling per unit).

4.2. Land Use Land Cover

Changes of Land Use and Land Cover (LULC) affect the energy demand of buildings. Many studies have concerned to that by measuring surface area (OSORIO *et al.,* 2016; PALME *et al.* 2017), green area and/or trees setups (DU; WOOD; STEPHENS, 2016; ZINZI; CARNIELO; MATTONI, 2018; PALME et al. 2017) and reflectance of surrounding surfaces (LIAO; CHENG; HWANG, 2015; LIMA et al., 2017).

Vegetation cover is considered in the majority of studies related to LULC and its is a consensus that it would reduce the cooling energy use. The close relation between urban land use policies makes these measures very important to make contributions directly applied to cities urban planning. But some researches consider that is not enough to quantify the impact of urban density on the thermal performance of buildings (ZINZI; CARNIELO; MATTONI, 2018).

4.3. Geometry

The last type of urban density assumption is geometry. It has been adopted by many studies and the focuses of geometry are very diverse. Studies that adopted geometric measures tend to present hypothetical scenarios and not real urban patterns. In general, simulation studies often explore urban and/or buildings configuration as well as street and building orientation (AHMED; ALIPOUR, 2019; GROS *et al*. 2016; LI, SONG; KAZA, 2018; LIAO; CHENG; HWANG, 2015; SHEN; BRAHAM; YI, 2018; ZINZI; CARNIELO; MATTONI, 2018). Some measures are usual such as building floor area ratio (FAR), surface–volume ratio (S/V), window wall ratio (WWR) and street height–width ratio (H/W).

The influence of building shape on heating energy demand has consensus findings. Building with compact form tend to be more energy efficient due to reduction on solar irradiation gains because the outside exchange area (AHMED; ALIPOUR, 2019; GROS et al., 2016). On the other hand, there are different conclusions about street and building orientation. The correlation between energy use and street or building orientation is quite complex. Therefore, more studies could examine the significance of this variable on the UHI effect and its consequences on energy efficiency of buildings.

5. FINAL CONSIDERATIONS AND NEXT STEPS

The review on urban density and it impact on building energy use seems to have some important findings of consensus. First, it is well known that the effect of the UHI on building energy consumption is not negligible and, in many cases, it is still not considered in building simulations. The effects of the UHI on the energy consumption of buildings have been widely investigated and this phenomenon clearly affects the energy performance of buildings.

In this first stage of this study, it is concluded that the most relevant urban factors in the articles reviewed are density, LULC and geometry. The characterization of the studies revealed the prevalence in the focus of both heating and cooling energy demand (79%) and considers an annual analysis period (72%). The main reason why some studies were done over a period of specific days, weeks or months is because it results in a shorter simulation time.

In sequence, we intend to carry out an analysis of each simulation tool to identify settings used to approximate the real urban environment on the simulation process. Besides that, as the urban factors measures are very diverse, we also will discuss the differences and potentials of each one. Finally, the synthesis of results and the final considerations will permit a comparative framework useful for futures research about the relationship between urban density and building energy performance.

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