# Buildings Energy Consumption and Thermal Comfort Assessment using Weather and Microclimate data: A Numerical Approach in Humid-Tropical Climate

Katherine Rodríguez Maure, Engineering student[1], Dafni Mora, Ph.D.[1,2], and Miguel Chen Austin, Ph.D.[1]
[1]Research Group Energética y Confort en Edificaciones Bioclimáticas, Faculty of Mechanical Engineering, Universidad Tecnológica de Panamá, Panamá, [katherine.rodriguez8, dafni.mora, miguel.chen]@utp.ac.pa
[2]Centro de Estudios Multidisciplinario en Ciencias, Ingeniería y Tecnología (CEMCIT-AIP), Ciudad de Panamá, Panamá

***Abstract*– A numerical approach between standard weather and urban microclimate data have been analyzed. This study applies a methodology that integrate microclimatic boundary conditions to predict energy cooling demand. It was evaluated in the climatic context by coupling ENVImet and DesignBuilder (EnergyPlus). The coupling was explored at urban scale in Panama, tested for a case study considering morphological configuration, construction materials, occupation profiles and equipment usage. Results show an average difference percentage of as 5.07% in cooling demand when the microclimatic weather data is considered. Also resulting indoor operative temperature indicated that thermal comfort levels are not achieved, which natural ventilation is not a suitable strategy to be implemented even at night hours.**

***Keywords*—Dynamic energy simulation, energy consumption, microclimate data, standard weather data, thermal comfort, urban scale.**

## I. Introduction

Buildings from an urbanization are not environment independent systems, they interact with the outside environment through factors such as wind, solar radiation, and energy exchange. Nowadays, urbanizations must be designed in a sensitive way to the climatic conditions, with transition zones between inside and outside buildings, in such a way that it allows understanding each individual building contribution to the urban microclimate system [1].

The analysis on an urban scale can be achieved through simulations with tools that allow evaluating the behavior of energy exchange on buildings. As of the year 2000, the new technique that combines energy simulation with optimization gives rise to an emerging technology that allows generating new designs based on computational modeling results; This being an efficient methodology that probably guarantees the optimal design by providing a solution to various problems [2].

Choo Yoon y Chengzhi Peng [3] proposed the coupled outdoors-indoors simulation of the microclimate for the passive design of buildings on an urban scale. Through simulations in ENVI-met, they extracted the microclimate condition of the urbanization allowing the visualization of the wind direction and the areas that presented higher temperatures. It was observed that the wind speed around of the building is reduced drastically, which could generate an impact on the internal thermal conditions of the building. The authors highlight that the indoors thermal performance of a building interacts with specific outdoors microclimates, thus showing the importance of a coupled indoors-outdoors simulation at the microclimate level to implement passive design characteristics in buildings [3].

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Jiang, Wu and Teng [4] used ENVI-met to simulate the wind parameters in six case studies based on the diverse spatial distribution of a set of buildings. The characteristics of the microclimatic conditions were compared and evaluated through the wind and the air temperature. This study highlights the relationship between the distribution of buildings and the wind in an outdoor environment. It points out that a correct arrangement of the buildings, according to the prevailing wind direction, allows the formation of a ventilation corridor that favors the flow of air, thus preventing the structures from causing the barrier effect. They indicate that urban trace must be adequate in such a way that it allows the insertion of the wind in the constructions and facades of the buildings.

Most studies have revealed that air flow is extremely sensitive and there are different variables of urban morphology that represent an axis of action in it. The study by Tong, Chen and Malkawi [5] was based on the configuration of a surrounding urbanization and the air flow through the buildings with natural ventilation. The authors refer to the coupled outdoors-indoors technique which they achieve through computational fluid dynamics (CFD) simulations. They establish that key urban parameters influence such as wind condition (direction and speed), H / W aspect ratio (height of the building / width of the street), the height of the buildings in relation to the environment and the number of obstacles in the direction of the wind current. The analysis showed the influence of the building's layers surrounding to the building under study, they also showed that the effect of wind direction is very important for the flow pattern through and around buildings. They indicate that flow field around buildings is more "aerodynamic" under an oblique direction to the wind (45°); in this way the rate of change of the air per hour was notably higher.

On the other hand, Kusumastuty [6] considered building configurations such as the distance between structures, average height, orientation, and road width for the analysis of an investigation based on climate-sensitive urban design. principle.

Bouchahm, bourbia and bouketta [7] carried out a numerical simulation conducted to evaluate wind effect considering parameters such as orientation, buildings geometry, spatial arrangement, wind and vegetation angle incidence.

Feijó-Padilla [8] presented a model capable of qualifying and quantifying the available natural ventilation flows applied to the energy modernization of residential districts. It considered factors such as wind pressure, building envelopes and turbulence phenomena.

At Hong Kong University [9], a study was conducted in which the influence of the urban canyon aspect ratio and tree configuration on microclimate and thermal comfort was examined. This study included the relationship between tree height and crown diameter, trunk height, leaf area index and planting pattern, subject to different wind conditions. It was visualized that there was some reduction in air temperature and mean radiant temperature; the latter, dependent on radiative flux (specifically short-wave direct radiation). The shading effect of the trees is the factor attributed to these changes in the microclimate and thermal comfort of the urban canyon.

This paper analyzes an integrated methodology applied at urban scale in Panama. A case study is defined, it is based on an existing urbanization taking in account standard occupation profiles and energy use. A dynamic simulation energy performance using ENVI-met program allowed to obtained microclimate data. Results were used in DesignBuilder program to obtain buildings consumption. Building's energy consumption and thermal comfort assessment was analyzed using standard weather data and microclimate data.

## II. METHODOLOGY

It was established an integrated simulation method based on two software: ENVI-met urban microclimate model and DesignBuilder building energy simulation program (EnergyPlus). ENVI-met model has great acceptance and diverse applications in landscape studies and built environments [10]. This model was used to predict the external thermal environment respect to the urban configuration of the case study. The outer meteorological conditions limits adopted were derived from data observations in satellite meteorological stations. A historical meteorological compendium data from CLIMdata Solargis © service was used for this study. Microclimate variables such as air temperature, relative humidity and dew point temperature were extracted from the ENVI-met simulation results and there were used to create the microclimatic data. This was taken as input weather conditions data in DesignBuilder software. In this way, the microclimatic effects on building's energy performance could be incorporated into the simulation in DesignBuilder and obtain inside building´s thermal conditions.

### A. *Case study description*

Casco Antiguo in Panama City was taken as urban area reference for this case study (see Fig. 1), it has socio-historical spatial and environmental characteristics. It was the second Spanish colony city on the isthmus (1673) and obeys the urbanization plan legislated by the laws of the Indies (1680) which established guidelines on the design of cities colonized by the Spanish Crown. Currently, it´s considered a World Heritage site by UNESCO and remains under conservation standards of Panama Historic Heritage as a National Monumental Complex [11].

Fig. 1 Casco Antiguo geographical location using Google Earth Pro.


Fig. 2 Casco Antiguo at Panama City.

Layout is aligned according to cardinal points where the main square includes the main church. Buildings maintain heights regulation according to vernacular constructions. It is composed of materials such as: calicanto, wood, clay blocks and concrete, with tile roofs and concrete slab roof. There are streets made of red cobblestones with 4.5 m to 9 m wide dimensions (see Fig. 2).

Casco Antiguo study area is classified as a type 3 local climate zone [12]. It consists of low-level and high-density buildings. It is made up between one and three levels buildings, few trees, paved ground and characterized mainly by construction materials such as concrete and brick.

*B. Microclimate modeling and data generation*

To define Casco Antiguo cutout area, an image format with a Bitmap extension (BMP) from Google Earth Pro was taken; This was cropped to scale with the dimensions of 290 m (x) by 226 m (y), encompassing the Metropolitan Cathedral Church, Plaza de la Independencia and part of Plaza Tomás Herrera (see Fig. 3).

Fig 3 Casco Antiguo cutout area using Google Earth Pro.

It proceeded to define the pixel of the simulate space (GRID): for (z) double the height of the highest building on the stage was placed, for (x) and (y) values between 2 and 3. The pixel size should be in accordance with the scene, so that it fits correctly to the details of the cut-out surfaces.

From this, it proceeded to the construction of the model for the simulation of the urban microclimate. The information referring to the building's heights, surface materials, pavements, and plant species (see Fig. 4) compatible with the software data bank was selected and placed.

Fig. 4 Modelado del recorte del Casco Antiguo en ENVI-met.

The model was constructed with ENVI-met plugins (ENVI-core, Leonardo, BIO-met). ENVI-core allowed the extraction of the maps that collect the modelling microclimate behaviour algorithms, BIO-met interprets the comfort indices, and Leonardo generates the maps of environmental variables (air temperature, relative humidity, mean radiant temperature, wind speed).

TABLE I
STANDARD WEATHER DATA

| Critical day per month | Tmáx (°c)<br>Hour | Tmin (°c)<br>Hour | Hrmáx (%)<br>Hour | Hrmin (%)<br>Hour | Wind speed (m/s) | Wind direction (°) |
|---|---|---|---|---|---|---|
| January 3 | 35.0<br>15:00 | 23.9<br>6:00 | 94<br>5:00 | 44<br>15:00 | 0.43 | 126 |
| February 20 | 34.6<br>15:00 | 22.2<br>6:00 | 93<br>6:00 | 40<br>15:00 | 2.77 | 85.67 |
| March 17 | 35.6<br>15:00 | 24.9<br>6:00 | 73<br>6:00 | 36<br>16:00 | 2.3 | 49 |
| April 11 | 35.3<br>15:00 | 24.8<br>6:00 | 82<br>00:00 | 44<br>16:00 | 1.75 | 87 |
| May 20 | 34.8<br>15:00 | 24.5<br>6:00 | 90<br>6:00 | 53<br>16:00 | 0.87 | 83.3 |
| June 23 | 32.8<br>15:00 | 23.4<br>6:00 | 94<br>6:00 | 58<br>15:00 | 0.45 | 108.25 |
| July 21 | 35.5<br>16:00 | 24.3<br>5:00 | 97<br>4:00 | 49<br>16:00 | 0.3 | 89.3 |
| August 19 | 34.7<br>15:00 | 24.1<br>6:00 | 95<br>5:00 | 52<br>15:00 | 3.9 | 188 |
| September 1 | 32.5<br>15:00 | 23<br>6:00 | 98<br>00:00 | 60<br>15:00 | 2.1 | 83 |
| October 20 | 32.5<br>15:00 | 23<br>6:00 | 96<br>6:00 | 62<br>14:00 | 2.33 | 90.67 |
| November 11 | 32.9<br>15:00 | 23.7<br>6:00 | 94<br>5:00 | 61<br>13:00 | 2.55 | 80 |
| December 16 | 34.3<br>15:00 | 24.6<br>6:00 | 94<br>6:00 | 50<br>16:00 | 4.2 | 34.5 |

To perform the simulations, weather conditions of the most critical days for each month were obtained from the CLIMdata Solargis © service. The critical day for each month were selected according to the highest outdoor air temperature and highest direct solar radiation recorded. From this information (considered here as standard weather data), the initial data for the simulation were extracted (see Table I). The wind direction was obtained using histograms where values with the highest occurrence were selected, and the corresponding average windspeed of these selected values was obtained. According to the case study, a roughness factor value of 0.1 was used and the simulations were evaluated in the twelve months at 1.5 m height from the ground at: 7:00, 15:00, and 21:00 hours. Each simulation lasted around 19 hours employing a 64 Gb RAM with 3.0 GHz of CPU speed.

This before allows to generate the microclimate data at 1.5 m height within the urban area showed in Fig. 4. After simulations are complete, the environmental variables are extracted using maps representations to explore microclimate data distribution along the x and y axes.

As these maps representations only shows maximum and minimum values for each environmental variable within the urban area at certain hours of a day, the values for each variable are still needed for the rest of the hours. This before will serve to incorporate the microclimate data into DesignBuilder software, which was employed to determine indoor thermal comfort conditions and energy consumption. Since it is known that the behavior of some environmental variables can be approximated through a mathematical function, the outdoor air temperature and relative humidity are considered as harmonic functions of time with angular frequency ω and amplitude Ao.

For this, a period of 24 hours was considered where $\omega = 2\pi/24h^{-1}$. Therefore, the outdoor air temperature can be expressed as stated in (1), leading to (2) [13]:

$$T_a = \overline{T_a} + A_o\cos(\omega t) \quad (1)$$

$$T_a = \overline{T_a} + (T_{max} - \overline{T_a})\cos(\omega t - \emptyset) \quad (2)$$

where $\overline{T_a}$ is the mean outdoor air temperature, $T_{max}$ is the outdoor air temperature maximum value registered, $t$ is the time in hours, and y $\emptyset$ represents the phase shift.

Moreover, the outdoor relative humidity is considered here as to be expressed as stated in (3), leading to (4):

$$HR = \overline{HR} + A_o\, sen(\omega t) \quad (3)$$

$$HR = \overline{HR} + (HR_{max} - \overline{HR})\, sen(\omega t - \emptyset) \quad (4)$$

where $\overline{HR}$ corresponds to the mean relative humidity, and

$HR_{max}$ represents the maximum value of the outdoor relative humidity registered.

For the outdoor air temperature function, the phase shift was obtained by replacing the maximum value at the corresponding time ($T_a = T_{max}$ @ $t$) in (2), resulting in 3.93 rad. The same was performed to obtain the phase shift for the relative humidity ($HR = HR_{max}$ @ $t$) with (4), resulting in 0.26 rad.

Furthermore, DesignBuilder also needs the corresponding microclimate dewpoint temperature ($T_{dp}$), which was obtained by employing both the outdoor air temperature and relative humidity, in (5) [14]:

$$T_{dp} = T_a - ((100 - HR)/5) \quad (5)$$

In this way, the values of $T_a$, $HR$ y $T_{dp}$ were obtained for the 24 hours for each day, employing ENVI-met simulation results. Other environmental variables such as direct and diffuse solar radiation are considered as the same provided by the standard weather data. The same was done for the windspeed and wind direction since wind models are included in DesignBuilder software.

### *C. Modeling of the case study to evaluate the indoor thermal comfort and energy consumption*

The building block tool was used to build the cutout buildings in the DesignBuilder software. With the help of Google Earth Pro, data on the dimensions of streets, buildings, squares, and vegetation were obtained (see Figs. 5 and 6).

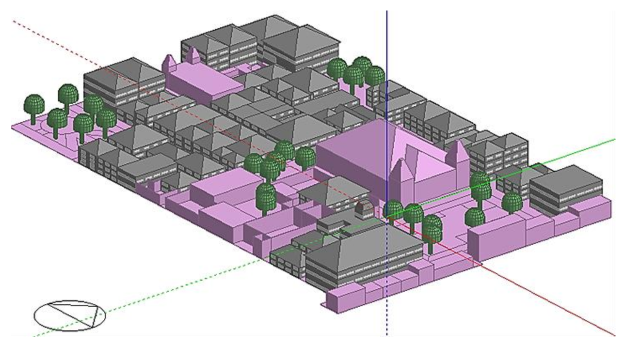
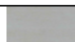


Fig. 5 3D model of urban area of Casco Antiguo in DesignBuilder.

For uninhabited buildings, churches, and historical ruins the component block tool was used (see Fig. 5). The information regarding the heights and levels of the buildings was selected and placed. Materials were selected according to the real characteristics of surfaces, pavements, and plant species (see Table II).

Fig. 6 3D model of urban area of Casco Antiguo in DesignBuilder.

TABLE II
MATERIALS CHARACTERISTICS EMPLOYED IN THE CASCO ANTIGUO MODEL

| Material | Texture | Conductivity (W/mK) | Specific heat (J/kgK) | Density ($kg/m^3$) |
|---|---|---|---|---|
| Concrete block |  | 1.04 | 921.10 | 1841.10 |
| Clay tile |  | 1.00 | 800 | 2000 |
| Brick pavement |  | 0.96 | 840 | 2000 |
| Concrete pavement |  | 0.96 | 840 | 2000 |
| Cultivated clay soil |  | 1.18 | 1250 | 1800 |

The cut-out of the Casco Antiguo has different occupancy profile depending on the building typology. Around 50% of the buildings are establishments dedicated to commercial activities such as restaurants and bars, causing high flows of people on weekends at night. Around 40% are facilities dedicated to hotel and residential services, and around 10% are public offices and institutions [15].

The town of San Felipe, where Casco Antiguo is located, has a population of approximately 3262 people [15]. The population density in the cut-out under study is presented in Fig. 7, which was considered equivalent to the occupancy profile for the simulation in the DesignBuilder software.

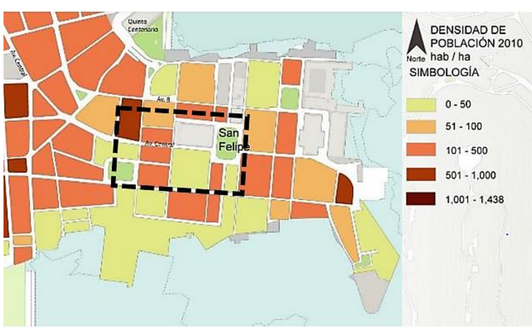



Fig. 7 Population density in the case study [8].

High-consumption equipment, critical for characterizing the energy use profile, are considered as: air conditioning units, refrigerators (running 24 hours a day), and fans (used during midday and afternoon hours). Multiple fluorescent lights are also consider using an energy use profile at night and early morning every day (see Table III). Other devices such as blender, microwave, television, coffee maker, etc. They are used in hotels, restaurants, and residences, but their use is very limited, so it was decided to omit them within the characterization.

For the evaluation of the thermal comfort, the operative temperature is employed as indoor temperature and according to Panama building regulations, indoor temperature levels, must be within 23.5 - 28.5 °C, with a relative humidity between 60 - 80%.

TABLE III
OCCUPATION AND EQUIPMENT USAGE

| | |
|---|---|
| Occupation profile:<br>-0 - 0.005 $hab/m^2$<br>-0.0051 - 0.01 $hab/m^2$<br>-0.0101 - 0.05 $hab/m^2$<br>-0.0501 - 0.1 $hab/m^2$ | Mon to Fri: 8:00 to 18:00<br>Sat to Sun: 13:00 to 17:00 |
| Luminaires (24 W) | Mon to Fri: 19:00 to 22:00<br>Sat to Sun: 19:00 to 5h00 |
| Fans (70 W) | Mon to Fri: 12:00 to 16:00<br>Sat to Sun: 11:00 to 16:00 |
| Computers (65 W) | Mon to Fri: 9:00 to 17:00 |
| Refrigerator (145 W) | Sun to Sat: 0:00 to 23:59 |
| Air conditioning unit | Mon to Fri: 9:00 to 17:00<br>Sat a Sun: 10:00 a 22:00 |

## III. RESULTS ANALYSIS AND DISCUSSION

### *A. Microclimatic data generation from ENVI-met results*

The resulting environmental variables from ENVI-met simulations, for March critical day, are presented in this section. The outdoor air temperature (Ta) at 15:00 is presented in Fig. 8, where the highest temperature values was registered. A maximum temperature value of 36.46 °C is recorded and covers almost the entire urban area, with a maximum relative humidity of 44.13% (Fig. 9). These high temperatures and low humidity in the afternoon are due to solar radiation that causes the heating of the surfaces and the air near them, depending on the material that constitutes it [16]. The albedo of the materials, that is, the fraction of reflected radiation with respect to the incident radiation is another of the characteristics responsible for this energy exchange process. Most of the materials used in the constructions of Casco Antiguo are opaque and surfaces with high emissivity predominate (paving stones, concrete, tiles, etc.).

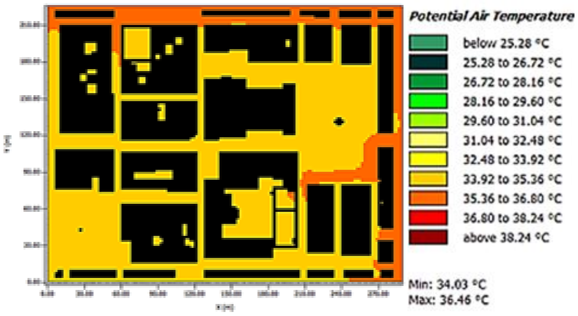



Fig. 8 Air temperature map (Ta) at 15:00 hour for March critical day.

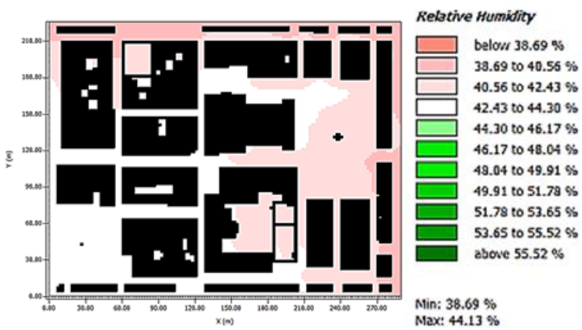



Fig. 9 Relative humidity map (RH) at 15:00 hour for March critical day.

The resulting windspeed within the urban area is presented in Fig. 10. The layout of the streets causes prevailing winds in a direction parallel to its streets and presenting a channeling effect. This channeling effect in the streets causes speeds to prevail in the road corridors up to a maximum of 2.63 m/s for this specific case. The streets perpendicular to the wind present the barrier effect on the windward side and the matting effect on the leeward side, registering minimal flows.

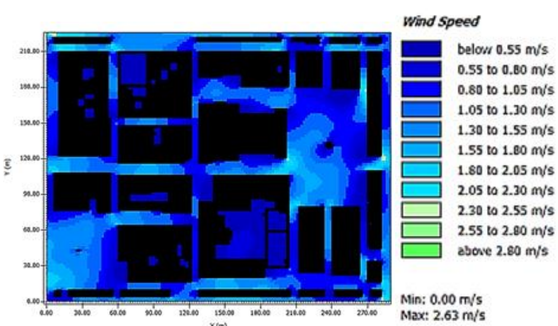



Fig. 10 Windspeed map at 15:00 hour for March critical day.

Moreover, the mean radiant temperature can be observed in Fig.11. At 15:00 the maximum value of 74.70 °C corresponding to the month of March is recorded. It is important to note that even the mustard-colored shaded areas maintain a high average radiant temperature. In relation to the arboreal vegetation, there is little decrease in the mean radiant temperature under the trees; a value close to 1 °C is displayed which is attributed to the extensive waterproof coverage of the place.

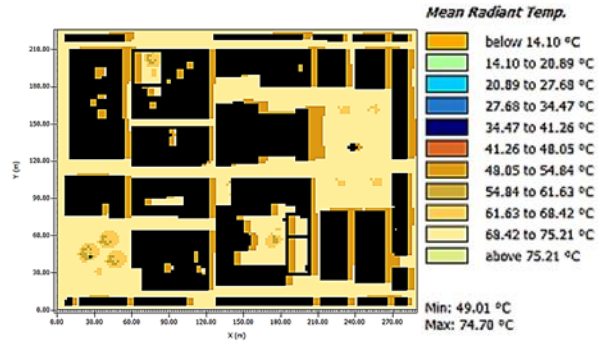



Fig. 11 Mean radiant temperature map (*Tr*) at 15:00 hour for March critical day.

Thus, the resulting microclimate data generated from ENVI-met simulations are presented in Figs. 12-14 for each month throughout the year. It can be observed that the critical month corresponds to March with the highest outdoor air temperature, as well as for the standard weather data showed in Table I.

The temperature levels encountered in Fig. 12 show that external thermal comfort is only achieved during the night and early morning hours. This is important since it certainly benefits the nocturnal activities; however, most cultural activities take place during afternoon hours.

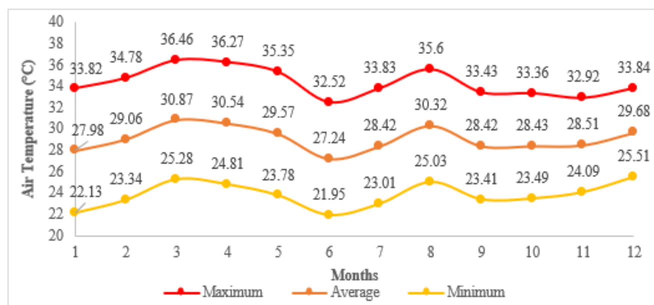



Fig. 12 Generated microclimate data: Monthly maximum, average and minimum air temperature.

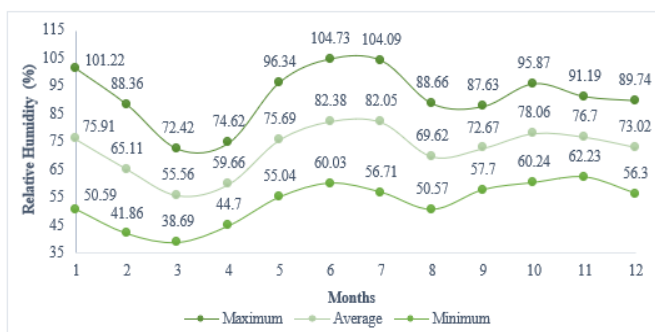



Fig. 13 Generated microclimate data: Monthly maximum, average and minimum relative humidity.

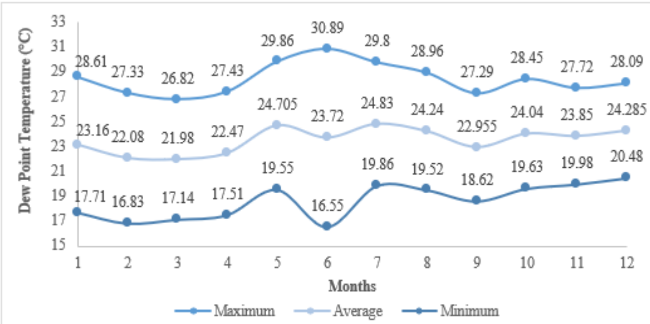


Fig. 14 Generated microclimate data: Monthly maximum, average and minimum dew point temperature

*B. Evaluation of the indoor thermal comfort using microclimate data*

The generated microclimatic data is then incorporated in DesignBuilder software to evaluate the indoor thermal comfort and energy consumption. For the evaluation of the thermal comfort, all buildings within the urban area were set to operate in passive mode (without air conditioning), and the operative temperature was implemented as comfort indicator (Fig. 15).

The values of the resulting indoor operative temperature indicate that thermal comfort levels are not achieved, respecting the monthly averages, which led to conclude that natural ventilation is not a suitable strategy to be implemented even at night hours. Note here that an inconsistency is found for the first month, which may be due to the numerical approach implemented.

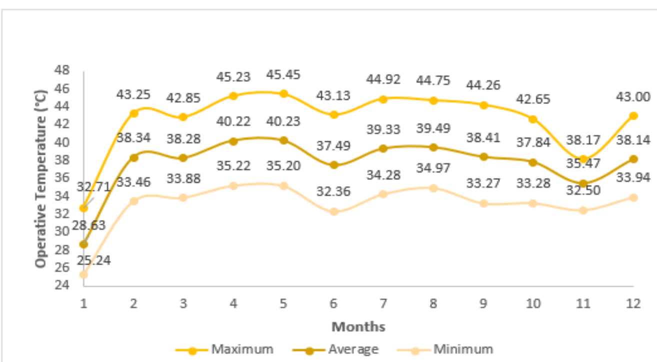


Fig. 15 Resulting indoor operative temperature: Monthly maximum, average and minimum values, using microclimate data.

It can be inferred that even if adequate windspeed might be encountered around the buildings (Fig. 10) with suitable outdoor air temperatures during the night (Fig. 12), significant heat release is not reached to successfully reduce the indoor air temperature and the mean radiant temperature, resulting in. Note here that highest operative temperature values are reached in May, and not during March as suggested by the microclimate and standard weather data. In fact, the indoor average conditions appear to be maintained throughout the year (regarding average values), also suggesting that heat stored inside buildings remain constant and natural ventilation is insufficient. This last remark might be justified by wind direction and small airways between the buildings.

*C. Evaluation of the indoor thermal comfort using standard weather data in passive mode*

The resulting indoor operative temperature using the standard weather data is presented in Fig. 16. As encountered for the results encountered with microclimate data, results in Fig. 16, also indicates that indoor thermal comfort levels are not achieved at any time throughout the year.

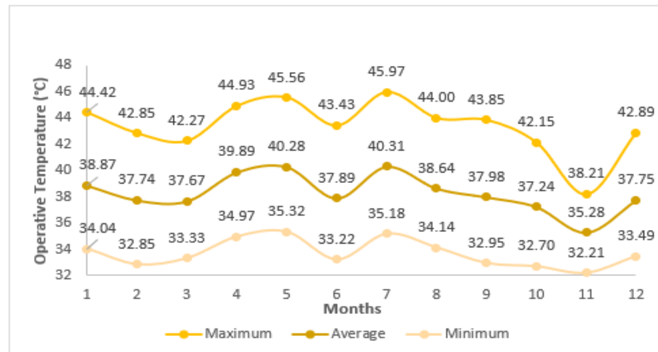


Fig. 16 Resulting indoor operative temperature: Monthly maximum, average and minimum values, using standard weather data.

Regarding the electrical consumption for air conditioning, the dwelling was simulated in active mode during the hours presented in Table III. A comparison of the resulting electrical consumption using microclimate data (dark green color) and standard weather data (light green color), is presented in Fig. 17. The red curve represents the difference between both electrical consumptions, taking the results obtained with standard weather data as reference. The highest electrical consumption is found in the corresponding month of which the operative temperature resulted with highest values.

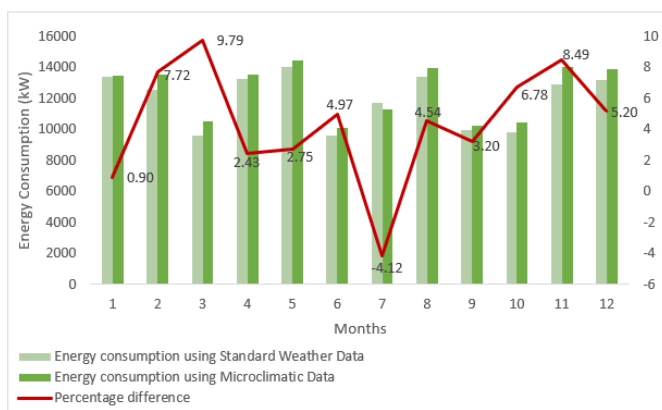


Fig. 17 Percentage difference in electricity consumption using standard meteorological data and microclimatic data.

Fig. 17 shows that significant difference is encountered for some months, where the highest difference of 9.79% (940 kWh) corresponds to March, and the lowest is 0.90% (121 kWh) found in January, being important in terms of energy consumption and energy costs. However, the difference between the electrical consumption does not appear to follow a clear tendency, since great variation is found per month, even if the internal heat gains from occupancy, lightning, and equipment remained the same for each case (with microclimatic and standard weather data).

Moreover, as the resulting electrical consumption is mostly higher when using microclimatic data (with average difference percentage of 5.07%), this sets an important precedent for future energy simulation, in this case study, when high accuracy is required. Note here that the type of urban area studied here is not typical for the rest of the urban developments encountered on the rest of Panama City, and it might be necessary to perform a similar study for such different urban areas.

Finally, the numerical approach implemented was performed using highly accurate licensed energy simulation software, but it has reduced significantly the time spend when large urban simulations are needed for design or retrofitting purposes.

## CONCLUSION

Computational tools which allow coupling urban performance and microclimatic considerations can be more effectively integrated in buildings energy performance design. This study showed the numerical approach in which air temperature, dew point temperature and relative humidity outputs from ENVI-met were used to account in an electrical consumption analysis. Resulting indoor operative temperature indicated that thermal comfort levels are not achieved, respecting the monthly averages, which led to conclude that natural ventilation is not a suitable strategy to be implemented even at night hours. Also resulting average difference percentage of 5.07% demonstrated the importance of accounting for microclimatic data. It showed how dense urban environments modify microclimate impacting on building energy performance.

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## REFERENCES

[1] Building and Climate», *ENVI-met*. https://www.envi-met.com/building-and-climate/ (access sep. 16, 2020).

[2] S.-H. E. Lin, «Designing in perfomance: Energy simulation feedback for early stage design decision making», p. 410, 2014.

[3] C. Y. Yi y C. Peng, «Microclimate Change Outdoor and Indoor Coupled Simulation for Passive Building Adaptation Design», *Procedia Computer Science*, vol. 32, pp. 691-698, ene. 2014.

[4] Y. Jiang, C. Wu, y M. Teng, «Impact of Residential Building Layouts on Microclimate in a High Temperature and High Humidity Region», *Sustainability*, feb. 2020.

[5] Z. Tong, Y. Chen, y A. Malkawi, «Defining the Influence Region in neighborhood-scale CFD simulations for natural ventilation design», *Applied Energy*, vol. 182, pp. 625-633, nov. 2016.

[6] K. D. Kusumastuty, H. W. Poerbo, y M. D. Koerniawan, «Climate-sensitive urban design through Envi-Met simulation: case study in Kemayoran, Jakarta», *Earth and Environmental Science*, mar. 2018.

[7] Y. Bouchahm, F. Bourbia, y S. Bouketta, «Numerical Simulation of Effect of Urban Geometry Layouts of Wind and Natural Ventilation Under Mediterranean Climate», feb. 2012.

[8] A. Meiss, M. Padilla, y J. Feijo, «Methodology Applied to the Evaluation of Natural Ventilation in Residential Building Retrofits: A Case Study», *Energies*, abr. 2017.

[9] T. Eniolu Morakinyo y Y. Fat Lam, «Simulation study on the impact of tree-configuration, planting pattern and wind condition on street-canyon's micro-climate and thermal comfort», *Building and Environment*, abr. 2016.

[10] T. Eniolu Morakinyo y Y. Fat Lam, «Simulation study on the impact of tree-configuration, planting pattern and wind condition on street-canyon's micro-climate and thermal comfort», Building and Environment, abr. 2016.

[11] Á. Mendes Da Silva y M. Romero, «Microclimas urbanos en la ciudad de Panamá: Estudio de tres recortes históricos de la ocupación urbana.», Simpósio Reabilitacao Ambiental Sustentável, Paranoá, 2020. Doi: 10.18830/issn.1679‐0944.n30.2021.03.

[12] K. R. Therán Nieto, L. Rodríguez Potes, S. Mouthon Celedon, y J. M. De León, «Microclima y Confort Térmico Urbano», Módulo arquitectura CUC, vol. 23, pp. 49-88, sep. 2019.

[13] J. Zhou, G. Zhang, Y. Lin, y Y. Li, «Coupling of thermal mass and natural ventilation in buildings», Energy and Buildings, August 2007, doi: 10.1016/j.enbuild.2007.08.001.

[14] M. Lawrence, «The Relationship between Relative Humidity and the Dewpoint Temperature in Moist Air. A Simple Conversion and Applications», Atmospheric Chemistry Department, Planck Institute for Chemistry, Germany, 2005.

[15] C. Padilla Arenas, «Plan integral para la mejora de la movilidad y seguridad vial para el centro histórico de la ciudad de Panamá», Alcaldía de Panamá y Banco Interamericano de Desarrollo, Panamá, Reporte técnico E.1, oct. 2016

[16] L. P. Thomas, M. Marino, y N. Muñoz, «Cuantificación de las Resistencias Térmicas Superficiales y Pérdidas de Calor por Conducción en Edificios Aplicando Termografía», *Avances en Energías Renovables y Medio Ambiente*, oct. 2014.