Ingeniería Investigación y Tecnología
Volume XXVI (Issue 3), July-September 2025 1-11
ISSN 2594-0732 FI-UNAM Peer-reviewed article
Article information: Received: September 13, 2024, accepted: April 9, 2025

https://doi.org/10.22201/fi.25940732e.2025.26.3.017

Natural ventilation in a typical Mexico City building
Ventilación natural en un edificio típico de la Ciudad de México

Fernández-Zayas, José Luis (corresponding author)
Universidad Nacional Autónoma de México
Instituto de Ingeniería
Subdirección de Electromecánica
E-mail: JFernandezZ@iingen.unam.mx
https://orcid.org/0000-0002-9914- 6709

Chargoy del Valle, Norberto
Universidad Nacional Autónoma de México
Instituto de Ingeniería
Subdirección de Electromecánica
E-mail: NChargoyV@iingen.unam.mx
https://orcid.org/0009-0000-3311-6622

Abstract

The Engineering Tower is a ten-story building, which includes a six-story office block in Ciudad Universitaria, in the south of Mexico City, and has been fully operational for the last twenty five years. Passive design is eminently sustainable in the use of water and energy and in the control of comfort. The building includes a central atrium, which induces a permanent air current, generating all the necessary air changes without mechanical assistance. Occupants have adopted practices to operate windows in a manner that ensures a satisfactory interior comfort temperature, resulting in highly sustainable year-round thermal and comfort operation. A database of air temperature and humidity on various floors and offices, as well as outside, has been recorded since the beginning of commercial operation, confirming some of the best architectural practices, such as proper porous external skin performance, induction of vertical currents in the atrium and air flow controls to limit air exchange with the environment. A mathematical model is proposed that correlates the main parts of the building and their energy flows, and the results are compared with measurements from several years. It is proposed that the model, which is appropriately validated, will allow architects to design future buildings in a similar climate, with the same degree of sustainability. Overall, the study validates the use of an atrium to provide year-round passive comfort.
Keywords: Passive building, bioclimatic architecture, sustainable architecture for comfort, passive design for environmental control, natural ventilation, porous facades.

Resumen

La Torre de Ingeniería es un edificio de diez pisos que incluye un bloque de oficinas de seis, se ubica en Ciudad Universitaria al sur de la Ciudad de México y ha estado en pleno funcionamiento durante los últimos veinticinco años. Su diseño pasivo es eminentemente sostenible en el uso de agua y energía, así como en el control del confort. El edificio incluye un atrio central que induce una corriente de aire permanente, generando todas las renovaciones de aire necesarias sin asistencia mecánica. Los ocupantes han adoptado prácticas para operar las ventanas de manera que se garantice una temperatura interior satisfactoria, lo que resulta en un funcionamiento térmico y de confort altamente sostenible durante todo el año. Desde el inicio de su operación comercial, se ha registrado una base de datos de temperatura y humedad del aire en varios pisos y oficinas, así como en el exterior, lo que confirma algunas de las mejores prácticas arquitectónicas, como el correcto funcionamiento de la piel externa porosa, la inducción de corrientes verticales en el atrio y los controles del flujo de aire para limitar el intercambio de aire con el ambiente. Se propone un modelo matemático que correlaciona las partes principales del edificio y sus flujos de energía, y los resultados se comparan con mediciones realizadas durante varios años. Se propone que el modelo, debidamente validado, permitirá a los arquitectos diseñar futuros edificios en un clima similar, con el mismo grado de sostenibilidad. En general, el estudio valida el uso de un atrio para proporcionar confort pasivo durante todo el año.
Descriptores: Edificio pasivo, arquitectura bioclimática, arquitectura sostenible para el confort, diseño pasivo para control ambiental, ventilación natural, fachadas porosas.

Introduction

Passive environmental control to eliminate electrical loads for HVAC is highly sought after in tropical and subtropical regions of the world, where outdoor environmental conditions oscillate around ideal comfort values most of the time (Kini *et al.,* 2017). The architectural design of buildings aims to take advantage of this condition, ensuring that excessive and deficient ambient temperatures are naturally avoided, while at the same time ensuring adequate ventilation (Chiesa & Grosso, 2017; Moosavi, 2015). Therefore, exposure to high solar insolation and high midday ambient air temperatures should be avoided, as should low temperatures in the early morning, generally accentuated in the winter months (Wang *et al.,* 2014). However, a good design can offer adequate comfort control at most hours of the year, appropriately modulating the environmental climate as it interacts with the building (Soares & Fernández, 2015). Complementarily, some automatic devices can be adopted to guarantee a better comfort condition in buildings, such as presence detectors to turn off lights in empty rooms and smart windows to improve ventilation when necessary (Allen *et al.,* 2017).

Several research findings have addressed the problem of controlling ventilation to ensure an adequate building comfort environment (Gagliano *et al.,* 2015). The most common approach by professionals and experts is to provide as automatic control as possible (Bayoumi, 2017) to optimize the results of louvers, openings and shading, to minimize the operation of conventional HVAC auxiliary machines, thus reducing energy consumption, ensuring adequate comfort conditions (Michailidis *et al.,* 2016; Barzegar *et al.,* 2016; Fitriani *et al.,* 2017; Rackes *et al.,* 2016; Castilla *et al.,* 2016). This strategy has enabled a considerable reduction in power requirements, the emergence of a high-quality sensor industry, and a symbiotic relationship of automated systems and sophisticated simulation programs, capable of generating a continuous flow of artificial intelligence devices that constantly innovate. Each other, resulting in a powerful new industry that also promotes considerable energy savings.

When designing a building to achieve comfort with minimal use of external energy, attention must be paid to the occupancy rate and the contribution of users to thermal loads and operating habits, so that the human element works towards optimal operating condition, not despite it (Peng *et al.,* 2017). It should be noted that occupants with certain operating and clothing habits and traditions will affect the set points of auxiliary comfort equipment, but also that certain construction standards may encourage better occupant clothing and habits (Mohd, 2016). It should also be considered that the relationship between comfort conditions and the building is a dynamic circumstance, given the changing nature of the occupants and their environmental operating conditions (Pallubinsky *et al.,* 2017).

It is true that this approach, derived from the supply side of sustainability systems, will have an increasingly important presence. It is also stated that (Hamza *et al.,* 2015) "sustainable construction methods have progressed enormously in recent decades. The example of the German Energy-Plus-House technology uses a combination of (almost) carbon-free passive heating technologies. A web-enabled for residents and greater efficiency." It is so that the technology developed to improve sustainability is also present from the early stages of building design. The availability of high-end simulation models, both to help design and operate buildings, has also improved tremendously over the last decade.

Sustainability procurement has also induced notable progress in the application of more fundamental analyzes to building design and operation, such as exergy analyses, continuous improvement of savings, and thus the emerging urgency of retrofitting buildings, energetically emblematic (García *et al.,* 2016). To alleviate the increasing energy demand for HVAC in countries with hot climate, other cooling methods are developed and evaluated, such as underground cooling devices (Ahmed *et al.,* 2015), sun shading traps to reduce and control heatstroke. On external facades (Lavin & Fiorito, 2017; Ascione *et al.,* 2017; Hariyadi *et al.,* 2017), the control of the physical properties of the external skin (Favoino *et al.,* 2016), and the use of radiant slabs in tropical Malaysia (Yau & Hasbi, 2015).

A very important development path has been opened to accommodate phase change materials, to produce the positive effect of additional inertia for thermal storage (Kircher & Zhang, 2015; Solgi *et al.,* 2017; Saffari *et al.,* 2016). It is a fact that the ability to control the heat capacity of active part construction can improve thermal comfort at reduced cost and energy requirement. However, the review of successful strategies in the search for adequate thermal comfort in buildings is still making little use of the available automatic control technologies, which rising energy costs may make more popular soon.

The Engineering Institute building

The building mentioned hereinafter was built between 1998 and 2001 to provide additional areas to various engineering organizations within the National University of Mexico (UNAM). It is known as the Engineering

Tower, and several university authorities mentioned, at the time of its conception, that it would be a good contribution to celebrate the turn of the century at UNAM. The building was designed by a Mexican architecture firm, Saya and Associates, after an international competition was held by a society of alumni, with the aim of selecting an innovative building design. The building has been awarded several architectural and energy efficiency awards. The ten-story high building is represented in Figure 1, where the main entrance is shown, as part of the west-facing façade. The diagram in Figure 2 shows an elevation view of the building which includes a lower floor for storage, an auditorium and session room level, the entrance level, a six-story high office block and a terrace with sunroof. Temperature measurement points 1-6 are shown. The overall dimensions of the plan are 54 m by 27 m, and the interior dimensions of the office block are approximately 50 m by 25 m (Figure 3). This office block has a central atrium that is partially segmented between office floors 2 and 3, although natural air convection is always enabled through a vast stair opening, as illustrated in Figure 4 (four upper floors).

The west-facing façade, as well as the east-facing face, looks as shown in Figure 1, with floor-to-ceiling windows on the right and metal louvers on the left. The offices are therefore illuminated by sunlight, while the blind part of the face houses service areas. The central terraced face on the west side offers a pleasant view of a small forest and the university swimming pool. The corresponding section on the east face houses two elevators. The elevator shafts and adjoining spaces are unobstructed and provide additional vertical ventilation ducts.

Figure 1. Main entrance on west façade of building

The storage basement, as well as the auditorium and entrance floors, are structurally constructed of reinforced concrete, and from the first floor to the top, the steel structure is configured by four open 3D pipe columns

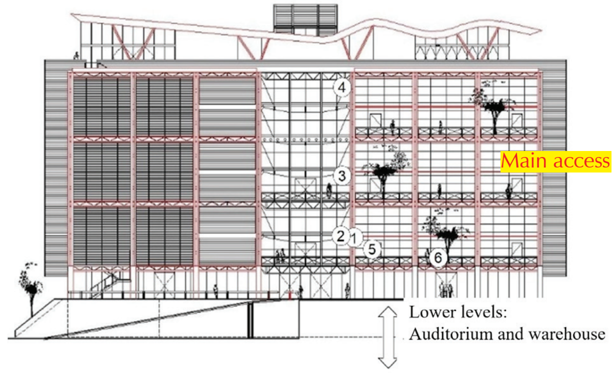

Figure 2. Office building block and location of thermal sensors

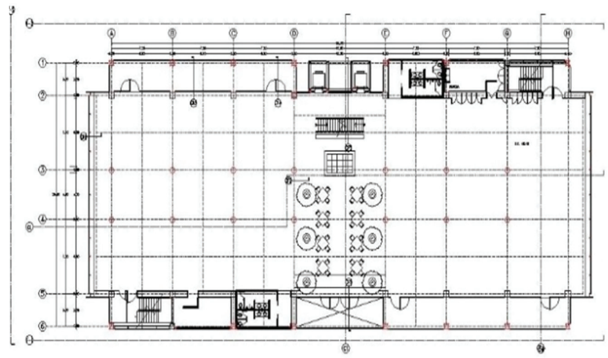
Figure 3. Typical plan of office building block


Figure 4. Atrium with camera facing east, four upper office floors

and beams, as shown (shown in Figure 5). Structure and equipment is "apparent", and the materials of the data and voice cabling and lighting system are not disguised or hidden. Therefore, most pieces of structural and building equipment, including elevators and stairs, are heated and cooled as the building exchanges air with the environment, playing an important role in providing thermal mass.

Each of the terraced facades (floors 1, 3 and 5) is provided with access doors that provide ample ventilation to the building (Figure 6). The right half of the eastern façade and the right half of the western façade have two entrances each.

These doors and some associated windows can be operated manually by the occupants; therefore, a current practice has been established whereby occupants arriving early in the morning decide whether the building deserves more ventilation. They can then open the ventilation doors, if they wish, and the resulting natural vertical draft is established very quickly across the atrium. When doors are not opened, a certain amount of natural ventilation is induced, in any case, given the lack of sealing elements both on the doors and in other parts of the façade. When there is no thermal discomfort from the occupants, and the ventilation doors are not opened, the building is adequately ventilated by this natural process.

Figure 5. Typical terrace in odd floors

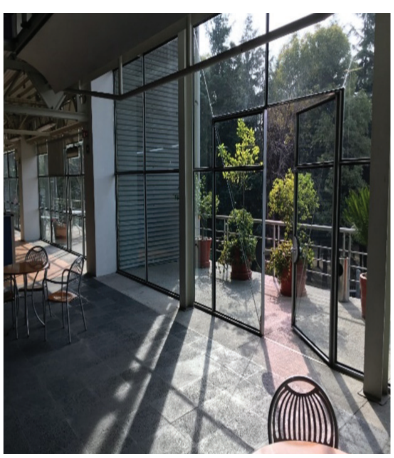

Figure 6. Atrium ventilation to terrace

Experimental procedure

Temperature records

Temperature and relative humidity measurements have been taken and recorded in various parts of the building since its commissioning in 2002. Measurements are taken every half hour, and since 18 measurement points have been selected throughout this period, a database of more than 9 million data has been built. A small sample (sensors 1-6, see Figure 2) is used in the following pages to illustrate some of the most relevant findings. We only refer to the temperature readings on this occasion and leave other data for later analysis. Not all data points have continuous readings, given the various maintenance and replacement schemes that most measuring equipment had to endure.

Ambient temperature

The sensors measuring room temperature are located about 3 m away from the western windows between floors 2 and 3, and are protected from sunlight, although surrounding air currents will certainly influence their readings (sensor 1, Figure 2). A first insight into the ambient temperature can be obtained if the average ambient temperature is plotted over three typical years (2006, 2011 and 2016). Figure 7a shows this evolution of temperature during the 12 months of the year. Temperatures are always low in the winter months and high in summer. There appears to be no obvious explanation for temperatures in 2006 being consistently lower than in later years, other than the surrounding trees being younger at that time and therefore shorter. As the trees grow, they provide thermal shelter to the building. We compared our measurements to those of other buildings on campus, which are available as of 2011, but found no apparent reason for the inconsistency depicted in Figure 7a. The evolution of the monthly maximum and minimum ambient temperature is shown in Figure 7b and Figure 7c. Since our ambient temperature readings are consistent year after year, after 2011, we will use the latter in other comparisons. In the following sections, selected data are used to illustrate the natural effects of air circulation on comfort.

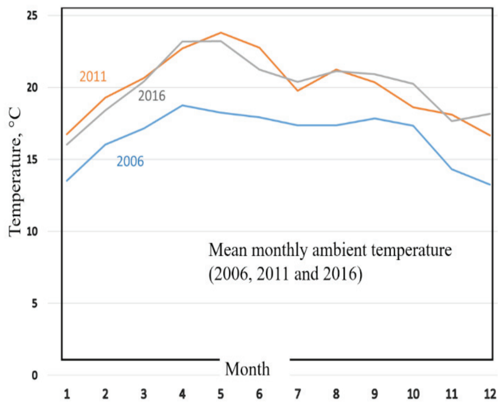

Figure 7a. Ambient temperature along three typical years

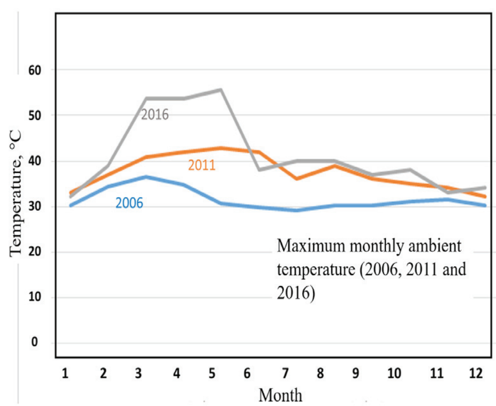

Figure 7b. Maximum ambient temperatures

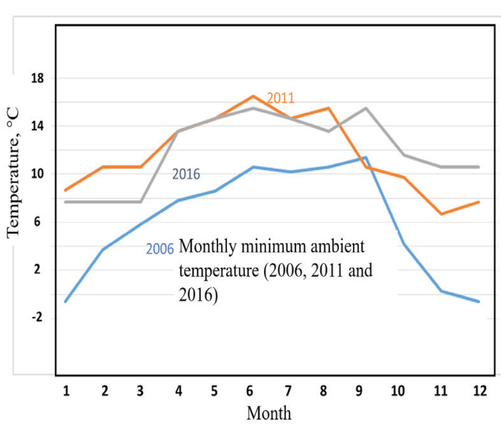

Figure 7c. Minimum ambient temperatures

Thermal mass

The relevance of the various parts of the building in terms of their contribution to comfort, given their heat storage capacity, is illustrated in Figure 8a for a typical week in August (summer) and in Figure 8b for a week in Winter (sensors 1 and 5, Figure 2). The large temperature swing is always associated with the ambient temperature, and the softening of the temperature changes results from the "damping" effect of thermal mass. This mass is certainly associated with heat exchange between structural elements (as shown in Figures 4-6) and the indoor air. In Figures 8a and 8b, the smoothest graph belongs to temperature readings inside an office (sensor 5, see Figure 2). It is very likely that other parts of the building and office, such as furniture and books, contribute to local thermal inertia and therefore buffer changes in ambient temperature.

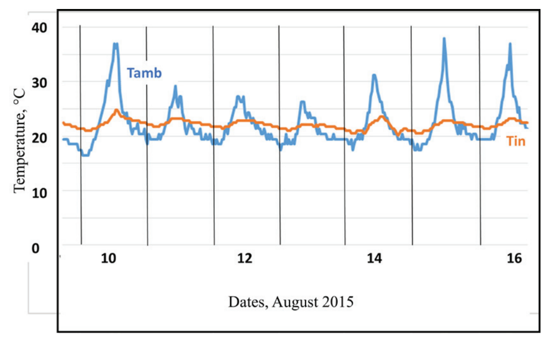

Figure 8a. Interior temperature (Tin) *v* ambient temperature in Summer

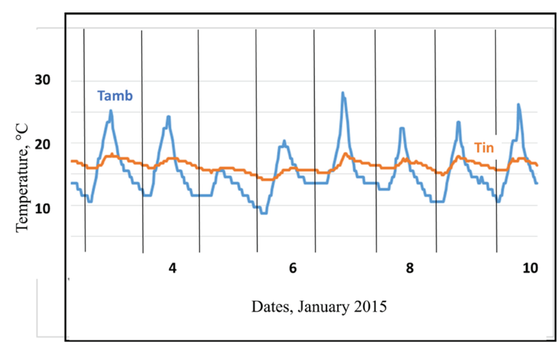

Figure 8b. Interior temperature (Tin) *v* ambient temperature in Winter

As shown in these two graphs, although the temperature inside the office is very constant over time, its value is not optimal. During summer days (Figure 8a) the internal temperature is quite close to the ideal value, which is generally perceived as optimal between 23 °C and 26 °C. These values belong to a relative humidity between 50-60 %, which is the usual range in Coyoacán, México City. On the other hand, inside temperature is colder than desired during the cold season, when it should ideally be between 20 °C and 24 °C (Figure 8b). Several comfort standards are published by HVAC specialists for this part of the city. Typically, free winter ambient heat must be provided by an external heat source for complete comfort. This additional heat could be supplied by any suitable appliance, powered by conventional or renewable energy sources. However, in the building described satisfaction with indoor temperatures and comfort is widely reported as measured by appropriate satisfaction surveys (Götz, 2005). Still, some occupants on floors one and two complain that air temperatures at their office level are below Winter comfort standards, while some (but only a small fraction of them) on the floors five and six report too much heat in the summer period. Complaints to this effect are more common after the natural ventilation grilles at the top of the atrium were removed and replaced by fixed closed windows for maintenance reasons. However, widely held beliefs in sustainable design, much appreciated by the wider user community, which demands warmer clothing in winter, certainly help to maintain very low use of local electric heaters. This is no doubt due to the comparatively small heat deficit, although the architecture of the building should be very different in a less benign climate.

Natural circulation

The building exhibits the classical temperature distribution belonging to the natural circulation of the central atrium, or the "chimney" effect of the atrium volume, which reveals the existence of an inward upward draft most of the time. This effect is most visible in winter, as shown indirectly in Figure 9. This graph includes temperature readings of the air space inside the atrium at "ceiling" level on floors 1, 3 and 6 (sensors 2-4, Figure 2). These three lines are constantly stacked on top of each other, with a temperature difference of about 2°C between adjacent ones. Air moving upward slowly increases its temperature as it flows upward. The ambient air temperature is also displayed, and you can see that most of the time, the indoor temperature exceeds the ambient temperature.

The nature of the storage effect is also revealed by the fact that indoor air exhibits very reduced daily variation, again resulting in greater comfort. It can also be seen that the maximum and minimum temperature values inside the building occur about an hour later than outside.

Separate observations of indoor air circulation confirm the existence of the vertical airflow, which can also be seen expressed in simple temperature readings. However, the important point is that no evidence indicates that ventilation is poor, and no mechanical means have been employed over the years to assist ventilation. If naturally flowing air is responsible for adequate ventilation, it is also desirable that the same air flow contribute to thermal comfort.

To conclude this section, it should be noted that natural air circulation is good enough to maintain a uniform temperature within each floor of the office. To this end, the air temperatures near the floor (sensor 6, Figure 2) and the ceiling at each level (sensor 2, Figure 2) were recorded, and it was concluded that, in general, these readings differ very little from each other, as illustrated in Figure 10. The evidence suggests that air mixing is sufficient within each floor to ensure uniform heat distribution.

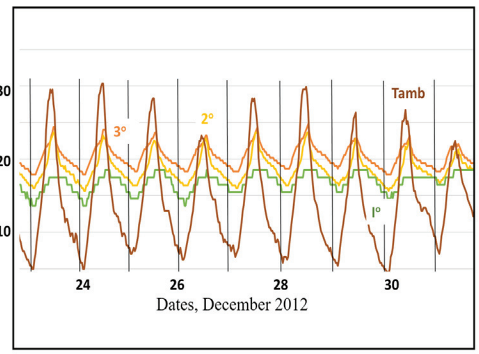

Figure 9. Temperatures in floors 1, 2 and 3 *v* ambient temperature

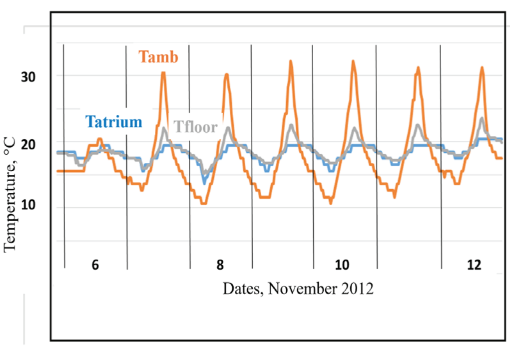

Figure 10. Temperatures inside building *v* ambient temperature

Measurements and data

Temperature data were collected between 2006 and 2017 continuously at sensor points 1-6 (see Figure 2) every half hour, some periods were also skipped for maintenance reasons. Temperature was recorded with an accuracy of 0.4 °C or better, and the data were treated in accordance with accepted best practice (Moffat, 1988). Conclusions and other findings are valid within the uncertainty of the data.

Mathematical model

Bases for a mathematical model

The steady state air velocity due to the natural draft of a chimney can be approximated with the following expression:

$$v = [(2g\ (\rho_o - \rho_r)\ h) / (\lambda\ l\ \rho_r / d_h + \Sigma\xi\ \rho_r)]^{1/2}$$

Where v is the constant velocity, in *m/s*, the air density coefficient ρo and ρr refer to the densities of the ambient, which is colder, and indoor air, respectively. The height of the chimney is h and the hydraulic diameter of the chimney is dh. The length of the pipe is l. Secondary roughness is characterized by Σξ. The Darcy coefficient or friction factor λ is obtained from graphs or tables, and can be approximated by the Colebroke relationship:

$$1 / \lambda 1/2 = -2 \log [2.51 / (Re\ \lambda 1/2) + (k /dh) / 3.72]$$

In this equation, the coefficient of friction appears on both sides, so it must be solved recursively. The value of *k*, the approximate bumps that limit airflow, can be very important. The logarithm has a base of 10. Strictly, a value of the friction factor or coefficient must be approximated to estimate the flow velocity, calculate the value of the Reynolds number *Re* and correct the friction factor through successive approximations.

The variability of air transport properties with temperature is explained by appropriate temperature-dependent expressions, therefore:

Density ρ = (-0.3373014 e-2) T + 1.01482358, [kg/m3]
Viscosity μ = ((0.46210882 e-2) T + 1.64594961) *10–5 [kg/m s]
Specific heat Cp = (0.29142857 e-4) T + 1.00568952 [kJ/kg K]
Thermal conductivity k = ((0.75612857 e–4) T + 0.2406014e–1) *10–3 [kW(m K]

The dimensionless numbers *Re, Pr* and *Nu* are derived from their definition with the help of these expressions.

The calculation of the temperature distribution along the vertical axis of the atrium can be approximated with the help of these expressions assuming that a typical temperature will adequately represent the temperature at the level of each building. This temperature will also depend on the atrium geometry of each level, airflow variables and thermal mass. A lumped parameter approach is visualized with the help of the schematic diagram in Figure 11.

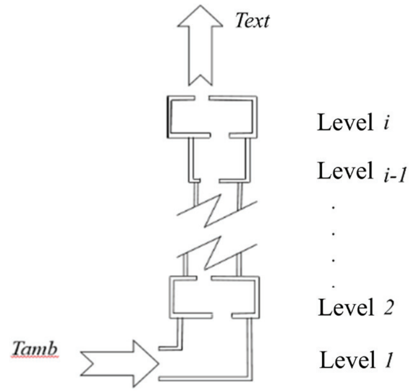

Figure 11. Simplified air flow diagram for i building levels

Assume that each office level (1, 2, ... *i*) can be represented by a particular level height h, a path length of equivalent flow *l*, a mean wall temperature *T*, a Darcy coefficient for friction losses λ, a hydraulic diameter *dh*, secondary roughness characterized by *Σξ*, and at each level, the flowing air would have a particular temperature and flow rate. The energy conservation equations, together with this simplified version of a vertical duct, comprising as many sections as considered convenient, can be solved to establish the temperature at room level at each stage or floor. The characteristics and approximate data of the physical level must be considered. Since the proper procedure to achieve this approximation has not yet been carried out, the following exercise provides physical data after making successive approximations with the help of this mathematical model.

Validation of the mathematical model

For model validation, experimental data from a typical date were used. The data from November 9 in Figure 10 was chosen to illustrate this section, although data from other days were also used to verify the validity of the approach.

The curves shown in Figures 12a and 12b illustrate the fit between the measured and calculated temperature values. From the top of the figure, it is evident that the relationship between the ambient temperature and the internal temperature, after several similar days, is to “smooth out” the daily variations inside, while the thermal inertia of the building acts as a buffer. This double function of attenuation and damping is discussed later, with the help of the mathematical model.

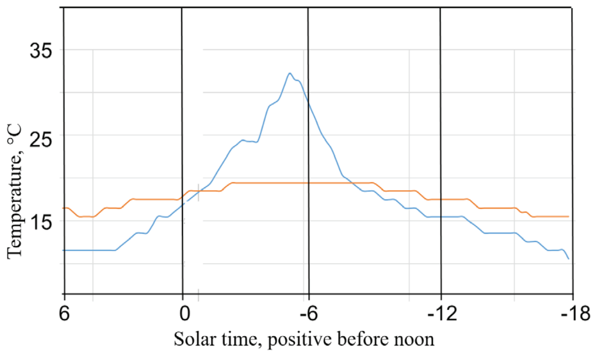

Figure 12a. Typical temperature measurements for ambient (blue) and inside (orange)

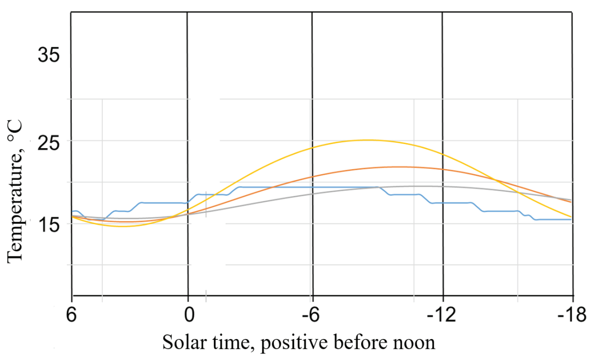

Fig 12b. Comparison of calculated v measured ambient temperature (blue)

To compare the results of the model with the measured data, the model is programmed with the following data, taken from the experiment: Maximum and minimum ambient temperatures, 32.2 °C and 16.1 °C respectively. Julian number of the day of the year: 340, corresponding to the date of the experimental data (for November 9) shown in Figure 12a, latitude 19.3° North. With these last two data, the theoretical length of the solar day is calculated as 10.88 h. Thus, the time of the minimum ambient temperature (one hour before dawn) is 6:44 a.m., solar noon occurs at 0 a.m. and the ambient temperature reaches its maximum value at –2 a.m. if the convention is adopted that the hours in the morning are positive and those in the afternoon are negative. To calculate a complete 24 h period, therefore, the calculation begins at 6:44 a.m. and ends 24 h later, at –5:56 p.m.

The theoretical ambient temperature is calculated from the extreme temperatures indicated and with the length of the solar day noted. Using synthetic data, the model can simulate a wide variety of climatic conditions. With the calculated temperature, the internal temperature can be estimated, as shown in Figure 12b. This calculation is made for the assumption that the mass of material participating in the thermal exchange in the atrium is 2,500 kg (yellow line), 5,000 kg (orange line) and 10,000 kg (gray line). The three solutions were obtained for the assumed values of H = 8, l = 3.5, λ = 0.07, dh = 2, $\Sigma\xi$ = 1 and the roughnesses Kprot=0.01 m. As can be seen in Figure 12b, in no case is the calculated estimate precisely as the measurements showed. However, qualitative data are obtained, such as, for example, the importance of thermal mass in the amplitude of internal temperature oscillations, which are, however, consistent with what was measured. The lower thermal mass better reproduces the extreme temperatures, when comparing those calculated with the measurements, but indicates a greater fluctuation throughout the day compared to the experimental data.

Note, however, that the agreement between the calculated and measured data is reasonable. The reproduction of general temperature trends is acceptable, particularly if it is remembered that no two days are the same (as revealed by the extensive database, lasting more than 15 years) and that the choice has been made to calculate the thermal response with data temperature synthetics. The agreement between what was measured and what was calculated increases very significantly if the internal temperature of the building is calculated based on the information on the ambient temperature measured on the corresponding day, as shown in Figure 12c.

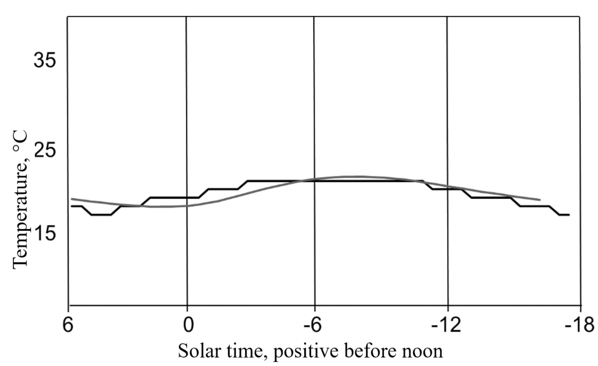

Figure 12c. Comparison of air temperature measured v calculated

Synthetic temperatures are more appropriate for exploring the relative importance of atria and building features, as argued in the next section. A great advantage of using them is that in general it is easy to obtain the extreme ambient temperatures on a monthly average for practically any place in the world. With the procedure proposed here, from this information, reliable instantaneous and continuous data can be generated for environmental temperature, very useful for numerical simulation.

Exploring building features

Two different construction features are illustrated in this section. First the relative importance of building height is explored, and then the importance of thermal inertia is explored. The effect of reducing the air flow is then calculated. The numerical solutions are shown in Figure 13 for the atrium heights of 20, 60 and 200 m, when the mass of the atrium is estimated as a linear function of the height H. On the other hand, Figure 14 illustrates the calculation of the temperature of the atrium for a constant height of 20 m, but for a mass that increases from 150 to 1500 kg/m, in relation to the height of the atrium. In the second case, the increase in thermal inertia dampens internal temperature variations more markedly, while the increase in the height of the building increases the entry of air at room temperature. On cold days, stronger atrium air circulation will cool the building more intensely if the internal thermal mass is low.

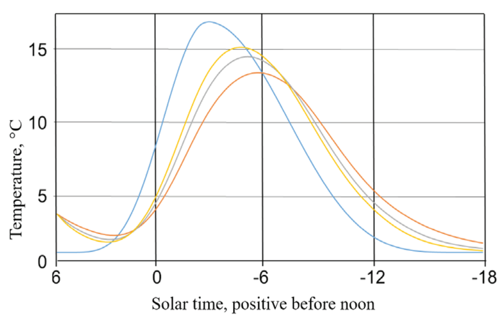

Figure 13. Ambient temperature variation (blue) gets damped with increased atrium height

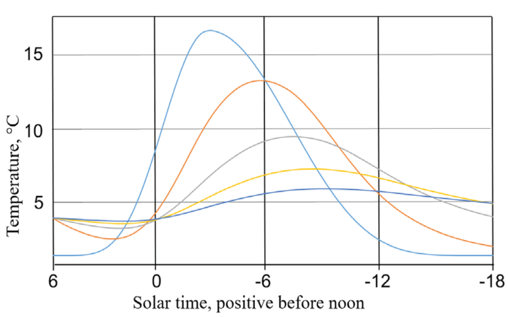

Figure 14. Air temperature variation (blue) is damped with building mass

It is evident that the choice of construction materials, which would determine the amount of mass to be heated and cooled in each daily cycle, is a powerful tool to moderate the most detrimental effects on the comfort of the atrium's natural circulation in cold climates. Another design variable is the possible blocking of air flow, which would immediately reduce the entry of atmospheric air and therefore allow the building's heat to be preserved inside. A compensation is established with a reduced capacity to cool the CO_2-saturated air in the atrium. As shown in Figure 15, air circulation can be blocked to reduce daily indoor temperature variations. A substantial blockage, resulting in the loss of almost entirely all natural air circulation, would allow for easy control of the interior temperature by simply adding a small amount of heat.

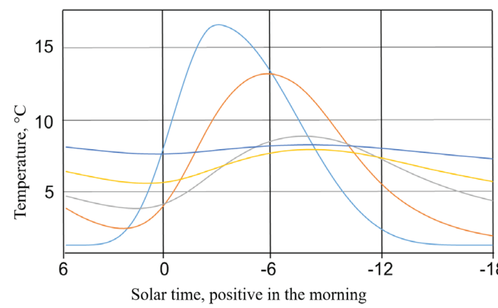

Figure 15. Air temperature variation is damped with atrium blocking

The various temperature curves in Figure 15 refer to blocking fractions of the effective air circulation area in the atrium, which is proportional to the square of the hydraulic diameter *dh*. It should be noted that the initial temperatures for calculating the internal temperatures in the building are considered higher the less air circulates, because of preserving interior heat from one day to the next. From the calculation point of view, the value of the start temperature is established with successive calculations of each 24 h cycle, and the start temperature of the calculation is then modified using the end temperature of the calculation of the previous cycle.

Conclusions

Vertically connected office floors, which will together act as a flow inducer for air ventilation in buildings, can lead to very considerable energy savings and generally comfortable workspaces. These features are welcome in tall buildings in tropical climates, where atrium circulation induces perceptible air movement and therefore improves comfort, at least most of the year. However, natural draft can be an undesirable feature in cold weather. Under low temperature environmental conditions, the natural circulation mechanism becomes more effective and can make building inhabitants feel that the indoor temperature is lower than the ambient temperature. This situation will arise only a few days a year, probably enough for occupants to become unhappy with the comfort in the building.

The implemented mathematical model can be adapted to simulate possible changes in the building design and evaluate their effects on comfort. This approach can provide building designers with a better understanding of the provisions that must be made so that comfort does not suffer catastrophic damage on winter days. The analysis presented by Rackes *et al.* (2016), which was extensively validated with our own 20-year temperature measurements in a 6-story office building in Mexico City, provides the basis for equipping a building with various materials to compensate. The direst adverse effects of natural draft in winter. This method can equally be implemented with any solar gain and other thermal loads that the builder wishes to contain. Thermal design can be improved and therefore human comfort, which means more value under similar sustainable approaches. This mathematical model will have to be validated with at least some additional physical measurements on other buildings to gain the designer's confidence in the future.

Acknowledgements

The initial stages of this research was financed by PAPIIT IN105619 so that several students could be given grants and some sensors and electronic components could be bought.

References

Ahmed, S., Khan, M., Amanullah, M., Rasul, M., & Hassan, N. (2015). Performance assessment of earth pipe cooling system for low energy buildings in a subtropical climate. *Energy Conversion and Management*, 106, 815-825. http://dx.doi.org/10.1016/j.enconman.2015.10.030

Allen, K., Connelly, K., Rutherford, P., & Wu, Y. (2017). Smart windows-Dynamic control of building energy performance. *Energy and Buildings*, 139, 535-546. https://doi.org/10.1016/j.enbuild.2016.12.093

Ascione, F., Böttcher, O., Kaltenbrunner, R., & Vanoli, G. P. (2017). Methodology of the cost-optimality for improving the indoor thermal environment during the warm season. Presentation of the method and application to a new multi-storey building. *Applied Energy*, 185, 1529-1541. http://dx.doi.org/10.1016/j.apenergy.2015.10.169

Barzegar, Z., Afshinmehr, V., & Hayatinezhad, M. (2016). Examining shadow, solar radiation, and daylight in qalat commercial-administrative complex using ecotect simulation. *In Immunology and Microbiology: Appl. Microbiology and Biotechnology*, 7, 191-199. Retrieved on https://www.researchgate.net/publication/311433636_Examining_shadow_solar_radiation_and_daylight_in_qalat_commercial-administrative_complex_using_ecotect_simulation

Bayoumi, M. (2017). Impacts of window opening grade on improving the energy efficiency of a façade in hot climates. *Building and Environment*, 119, 31-43. https://doi.org/10.1016/j.buildenv.2017.04.008

Castilla, M., Bonilla, J., Álvarez, J. D., & Rodríguez, F. (2016). A room simulation tool for thermal comfort control in a bioclimatic building: A real example of use with an optimal controller. Special Issue: *Optimal Control Applications and Methods*, 37, 479-495. http://dx.doi.org/10.1002/oca.2116

Chiesa, G., & Grosso, M. (2017). Cooling potential of natural ventilation in representative climates of central and southern Europe. *International Journal of Ventilation*, 16. https://doi.org/10.1080/14733315.2016.1214394., 84-98

Favoino, F., Fiorito, F., Cannavale, A., Ranzi, G., & Overend, M. (2016). Optimal control and performance of photovoltachromic switchable glazing for building integration in temperate climates. *Applied Energy*, 178, 943-961. https://doi.org/10.1016/j.apenergy.2016.06.107

Fitriani, I., Sangadji, S., & Kristiawan, S. A. (2017). Energy efficiency evaluation of hospital building office. IOP Conf. *Series. Journal of Physics: Conf. Series*, 795. https://doi.org/10.1088/1742-6596/795/1/012067

Gagliano, A., Berardi, U., Nocera, F., & Salerno, N. (2015). Influence of natural ventilation on the thermal behavior of a massive building. In 6th International Building Physics Conference, IBPC 2015. *Energy Procedia*, 78, 1287-1292.

García-Kerdana, I., Raslan, R., Ruyssevelt, P., & Morillon-Gálvez, D. (2016). An exergoeconomic-based parametric study to examine the effects of active and passive energy retrofit strategies for buildings. *Energy and Buildings*, 133, 155-171. http://dx.doi.org/10.1016/j.enbuild.2016.09.029

Götz, R. (2005). *Design, simulation and optimization of the natural ventilation system of the Engineering Tower*. CDMX, Mexico: Institute of Engineering, UNAM.

Hamza-Lup, F. G., Borza, P., Dragut, D., & Maghiar, M. (June 18 - 21, 2015). X3D Sensor-based Thermal Maps for Residential and Commercial Buildings, Web3D '15, ISBN 978-1-4503-3647-5/15/06. HERAKLION. Greece © 2015 ACM. Retrieved on http://dx.doi.org/10.1145/2775292.2775300

Hariyadi, A., Fukuda, H., & Ma, Q. (2017). The effectiveness of the parametric design 'Sudare' blind as external shading for energy efficiency and visibility quality in Jakarta. *Architectural Engineering and Design Management*, 13, 384-403. http://dx.doi.org/10.1080/17452007.2017.1296811

Kini, P. G., Garg, N. K., & Kamath, K. (2017). To investigate the influence of building envelope and natural ventilation on thermal heat balance in office buildings in warm and humid climate. In International Conference on Sustainable Energy Engineering.

Kircher, K. J., & Zhang, K. M. (2015). Model predictive control of thermal storage for demand response (Invited Paper). In American Control Conference. Palmer House Hilton, Chicago, IL, USA.

Lavin, C., & Fiorito, F. (2017). Optimization of an external perforated screen for improved daylighting and thermal performance of an office space. *Procedia Engineering*, 180, 571-581. https://doi.org/10.1016/j.proeng.2017.04.216

Michailidis, I. T., Korkas, C., Kosmatopoulos, E. B., & Nassie, E. (2016). Automated control calibration exploiting exogenous environment energy: An Israeli commercial building case study. *Energy and Buildings*, 128, 473-483. https://doi.org/10.1016/j.enbuild.2016.06.035

Moffat, R. (1988). Describing the uncertainties in experimental results. *Experimental Thermal and Fluid Science*, 1(1), 3-17. https://doi.org/10.1016/0894-1777(88)90043-X

Mohd Sabri Mustapa, S. A. (2016). Thermal comfort and occupant adaptive behavior in Japanese university buildings with free running and cooling mode offices, during summer. *Building and Environment*, 105, 332-342. http://dx.doi.org/10.1016/j.buildenv.2016.06.014

Moosavi, L., Mahyuddin, N. & Ab-Ghafar, N. (2015). Atrium cooling performance in a low energy office building in the tropics, a field study. *Building and Environment*, 94. https://doi.org/10.1016/j.buildenv.2015.06.020

Pallubinsky, H., Kingma, B. R., Schellen, L., Dautzenberg, B., van Baak, M. A., & van Marken Lichtenbelt, W. D. (2017). The effect of warmth acclimation on behavior, thermophysiology and perception. *Building Research & Information*, 45(7), 800-807. https://doi.org/10.1080/09613218.2017.1278652

Peng, Y., Rysanek, A., Nagy, Z., & Schlüter, A. (2017). Occupancy learning-based demand-driven cooling control for office spaces. *Building and Environment*, 122, 145-160. https://doi.org/10.1016/j.buildenv.2017.06.010

Rackes, A., Melo, A. P., & Lamberts, R. (2016). Naturally comfortable and sustainable: Informed design guidance and performance labeling for passive commercial buildings in hot climates. *Applied Energy*, 174, 256-274. https://doi.org/10.1016/j.apenergy.2016.04.081

Roberson, J. A., Brown, R. E., Koomey, J. G., Greenberg, S. E., & Orlando, E. (December 1998). LLBN 40378 UC000, Recommended ventilation strategies for energy-efficient production homes. Los Angeles, California: Lawrence Berkeley National Laboratory, University of California. 49 pp.

Saffari, M., Gracia, A. d., Ushak, S., & Cabeza, L. F. (2016). Economic impact of integrating PCM as passive system in buildings using Fanger comfort model. *Energy and Buildings*, 112, 159-172. https://doi.org/10.1016/j.enbuild.2015.12.006

Soares-Gonçalves, J. C., & Fernández, J.-M. (2015). The environmental design of working spaces in equatorial highlands zones: the case of Bogotá. *Buildings*, 5(4), 1105-1130. https://www.mdpi.com/2075-5309/5/4/1105#

Solgi, E., Kari, B. M., Fayaz, R., & Taheri, H. (2017). The impact of phase change materials assisted night purge ventilation on the indoor thermal conditions of office buildings in hot-arid climates. *Energy and Buildings,* 150, 488-497. https://doi.org/10.1016/j.enbuild.2017.06.035

Wang, F., Pichatwatana, K., Roaf, S., Zhao, L., Zhu, Z., & Li, J. (2014). Developing a weather responsive internal shading system for atrium spaces of a commercial building in tropical climates. *Building and Environment*, 71, 259-274. https://doi.org/10.1016/j.buildenv.2013.10.003

Yau, Y. H., & Hasbi, S. (2015). Field analysis of indoor air quality in high rise and low rise green offices with radiant slab cooling systems in Malaysia. *Indoor and Built Environment*, 24(2), 174-184. https://doi.org/10.1177/1420326X13506130

How to cite:

Fernández-Zayas, J. L., & Chargoy del Valle, N. (2025). Natural ventilation in a typical Mexico City building. *Ingeniería Investigación y Tecnología,* 26(03), 1-11. https://doi.org/10.22201/fi.25940732e.2025.26.3.017