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MULTI-OBJECTIVE OPTIMIZATION OF ENERGY EFFICIENCY AND THERMAL COMFORT IN PUBLIC OFFICE BUILDINGS. CRITICAL SUMMER PERIOD IN THE CITY OF SAN JUAN -ARGENTINA[1]

OPTIMIZACIÓN MULTIOBJETIVO DE LA EFICIENCIA ENERGÉTICA Y EL CONFORT TÉRMICO EN EDIFICIOS DE OFICINA PÚBLICOS. PERIODO CRÍTICO DE VERANO EN LA CIUDAD DE SAN JUAN, ARGENTINA

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RESUMEN

El 40% de la demanda mundial de energía y de emisiones de CO_2 proviene de las edificaciones. En Argentina, los edificios son también responsables del 40% del consumo total anual de energía. El problema radica en el desequilibrio provocado entre la necesidad de proveer de una elevada calidad de vida y confort a los espacios de oficina y el costo de energía requerido para acudir a tal propósito. Tanto un alto nivel de confort como el ahorro energético representan dos objetivos a alcanzar. En ese sentido, este artículo propone una nueva metodología que combina la medición *in situ* con herramientas de simulación matemática. Se incorporan técnicas y modelos innovadores para la elaboración de la herramienta aplicando una optimización multiobjetivo termo-energética, que opera dinámicamente durante el horario laboral. Los resultados muestran un importante ahorro en el consumo energético para refrigeración de espacios de oficinas en verano (del 57,5% al 83,3%), junto con un aumento en la calidad del confort térmico de entre el 4,7% y el 29,4%.

Palabras clave
optimización en edificios, ahorro energético, confort interior

ABSTRACT

Buildings represent 40% of the world's energy demand and CO2 emissions. In Argentina, buildings are responsible for 40% of the total annual energy consumption. The problem lies in an imbalance between the need to provide a high quality of life and comfort in office spaces, and the high energy cost required to meet that goal. Both a high comfort level and energy savings represent two objectives to be achieved. In this sense, this paper proposes a new methodology that combines onsite measurement with mathematical simulation tools. Innovative techniques and models are incorporated to make the tool, applying thermal-energy multi-objective optimization, which operates dynamically during working hours. The results show significant savings in energy consumption regarding cooling office spaces in the summer, from 57.5% to 83.3%, together with an increase in the thermal comfort quality, with improvements between 4.7% and 29.4%.

Keywords
Building optimization, Energy savings, indoor comfort

INTRODUCTION

Worldwide, buildings represent about 40% of energy use, naturally becoming potential scenarios for energy savings and emissions (Li, L. Zhang, Zhang & Wu, 2021; Abdou, Mghouchi, Hamdaoui, Asri & Mouqallid, 2021). The modern human being spends most of their time, from 80% to 90%, indoors (van Hoof, Mazej & Hensen, 2010). Multiple research projects have validated thermal comfort as one of the main variables that affect the comfort in indoor spaces and, in particular, the energy efficiency of buildings (Nguyen, Reiter & Rigo, 2014). Several international studies legitimize the perspective of adaptive thermal comfort as a key energy-saving strategy in buildings (Li *et al*., 2021; Sánchez-García, Rubio-Bellido, Marrero-Meléndez, Guevara-García & Canivell, 2017; Chandel, Sharma & Marwah, 2016), which leads to savings in the range of 30 to 60%, especially when the evolution of the outdoor climate is taken into account.

At a local level, analyses developed in the PICT2009-0014 Project Res.N°304/2010" "EEC, Energy Efficiency and Comfort in Workspaces" and doctoral studies (Arballo, 2020), in the city of San Juan, Argentina, substantiate the thermal dissatisfaction of inhabitants before their work environment and the potential of multi-objective optimization to improve energy efficiency and achieve important savings.

It is of particular relevance to consider the adaptability of inhabitants and onsite climatic variables in real-time, mainly the outdoor temperature (te), to delimit acceptance ranges (see Boerstra, van Hoof & van Weele, 2015). This database enables defining the variable thermal profiles needed to build models to control the indoor temperature of setpoints (Sp) (Rupp, Kim, de Dear & Ghisi, 2018; Rupp, Vásquez & Lamberts, 2015).

In this context, it is necessary to optimize building operation (EnBop, 2008) and develop a real-time multi-objective optimization between energy efficiency and the thermal comfort of inhabitants. These variables conflict since a significant energy saving in the air-conditioning system can result in indoor thermal discomfort conditions for inhabitants. In turn, the energy consumption of buildings depends significantly on the demands of the indoor environment, which affects health, performance, and comfort (Bliuc, Rotberg & Dumitrescu, 2007). The MOGA (Multi-objective Genetic Algorithm) genetic algorithms and the PSO (Particle Swarm Optimization), particle optimization algorithms are the most commonly used to optimize energy performance and comfort in buildings (Nguyen ***et al***., 2014), due to their favorable characteristics and broad degree of applicability (Chambers, 2000). The mathematical theory of genetic algorithms, or MOGA, is presented in Coello, van Veldhuizen and Lamont (2002), and their application to the optimization of HVAC systems, in Lu, Cai, Xie, Li, and Soh (2005), and Atthajariyakul and Leephakpreeda (2005), among others. Genetic algorithms prove to be very useful when it comes to seeking an optimal solution of choice within a set of possible solutions in static situations (Stanislav, 2003). However, they have difficulties when defining possible solutions for dynamic control due to the randomness that their operations characterize. In the Argentine Coastal region, the Center for Computational Methods Research (CONICET-UNL, in Spanish) applies genetic algorithms (NSGA-II), using simulation (Building Energy Simulation) for the reduction of energy consumption (Bre & Fachinotti, 2017), as well as combining genetic algorithms with Artificial Neural Network Metamodels (Bre, Roman & Fachinotti, 2020).

Other less used and little tested algorithms, though they demonstrate very good results in dynamic situations (Y. Yuan, J. Yuan, Du & Li, 2012), are the heuristic ant colony optimization algorithms MOACO (Multiobjective Ant Colony Optimization). One of these is the MIDACO (Mixed Integer Distributed Ant Colony Optimization) algorithm, used to calculate space flight trajectories (Schlueter, Wahib & Munetomo, 2021). In this research, MIDACO is applied for the first time to the field of architecture.

METHODOLOGY

ONSITE COMFORT MEASUREMENTS AND MATHEMATICAL SIMULATION

The measurement methodology consists of conducting a systematic data collection procedure. To measure thermal comfort onsite, a HOBO U12-066 type temperature and humidity sensor (indoor temperature) is used, anchored to a mobile measuring device that moves inside the building (Arballo, 2020). At the time of the measurement, the mobile sensor is located in each office space, at 0.90 ± 0.20 m above floor level and at a radius not greater than one meter from the workplace of the evaluated inhabitant. This makes it possible to capture the environmental conditions perceived by them. This measurement provides objective thermal comfort data. A fixed UA-001-64 type outdoor rooftop sensor, allows recording the outdoor temperature. The operating temperature is considered as an average of the air temperature and the average radiant temperature ($t_{op} = \frac{t_a + t_{rm}}{2}$) (ISO 7730, 2005), considering that the air velocity remains below 0.2m/s and the difference

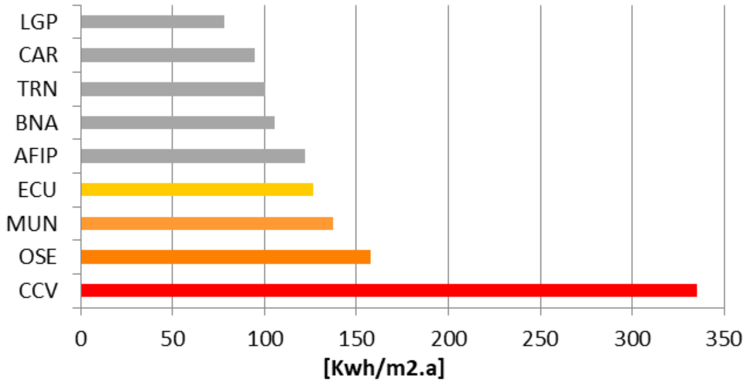

Figure 1. Annual electricity consumption in (kWh/m2.a), with office buildings in the civic intra-ring sector of the city of San Juan, Argentina, standing out. Source: EPRE (2017).

	I	II	III		IV
			A	B	
Name	CCV	OSE	MUN		ECU
Orientation	E-W	N-S	N-S	E-W	N-S
Surface area (m2)	80873	2455	4920		5320
Energy Consumption (Kwh/m2a)	335	158	137		126
Surveys	885	84	86	49	121

Table 1. Relevant information - case studies. Source: Arballo (2020, p. 48).

between air temperature and average radiant temperature is below 4K (Kelvin). In parallel to the measurement made with sensors, a comfort survey is made, which provides subjective information about the inhabitant regarding their workspace. Information on the comfort vote (CV) is obtained from the survey, based on a 7-point scale (ASHRAE Standard 55, 2004). Data on activity level (MET) and clothing (CLO) are also obtained, based on the ISO 7730 Standard. The measurement is carried out from Monday to Friday from 8 am to 1 pm in weeks that present climatic conditions.

CASE STUDIES

The four selected case studies (Figures 1 and 2) represent the highest percentage of annual electricity consumption (*Ente Provincial Regulador de Energía* [EPRE], 2017). They are located in the city of San Juan, Argentina (bioenvironmental zone IIIa, according to IRAM 11603, 2012), at an altitude of 630 meters, a latitude of 31.6° South, and a longitude of 68.5° West. They have a temperate warm dry climate, with an average annual outdoor temperature of 17.2°C, average relative humidity of 53%, high annual solar radiation of 2239.64 kW/m^2, 3300 hours of sunshine/year, high annual and daily thermal amplitude >14K (Kelvin), and winds from the south-east.

Based on these parameters, the main selection of the case studies corresponds to the following buildings (Table 1): I. Civic Center (CCV); II. State Sanitary Works (OSE); III. Central Building of the National University of San Juan (ECU); and IV. Municipality of the Capital (MUN).

The buildings have central air-conditioning equipment, except for the MUN building which is climatized with individual split-type air conditioning equipment. All have a sunshade system.

The CCV building has the largest percentage of public administration workers in the province of San Juan, with around 4,000 workers, and an average of 2,000 people who visit the building every working day. It is a systemic architecture, organized as a modular cell. The building structure is made up of reinforced concrete porticos. The scale of the building exceeds that of the city, and its characteristics are typical of those of architecture schools of the 1960s. The OSE and ECU buildings incorporated bioclimatic design criteria in the project stage, such as sunshades, a reduced window percentage, and 30 cm masonry to the north and west.

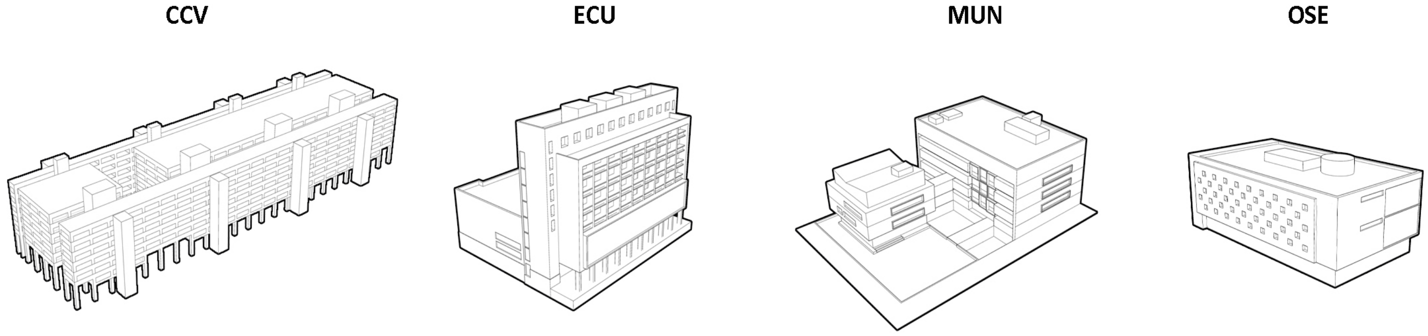

Figure 2. 3D layout of each building. Source: Arballo (2020, p. 62).

MULTI-OBJECTIVE OPTIMIZATION

Solving the problem of multi-objective optimization between energy efficiency and thermal comfort involves making the best decision considering a set of elements. In mathematics, optimization is related to obtaining the maximum or minimum of one or more evaluation functions of a system, where one speaks of single-objective or mono-objective optimization, and multi-objective optimization. In the latter, there are a series of evaluation functions that compete with each other, so one cannot talk about a single optimal solution value, but about a set of values that satisfy one or another objective to a greater extent. Said set of solutions can be found using the Pareto Optimality Criterion (Coello *et al.*, 2002).

From the real data based on measurements, the target functions are designed. The data matrices and the mathematical functions of the different variables are loaded into the MATLAB simulation program. The implementation of the multi-objective optimization algorithm, MIDACO, allows seeing the spectrum of possible solutions (Pareto Optimal Set), to which a preference selection is applied to reach the definitive optimum. Generally, the solution by "norm 2" or ideal vector is preferred to the utopia point.

The quantitative and qualitative evaluation of the results obtained leads to defining the energy efficiency proposals that entail an improvement in the inhabitants' quality of life (health and performance). The determination of the degree of applicability of the optimization proposals achieved thanks to this methodology, to cover energy and thermal demands, is carried out through qualitative analysis.

This multi-objective optimization is carried out in a standard/average space of each building in the most relevant period for the energy demand for air conditioning in the year: summer. By applying the optimization tool developed, the aim is to reduce the energy demand of each building by improving the comfort levels found. The thermal comfort value is expressed as *Diss* (% dissatisfied). The *Diss* variable is obtained from the thermal comfort model adopted (Kuchen, 2008). The energy demand variable, En, is marked in the figures with dotted lines on the x-axis.

DEFINITION OF THE MULTI-OBJECTIVE PROBLEM AND OBJECTIVE FUNCTIONS

At this point, the key variables that affect decision-making on the objective or evaluation functions in the course of the dynamic operation of the multi-objective optimization system, are defined.

The optimization setup assumes that there are two types of ventilation, both mutually exclusive:

a. Without air renewal: A ceiling fan that is capable of moving the air of the entire environment at a speed of V_a, without air coming in from outside. If the AA is off, the only influence is T_e.
b. With air renewal: A cross ventilation made up of two fans located inside using holes in exterior walls: One at one end of the room that blows air from outside and the second, at the opposite end, that extracts it. The result is an air movement with a speed of V_a, which brings in air from outside. The dynamic behavior is different from that of "a.".

The decision variables are updated at each "n" interval of the *k* sample. F is an input variable that differentiates the operating mode(s): F1, closed windows, AA off, ceiling fans move the air at a speed of *va*, as described in optimization setup "a."; F2, Operation of cross ventilation with outdoor air intake following optimization setup "b.", with air movement at speed V_a, and AA off; F3, AA on. Eventually, the ceiling fans described in "a." move the air.

Then, five evaluation functions are determined and all are related to the time space where the work schedule takes place. The decision variables are the air-conditioning setpoint - SPAA, the ventilation air speed, *va*, and the operation mode F. These variables are not static, but move throughout the operation period, usually 24 hours.

1. Energy demand:

$$f_1(\boldsymbol{x}) = E_n = \frac{\sum_{k=n_{w1}}^{n_{w2}} u_a(k)}{n_{w2} - n_{w1}} \qquad (1)$$

This equation, $u_a \in \{0, 1\}$, is a binary control variable of AA that depends on the sequence designed by the optimizer for the setpoint of AA, SPAA, which is ON/OFF type. When the compressor of AA is working and, therefore, consumes energy, it is described as $u_a = 1$; otherwise, as $u_a = 0$. The n_{w1} and n_{w2} values correspond, in sampling intervals, to the start and end times of work, marked with vertical dotted lines on all the time graphs shown below. In this way, 0 < En < 1 is a measure of relative and dimensionless energy consumption. The consumption, *En*, will be the maximum possible - the unit - when the compressor is permanently working, $u_a = 1$ for all $n_{w1} < k < n_{w2}$ and, then, $= \frac{(n_{w2} - n_{w1})1}{n_{w2} - n_{w1}} = 1$. This measure makes it possible to easily compare different AA use strategies for the same environment and the same AA.

2. Average quadratic difference of the percentage of dissatisfied, *Diss*:

$$f_{2(x)} = \frac{\sum_{k=n_w(1)}^{n_w(2)} (Disc(k) - DiscObj)^2}{nw2 - nw1} \quad \forall\, Disc(k) > DiscObj \qquad (2)$$

This is a function that, by its quadratic nature, reaches its minimum when for each sampling interval k, the percentage of *Diss*, dissatisfied, is equal to a certain target value *DissObj*, which is usually set between 7% - the admissible minimum of the Kuchen (2008) dissatisfied function - and 12%.

3. Control of temperature variations of the AA (air conditioning):

$$f_{3(x)} = \frac{\sum_{k=n_w(1)}^{n_w(2)} (SP_{AA}(k) - SP_{AA}(k-1))^2}{n_{w2} - n_{w1}} \qquad (3)$$

This function (3), like the two consecutive ones, has the objective of stabilizing the oscillations of the air-conditioning setpoint, SPAA, by reducing the changes between one sampling interval and the next.

4. Control of variations in V_a (airspeed). Function (4):

$$f_{4(x)} = \sum_{k=n_w(1)}^{n_w(2)} (v_a(k) - v_a(k-1))^2 \qquad (4)$$

5. Control of the number of changes in the operating mode F. Function (5):

$$f_{5(x)} = \sum_{k=h_w(1)}^{h_w(2)} (F(k) - F(k-1))^2 \qquad (5)$$

6. Restriction function (6):

$$Disc(k) < DiscMax \;\forall\; h_w(1) < k < h_w(2) \qquad (6)$$

This is the only restriction function implemented, and its purpose is that the instantaneous value of Diss never exceeds a DissMax limit that is always located above DissObj, for example, 15%.

RESULTS AND DISCUSSION

For the thermal comfort evaluation, the ISSO 74: 2014 Standard for class B buildings is considered, as defined in Boerstra *et al.* (2015) (Figure 3).

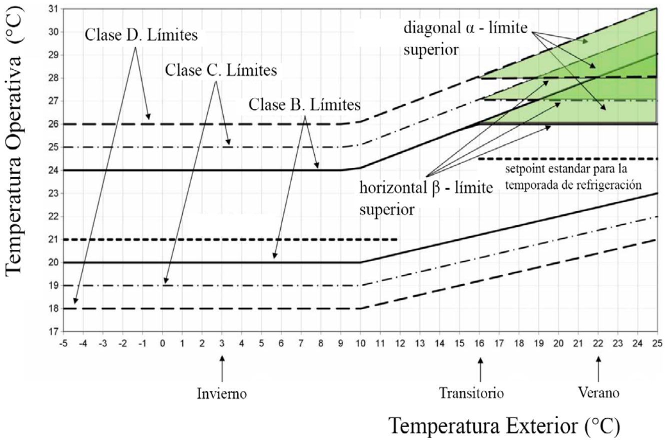

Figure 3. Requirements of ISSO 74: 2014 for operating temperature in relation to the outside temperature for Classes B, C, and D.
Source: Boerstra et al. (2015, p. 28).

According to the ISSO 74: 2014 Standard, all the workspaces of the CCV building are determined as type Beta (β) (Boerstra *et al.*, 2015). The expectation level of indoor thermal comfort is defined as normal, category B. 80% of the office spaces analyzed do not have access to opening windows (a fundamental strategy to restore personal comfort), and 100% of the spaces do not allow personally adjusting the thermostat. The average metabolic rate values (MET) are 1.35 (this is considered normal by ISSO 74). The CLO (clothing insulation) values have an average of 1.44 (values for normal office clothing regulations).

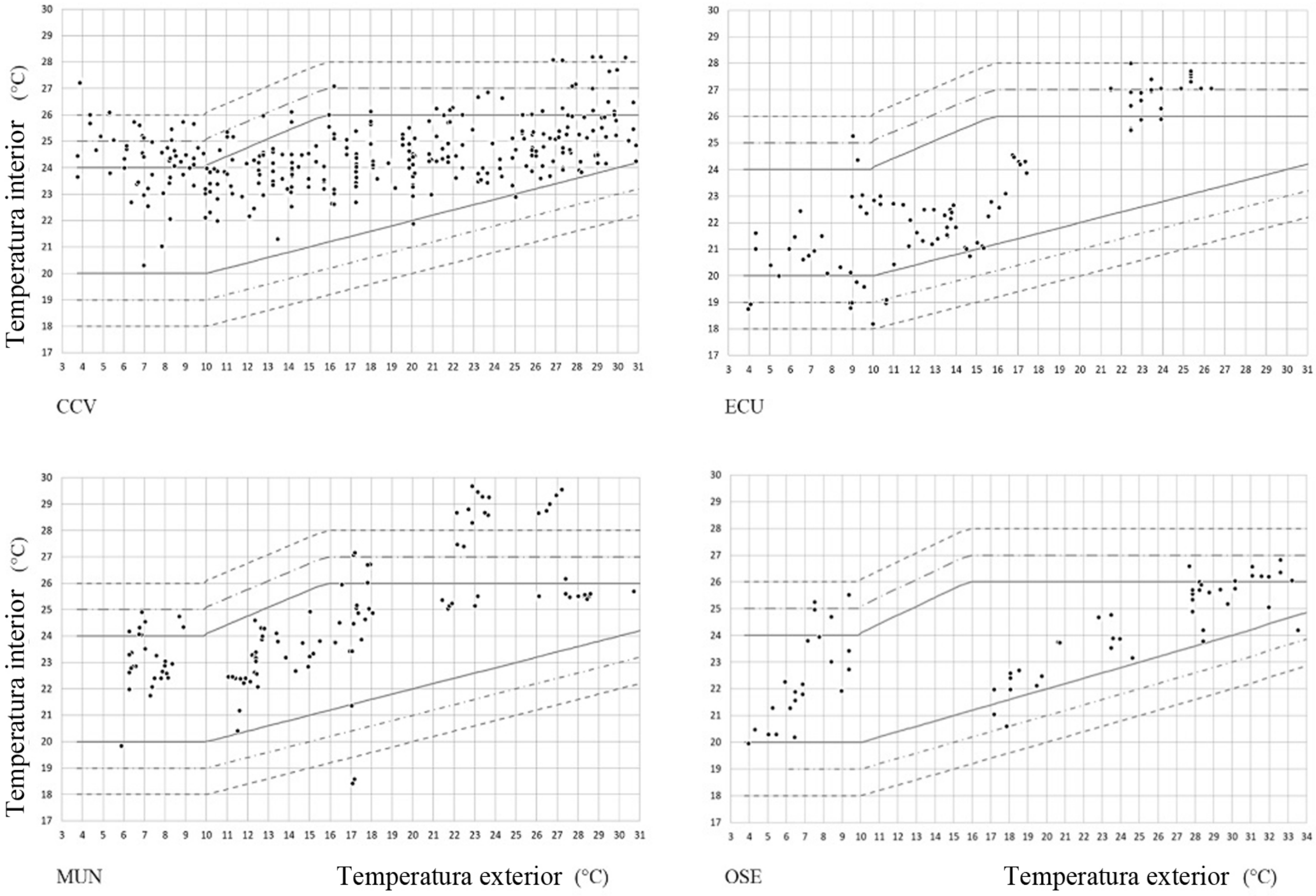

Figure 4. Thermal comfort evaluation for the annual period and comparison of buildings. Source: Arballo (2020, pp. 72-73).

In the annual data compendium (Figure 4) it can be seen that 70% of the data is included in the 90% acceptability area, complying with an average thermal comfort level based on the limits proposed by the ISSO 74: 2014 Standard for type β, class B office spaces.

For the case of the ECU building, the office spaces are determined as type β. The expectation level of indoor thermal comfort is defined as normal, category B. The office spaces have access to opening windows (a fundamental strategy to restore personal comfort), and 100% of the spaces cannot personally adjust the thermostat. In all spaces, the air conditioning system is clearly perceived. The average metabolic rate values (MET) are 1.40 (this is considered normal by ISSO 74). The CLO values (clothing insulation) are 0.76 for summer and 1.44 for winter (normal values for office spaces) (Toranzo, Kuchen & Alonso, 2012).

For the summer, 14% of the data are within class B (90% acceptability) and have an average percentage of acceptability of 86%. For the transitional period, 88% of the data match the class B area. For winter, 92% of the data responds to the class B area.

In the annual data compendium (Figure 4), it can be seen that 82% of the data are included in the 90% acceptability area, complying with the medium/high thermal comfort level according to the limits proposed by the ISSO 74: 2014 Standard for type β, class B office spaces. The summer is the most critical period of the year regarding the thermal acceptability of the inhabitants of ECU.

In the annual data compendium for the MUN building (Figure 4), it is seen that 78% of the data are included in the 90% acceptability area, complying with the average thermal comfort level, according to the limits proposed by the ISSO 74: 2014 Standard for office spaces of type β, class B.

For the case of the OSE building, the annual data compendium (Figure 4) shows that 85% of the data are included in the 90% acceptability area, complying with the medium/high thermal comfort level, according to the limits proposed by the ISSO 74: 2014 Standard for office spaces of type β, class B.

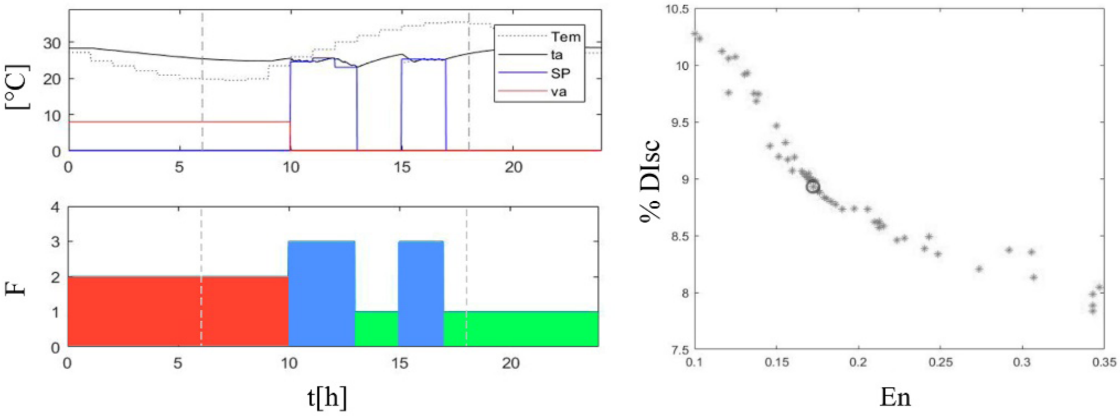

Figure 5. Left: Hourly evolution of operating modes F. Right: Pareto profile of Diss and En variables. Multi-objective optimization of a typical summer day in the CCV building. Source: Arballo (2020, p. 96).

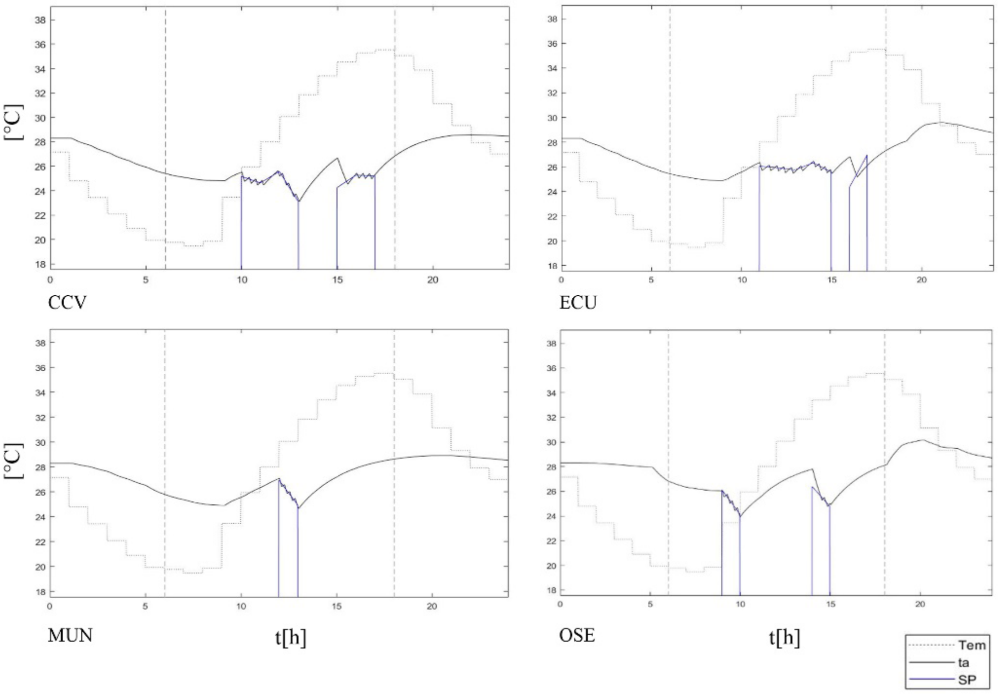

Figure 6. Hourly evolution of Tem (average outdoor temperature), ta (indoor air temperature), and SP (temperature of setpoint). Multi-objective optimization of a typical summer day for the four buildings. Source: Arballo (2020, pp. 97, 100, 104, and 107).

MULTI-OBJECTIVE OPTIMIZATION IN CCV

Figure 5 illustrates the optimization results for the case of the CCV building. According to the daily evolution, the system decides the *F2* (Window, red) strategy during the night (beyond this, it is not currently possible), until 10 AM the next day, when, due to the increase in outdoor temperature, the multi-objective optimizer changes to strategy *F3* (Air conditioning, blue).

In an intermediate segment of the work schedule, it is decided to move on to strategy *F1* (Envelope, green). This cut in the use of air conditioning (AA) allows considerable energy savings. Figure 6 shows, in detail, the evolution and relationship between the average outdoor temperature (*Tem*) and the indoor air temperature (*ta*). As noted, before 10 am, *ta* increases, leading to a change of strategy to *F3* (AA), with *ta*=26°C. With the use of AA, it decreases to *ta*=23.5°C. The system then turns the AA off and on again when *ta*=27°C (3 pm). Maybe during this time (strategy *F1* from 1 pm to 3 pm), even though the system defines this option as the most optimal one, this increase in temperature leads to narrow ranges of thermal acceptance for the inhabitants. However, this intermediate range in strategy *F1* does not imply energy costs, so it contributes to achieving significant energy savings.

These results are obtained from the optimal solution selection for Standard 2 (minimum distance to the ideal vector) found in the Pareto profile (Figure 5). For the CCV building, through optimization, *Diss*=8.85 and *En*=0.17 are achieved.

MULTI-OBJECTIVE OPTIMIZATION IN ECU

The work schedule is marked with dashed lines on the x-axis. In this case (Figure 7), the system decides the strategy *F2* during the morning, until 9 am; there are 2 hours of strategy *F1* and then it is modified to strategy *F3*. In a similar way to the case of the CCV building, it is decided as 1 hour - from 3 pm - of strategy *F1* (Figure 7).

At about 11 am, *ta* exceeds the 26°C limit (Figure 6), suggesting a change of strategy to *F3* (AA). With the use of AA, it decreases to *ta*=26°C. Then, the system proposes turning off the AA and turning it back on when *ta* it is approaching almost 27.5°C.

For the ECU building, through optimization, *Diss*=7.95 and *En*=0.12 are achieved. (Figure 7).

MULTI-OBJECTIVE OPTIMIZATION IN MUN

In this situation, the system advises the strategy *F2* during the morning until 10 am, then 2 hours of strategy *F1*, and finally, it is modified to strategy *F3*, which is maintained for 1 hour (Figure 8). In this case, the energy cost is minimal, compared to CCV and ECU.

With the use of AA, it decreases to *ta*=25°C. The system proposes turning off the AA 1 hour later, achieving significant energy savings. Towards the end of the working hours, *ta* reaches 28°C (Figure 6). Figure 7 shows the Pareto profile obtained based on the optimal selection preferred by Standard 2. For the case of the MUN building, through optimization, *Diss*=8.6 and *En*=0.05 are achieved.

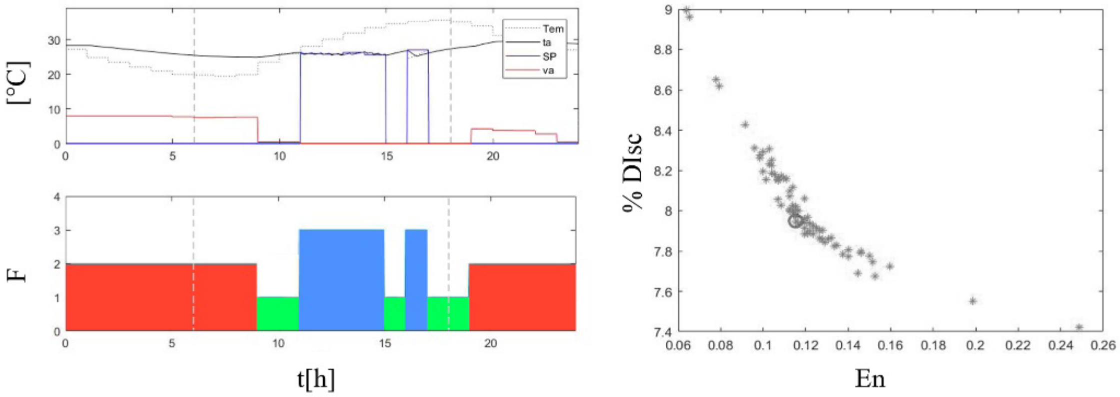

Figure 7. Left: Hourly evolution of operating modes F. Right: Pareto profile of variables Diss and En. Multi-objective optimization of a typical summer day for the ECU building. Source: Arballo (2020, p. 99).

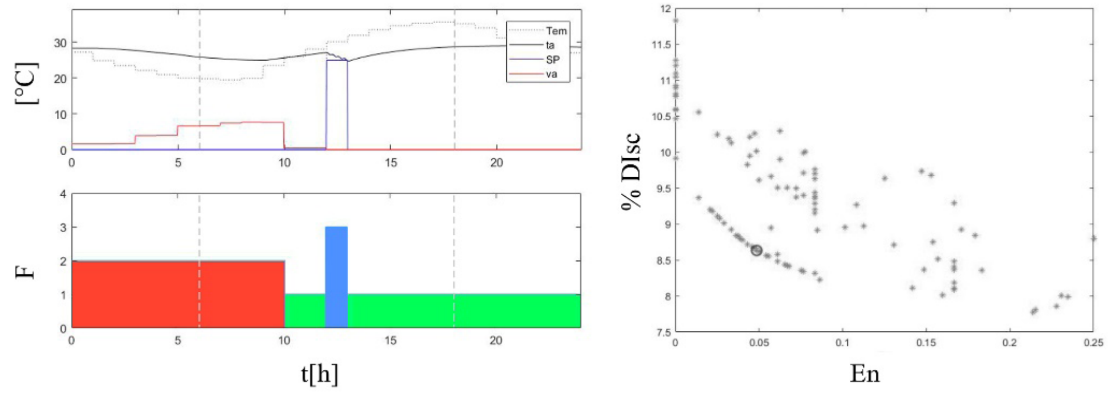

Figure 8. Left: Hourly evolution of operating modes F. Right: Pareto profile of variables Diss and En. Multi-objective optimization of a typical summer day for the ECU building. Source: Arballo (2020, p. 103).

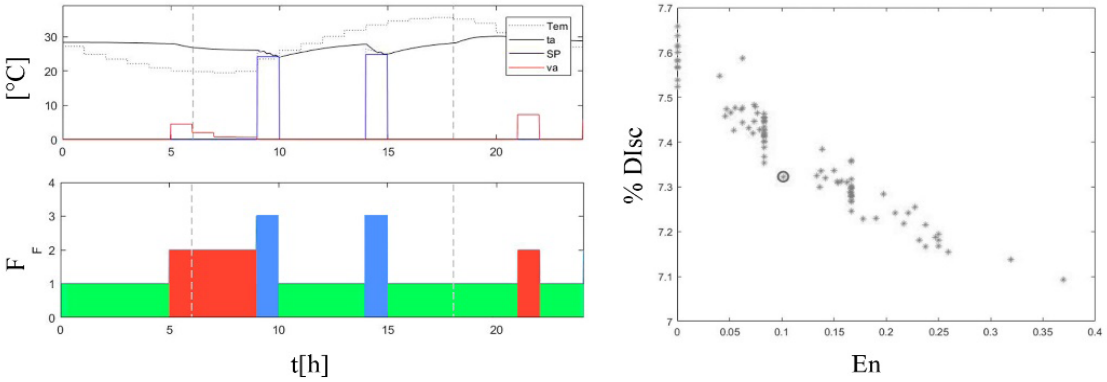

Figure 9. Left: Hourly evolution of operating modes F. Right: Pareto profile of variables Diss and En. Multi-objective optimization of a typical summer day for the ECU building. Source: Arballo (2020, p. 106).

	DISC			EN		
	MED	OPT	%	MED	OPT	%
MUN	38	8.6	29.40	0.3	0.05	83.33
ECU	35	7.95	27.05	0.4	0.12	71.25
CCV	14	8.85	5.15	0.4	0.17	57.50
OSE	12	7.32	4.68	0.3	0.10	66.67

Table 2. Improvements through Diss and En optimization (summer). Source: Arballo (2020, p. 108).

MULTI-OBJECTIVE OPTIMIZATION IN OSE

In the study situation of the OSE building, the system promotes strategy *F2* during the morning until 9 am. Until 3 pm, the system advises 2 hours of strategy *F3*, with an intervening 4-hour period in *F1* (Figure 9).

This is then modified back to strategy *F1*, which is maintained until the end of working hours.

At 9 am, the system is ahead of the increase in *ta* depending on *Tem*, requesting a change of strategy to *F3* (AA). With the use of AA, it decreases to *ta*=24°C (Figure 6). The system turns off the AA 1 hour later, achieving significant energy savings. Towards the end of the working hours, *ta* reaches close to 28°C. For the case of the OSE building, through optimization, *Diss*=7.32 and *En*=0.10 are achieved (Figure 9).

ANALYSIS OF THE RESULTS

This research shows (Table 2) that, when applying the proposed multi-objective optimization improvements in the *Diss* variable (greater thermal comfort) are obtained in all cases - for the summer -, with an average percentage of 20.53%. The normalized energy variable, *En*, also improves in all cases, with an average percentage of 69.6%. The results demonstrate that, through the implementation of the thermo-energy multi-objective optimization tool, the energy demand for the air conditioning of office spaces can be greatly reduced and, simultaneously, it can significantly improve the quality of thermal comfort.

From the classification of energy consumption according to items (for the summer), the consumption corresponding to the "cooling" item is determined (Table 3), which represents, for each building, the following percentages: CCV=45%; OSE=24%; MUN=12%; ECU=8% (Kuchen *et al.*, 2016).

There are energy benefit contributions of the thermo-energy optimization tool, achieving savings of up to 83.3% - in the case of the MUN building - of energy dedicated to cooling during the summer (Table 3). In this way, an energy-saving projection can be confirmed for the CCV building (building with the highest consumption in the province of San Juan), whose consumption is reduced in the cooling item in summer from 62 kWh/m^2 to 26.4 kWh/m^2 (cooling months).

For the buildings that consume the most and that were analyzed, the percentage of savings is reduced (57.5% and 66.7%), but for the buildings that consume the least,

	Annual energy consumption [kWh/m2.a]	Summer energy consumption [kWh/m2.(summer)]	Cooling consumption [kWh/ m2.(summer)]	
			Without savings	With savings
CCV	335	137.5	62	26.4
OSE	158	71.1	17.1	5.7
MUN	137	50.7	6.1	1.0
ECU	126	56.9	4.6	1.3

Table 3. Consumption in summer according to each building and savings for the "air conditioning" item. Source: Arballo (2020, p. 108).

the potential savings are much higher, in the range of 71.3% and 83.3%. The ECU and MUN buildings consume the least, but at the cost of a higher average percentage (35% and 38%, respectively).

CONCLUSION

This research contributes to the creation of techniques and tools for architects, engineers, and specialists in the area, dedicated to the planning of new and existing buildings, which tend to compromise the use of (scarce) natural resources for operation, as well as the emission of greenhouse gases.

Knowing the sanitation advantages of existing buildings or, failing that, the creative solution possibilities in the development of new architectural projects, varying orientation layouts, ventilation, insulation and uses, namely, making the incorporation of bioclimatic concepts that are effective and necessary, positions the building sector on the verge of the change of the environmental paradigm in the reduction of emissions to the atmosphere.

In this work, the incorporation of techniques implemented for the first time in the architectural area of building energy retrofitting is highlighted, identifying design variables (natural/mechanical ventilation, air-conditioning power to be installed), and the control of indoor climate through MIDACO multi-objective optimization algorithms (ant colony). These contributions extend the range of optimization tools, in comparison with applications to office buildings in the project stage (thermal-energy simulation software, like, for example, Energy Plus, Trnsys, and others), which are revealed in the state-of-the-art, addressing the daily dynamic optimization for the retrofitting of existing buildings and future applicability to the development of smart control systems and definition of design guidelines (ventilation), in new buildings.

Specifically, the new design tool is validated by applying multi-objective optimization, where the gap between energy consumption and thermal comfort is reduced, achieving significant energy savings in the four case studies. The solutions found in the Pareto Sets allow contrasting the proposed hypotheses. The scope of significant electrical energy savings for air conditioning (cooling item) in the summer is highlighted, of between 57.5% and 83.3% savings, maintaining thermal acceptance percentages above 90% in all cases.

The design tool allows obtaining target values, that is to say, the definition of "design energy demands" values with a high level of daily detail and by workspace for the summer (in this case), introducing the operating temperature variables, outdoor temperature, and comfort level, in relation to energy consumption, that can be obtained through modeling in energy simulation software (Energy Plus or similar). This is validated in this work, focusing on office buildings with air conditioning in a dry warm temperate climate.

Currently, this research is associated with the technological development of a control system to dynamically optimize comfort variables and air conditioning/ventilation strategies in indoor spaces, in real-time. A State subsidy for the purchase of high-quality supplies and commissioning has been awarded.

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