RESUMEN
El objetivo del trabajo que aquí se presenta fue desarrollar una herramienta metodológica que evaluará el rendimiento laboral de los espacios de oficina durante el periodo de verano. La herramienta propuesta se tradujo en un indicador de rendimiento laboral óptimo denominado IRLO, que combina variables ambientales de influencia térmica, calidad del aire, visual y acústica. Para su desarrollo, se practicaron mediciones integradas y, paralelamente, encuestas a los usuarios-trabajadores de un edificio de oficinas de la Ciudad de San Juan-Argentina. Los resultados revelan los rangos de preferencia de cada variable, reconociendo que en las oficinas de tipología abierta acontece una mayor capacidad adaptativa ambiental que en las de tipología cerrada. Se concluye que el indicador destaca por sentar una base para identificar rendimientos laborales conforme a variables ambientales que deben, en adelante, ser consideradas en fase de diseño.

Palabras clave
calidad ambiental, edificio de oficinas, tipología

ABSTRACT
The purpose of this work was to develop a methodological tool to evaluate office space work performance during the summer period. The proposed tool is an optimal work performance indicator called IRLO, which combines environmental variables on thermal, air quality, visual and acoustic influence. Integrated measurements were run for its development alongside surveys to users-workers of an office building in the city of San Juan - Argentina. The results reveal the preference ranges of each variable, recognizing that in open plan offices, there is a greater environmental adaptive capacity than in closed plan offices. It is concluded, that the indicator stands out by providing a basis to identify work performance considering environmental variables that should, in the future, be considered in the design phase.

Keywords
environmental quality, office building, typology
INTRODUCTION

In the world, a fifth of the population inhabits their work spaces more than 48 hours a week (International Labor Organization [ILO], 2020). These spaces are diverse, depending on the type of activity taking place. In Argentina, 60% of them are from the office sector (National Institute of Statistics and Censuses [INDEC], 2010). These work sites are conceived in terms of elements containing the roles that users-workers (UW) perform, underestimating the important of indoor environmental quality (IEQ) (Marín Galeano, 2013), which is a priority, given that the spatial setup modifies environmental factors, and as a result, has an influence on the sensation of comfort and work performance (WP) of the UW (Nag, 2019).

From the scientific world, progress has emerged on the topic, indicating the indoor environmental variables that have the greatest impact on health and performance (WEI et al., 2020) and that, at the same time allow understanding issues related to spatial design. Among these the temperature (Wargocki & Wyon, 2017; Lamb & Kwok, 2016; Maula, Hongisto, Koskela & Haapakangas, 2016), CO₂ concentration (Candanedo & Feldheim, 2016; Shriram, Ramamurthy & Ramakrishnan, 2019), lighting level (Liu, Lin, Huang & Chen, 2017, Yang & Moon, 2019; H. Wu, Y. Wu, Sun & Liu, 2020), and the indoor noise level (Liebl & Jahncke, 2017; Kari, Makkonen & Frank, 2017) stand out. There is also research that addresses these variables holistically, seeking to find relations between them, as well as to identify those that have the greatest effect on people’s wellbeing (Haegerstrand & Knutsson, 2019; Lou & Ou, 2019; Shin, Jeong & Park, 2018, Wei et al., 2020). However, studies that address WP in offices and how this is holistically affected by the aforementioned variables, are not known, particularly in a warm template climate. For this reason, it is necessary to broaden knowledge focused on these latitudes, especially in a critical period, like summer.

This research has the purpose of getting to know the relationship between IEQ in offices and the WP of UW, for the purposes of determining optimal WP ranges, and making their numerical valuations. For this, an Optimal Work Performance Indicator (OWPI) is designed. In this sense, it is worth underlining that, from architectural spatiality, two clearly defined typologies are recognized, open (OO) and closed (CO). These are studied independently, seeking to find possible similarities and differences.
CHARACTERIZATION OF THE SITE

The city of San Juan (Argentina) is located 630 meters above sea level, at 31.6° south and 68.5 west. The climate, according to the IRAM 1163 standard (1996), is warm template with large temperature variations (Figure 1), atmospheric transparency (Figure 2), and low humidity (Figure 3). The rainfall is continental, with a medium low frequency (Figure 4). According to the Köppen classification (Minetti, Carletto & Sierra, 1986), it is a cold desert type (BWh), where winters are very cold, and summers template or warm. It has a regular moderate southeasterly wind, a characteristic dry-warm zonda wind, considered as a severe westerly event because of its intense gusts (Puliafito, Allende, Mulena, Cremades & Lakkis, 2015). It is most common in August and September (Perucca & Martos, 2012).

OBJECT OF STUDY

The choice of the case study is based on the environmental impact analysis arising from its level of consumption in the city of San Juan. For this reason, the energy consumption of buildings is analyzed and their relationship per meter squared of useful surface (with climate control), destined for work spaces (offices), considering those that exceed 3 (three) floors.

The Civic Center building (CCV) (Figures 6 and 7) has the highest electricity consumption, with values of over 340 kWh/m².year, which is why it was chosen as the case study. Table 1 summarizes its most relevant characteristics.

Figure 5. Electricity consumption per meter squared of office buildings located in the city of San Juan, Argentina. Source: Provincial Energy Regulating Entity.

Figure 6. Civic Center Building-Ground Floor. Source: Urban Development and Planning Direction.
Figure 7. East facade Civic Center Building. Source: Preparation by the Authors. Source: Preparation by the Authors.

Table 1. Characterization of the Civic Center building. Source: Preparation by the Authors.

| Characterization                              | Closed office (CO) | Open Office (OO) |
|-----------------------------------------------|--------------------|------------------|
| Presence of windows                          | Yes                | No               |
| Possibility to open                          | Yes                | No               |
| Daylight control                             | Yes                | No               |
| Height of enclosure-panel                    | 3.60 m. (100%)     | 0.80 m - 2.10 m. (25 %) |
| Average occupation factor                    | 5.10 m²/person     | 4.50 m²/person   |
| Capacity                                      | 2 to 6 people      | 3 to 11 people   |
| Activity                                     | Internal Work      | Internal work-attention to the public |

Table 2. Typological characterization of Offices. Source: Preparation by the Authors.
CLASSIFICATION OF OFFICE SPACES

The variability of IEQ requires distinguishing elements and grouping them by their characteristics. It is for this reason that in this work, office spaces are distinguished as OO (Figures 8 and 9) and CO (Figures 10 and 11). Both have differences that stand out, which a priori leads to thinking about the advantages of the CO over the OO (Pan et al., 2018). Table 2 shows the characteristics that allow establishing the main comparisons.

MEASUREMENT SYSTEMATIC

To collect data, the “Spot” type systematic (focused) was used, based on the techniques of De Dear (2004) and Kuchen and Fisch (2009), and adapted to the collection of the four environmental variables. In this framework, a mobile measurement unit (MMU) is designed (Figure 12), which allows examining 164 spaces, with 636 surveys made during the summer period.

The MMU comprises sensors (Figure 13) that are capable of identifying the following factors:

a. Thermal comfort: HOMO U12-006 sensor. This allows measuring the air temperature (°C) in a range of +40 to +100°C, with a precision of ±0.5°C to 20°C, in humidity conditions of 5 to 95% H.r without condensing. A stabilization time of between 4 to 5 minutes (in static air) is needed for the measurement.

b. Thermal comfort: Ajavision WH380 laser infrared thermometer. This allows measuring the mean radiant temperature (°C) in a range of +50°C to +380°C. It has a precision of ±3°C.

c. Air quality: TELAIRE 7001 sensor. This allows measuring CO₂(ppm) levels in a range of 0 to 2500 in real time. It has a reading sensitivity of ±1ppm and accuracy of ±50ppm.
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**Table: Questions about the indoor environment of your office**

| Question                                                                 | Options                                    |
|--------------------------------------------------------------------------|--------------------------------------------|
| 1. ¿Cómo percibe la temperatura en este momento? (En una escala de 7 puntos marcar la opción correspondiente) | mucha frío | frío | algo de frío | confortable | algo de calor | calor | mucho calor |
| 2. ¿Siente que su rendimiento se va afectado negativamente por la temperatura interior en este momento? | si | no |
| 3. De ser así, ¿En qué grado afecta negativamente a su rendimiento la temperatura en este momento? | Nada (0%) | Bajo (25%) | Medio (50%) | Alto (75%) | Muy alto (100%) |
| 4. ¿Cómo percibe la calidad del aire en este momento? (En una escala de 7 puntos marcar la opción correspondiente) | muy mala | mala | algo mala | regular | algo buena | buena | muy buena |
| 5. ¿Siente que su rendimiento se va afectado negativamente por la calidad del aire en este momento? | si | no |
| 6. De ser así, ¿En qué grado afecta negativamente a su rendimiento la calidad del aire en este momento? | Nada (0%) | Bajo (25%) | Medio (50%) | Alto (75%) | Muy alto (100%) |
| 7. ¿Cómo percibe el nivel de ruido en este momento? | Nada ruidoso | Casi nada ruido | Poco ruido | Medio | Algo ruidoso | Ruidoso | Muy ruidoso |
| 8. ¿Siente que su rendimiento se va afectado negativamente por el nivel de ruido en su oficina en este momento? | si | no |
| 9. De ser así, ¿En qué grado afecta negativamente a su rendimiento el nivel de ruido en este momento? | Nada (0%) | Bajo (25%) | Medio (50%) | Alto (75%) | Muy alto (100%) |
| 10. ¿Cómo percibe la iluminación en este momento? (En una escala de 7 puntos marcar la opción correspondiente) | Encendida | Demasiado luminoso | Luminoso | Algo luminoso | poco luminoso | Algo oscuro | Muy oscuro |
| 11. ¿Siente que su rendimiento se va afectado negativamente por el nivel de iluminación en este momento? | si | no |
| 12. De ser así, ¿En qué grado lo afecta negativamente el nivel de iluminación de su oficina en este momento? | Nada (0%) | Bajo (25%) | Medio (50%) | Alto (75%) | Muy alto (100%) |

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**Figure 13. Comfort/performance sensors. Source: Preparation by the users.**

**Figure 14. Survey made to UW. Source: Preparation by the Authors.**
d. Visual comfort: YK-2005LX light meter sensor. This allows measuring illuminance levels (lux) on the work plane, in a range of 000/100, 000Lux in real time, with a spectral sensitivity that follows the requirements of the CIE (International Commission on Illumination) curve with an accuracy of ± 4%+2 digits).

e. Acoustic comfort: SL-4023SD decibel-meter sensor. This allows measuring noise levels (dB) in an automatic range of 30 to 130 dB and in a manual range (3 ranges) of 30 to 80 dB, 50 to 100 dB and 80 to 130 dB. Time weight: quick/slow. Frequency weight of A (dBA) / C(dBC).

The measurement made in this work was done in a range of 50 to 100 dB, with a slow time weight and A frequency weight.

The survey helps to make a diagnostic of UW, that summarizes the effect of the influence variables. Among the questions asked, those that inquire about the Performance Vote (PV) of the UW become relevant. These are based on studies made by Humphreys and Nicol (2007), where they ask to what extent (0-100%) do they feel that IEQ negatively affected their WP. Figure 14 shows the survey questions made about the perception of IEQ by the UW, which allows obtaining the subjective data.

### IMPLEMENTATION AND RESULTS

WP ranges are built as a means to get to know the degrees of “vulnerability” of the UW, depending on the influence variable by office typology. The steps for its construction are detailed in this section.

1. The PV values of each environmental variable in which the UW self-reports zero influence (0%) on their performance, are recorded.
2. The maximum and minimum Thermal/Performance Vote (PVt), Air Quality/Performance Vote (PVa), Illuminance Level/Performance Vote (PVi) and Noise/Performance Vote (PVn) are defined, which determine the maximum possible variability of each environmental influence parameter.
3. The intermediate ranges are defined considering the division between the optimal value (PV=0%) and the maximum value, and the division between the optimal value (PV=0%) and the minimum value.
4. Finally, to obtain the ranges, numerical equivalents are defined (EqN) and scoring intervals to establish the qualitative evaluation of each range, from “excellent” with an EqN equal to 5, to “bad”, with an EqN equal to 1, for PVt, PVa, PVi and PVn, as indicated in Table 3.

### Table 3. Numerical equivalents of the performance ranges. Source: Preparation by the Authors.

| Qualitative evaluation | Numerical evaluation (EqN) | Scoring Interval |
|------------------------|-----------------------------|------------------|
| Excellent              | 5                           | 4.2 < to ≤ 5     |
| Very Good              | 4                           | 3.4 < to ≤ 4.2   |
| Good                   | 3                           | 2.6 < to ≤ 3.4   |
| Regular                | 2                           | 1.8 < to ≤ 2.6   |
| Bad                    | 1                           | 1 ≤ to ≤ 1.8     |

### ANALYSIS OF THE RESULTS

The relationship between each range by study variable and the WP variability valued qualitatively and quantitatively by means of EqN is shown in Tables 4 to 7, making a distinction between office typologies. In addition, each table is summarized in graphs comprising an X-axis for the measurement values of each environmental variable, and a Y-axis, for the EqN of the analysis variables.

The highest or lowest amplitude of the ranges in the graphs is associated to the UW's capacity to adapt regarding the variable in question. It is seen that these are represented with one or two poles of disconformity, depending on the environmental variable analyzed. Each one of these is described below.

### Operating temperature

The operating temperature values are taken to evaluate the WP affected by thermal variability, since this represents the temperature perceived by a person in an indoor environment. This constitutes the average between the air temperature and the mean radiant temperature, measured in degrees Celsius (°C).

Table 4 shows the WP variability considering the operating temperature ranges by office typology, while Figures 15 and 16 graphically represent the results obtained.

From the analysis made, it can be highlighted that the WP ranges found in the OO typology, have a greater amplitude compared to CO. This is seen to a greater extent on analyzing the “excellent” range. The variability for this level is of 0.8°C in OO, while in CO it is 0.3°C. This situation allows confirming that the UW of OO have a greater capacity to thermal adaptation compared to the CO. After this, it is noticed that there is a preference to work with higher temperatures in UW of CO, this is distinguished more on comparing the “excellent” range of both typologies, with the variability for OO being between 24.7 and 23.9°C, while for the CO, this variability increases on being 25.1 to 24.9°C.
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Table 4. Valuation of WP ranges (of thermal impact) during the summer period for OO and CO. Source: Preparation by the Authors.

| Qualitative evaluation | Bad | Regular | Good | Very Good | Excellent | Very Good | Good | Regular | Bad |
|------------------------|-----|---------|------|-----------|-----------|-----------|------|---------|-----|
| EqN                    | 1   | 2       | 3    | 4         | 5         | 4         | 3    | 2       | 1   |
| Maximum [°C]           | <21.5 | ≤22.3 | <23.1 | <23.9 | <24.7 | <25.5 | <26.3 | <27.1 | -   |
| Minimum [°C]           | -   | 21.5   | 22.3 | 23.1 | 23.9 | 24.7 | 25.5 | 26.3 | ≥27.1 |

Table 5 presents the variability of the WP considering the ranges of CO₂ levels by office typology, while Figures 17 and 18 graphically represent the results achieved.

In the study, a higher WP range amplitude is seen in OO compared to CO for an EqN equal to 5. The amplitude of this range allows identifying UW of OO with a greater adaptation capacity to values of up to 840 ppm (Figure 17), without their performance being affected. This range is lower for CO, admitting CO₂ levels that do not exceed 627 ppm (Figure 18).

Air Quality
The air quality is measured in the carbon dioxide (CO₂) concentration levels present. Said levels, dependent on the presence of people and the renewed air percentage, could affect the comfort of the UW, and with this, their WP. The CO₂ levels are measured in ppm (parts per million) in each analyzed space.

Table 5 presents the variability of the WP considering the ranges of CO₂ levels by office typology, while Figures 17 and 18 graphically represent the results achieved.

Lighting level
The light comfort is measured in terms of illuminance levels on the work plane, without considering the source of lighting (natural or artificial). These are measured in Lux.

Table 6 presents the WP variability considering the lighting level ranges by office typology on the work plane, and Figures 19 and 20 graphically present the results achieved.

From the observation of the ranges, it stands out that the excellent level (EqN =5) has a different luminance with higher values in CO compared to OO. This characteristic has an average difference of 100lux (Figures 19 and 20).

The behavior of the data allows determining that the UW of OO can work optimally at lower lux levels, without their performance being affected, i.e. they have a higher capacity to adapt to darker work planes.
Table 5. WP ranges valuation (air quality impact) during summer in OO and CO. Source: Preparation by the Authors.

![Figure 17. WP variability ranges, affected by air quality during summer in OO. Source: Preparation by the Authors.](image)

![Figure 18. WP variability ranges, affected by air quality during summer in CO. Source: Preparation by the Authors.](image)

Table 6. Valuation of WP ranges (light impact) during summer in OO and CO. Source: Preparation by the Authors.
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Figure 19. WP variability ranges, affected by light level during summer in OO. Source: Preparation by the Authors.
Figure 20. WP variability ranges, affected by light level during summer in CO. Source: Preparation by the Authors.

| Open Office (OO) |  |  |  |  |  |
|------------------|------------------|------------------|------------------|------------------|------------------|
| Qualitative evaluation | Excellent | Very Good | Good | Regular | Bad |
| EqN | 5 | 4 | 3 | 2 | 1 |
| Maximum [dBA] | <62 | <67 | <71 | <75 | - |
| Minimum [dBA] | - | 62 | 67 | 71 | ≥75 |

| Closed Office (CO) |  |  |  |  |  |
|-------------------|------------------|------------------|------------------|------------------|------------------|
| Qualitative evaluation | Excellent | Very Good | Good | Regular | Bad |
| EqN | 5 | 4 | 3 | 2 | 1 |
| Maximum [dBA] | <57 | <61 | <65 | <68 | - |
| Minimum [dBA] | - | 57 | 61 | 65 | ≥68 |

Table 7. WP range valuation (of acoustic impact) during summer in OO and CO. Source: Preparation by the Authors.

Figure 21. WP variability ranges, affected by sound level (dBA) during PVn in OO. Source: Preparation by the Authors.
Figure 22. WP variability ranges, affected by sound level (dBA) during PVn in CO. Source: Preparation by the Authors.
Noise Level

Sound comfort is affected by the noise level, when this is a sound that causes bother. It is measured in sound power (dBA, weighted decibel).

Table 7 shows the WP variability considering the noise level ranges by office typology, while Figures 21 and 22 graphically represent the results.

From the values found, it is detected that the ranges in OO have a higher amplitude compared to CO, with a difference of almost 5 dBA between both office typologies. As such, it is acknowledged that the UW of OO have a higher capacity to accept higher noise levels, without seeing their work performance affected.

Optimal work performance indicator

From the response to the question “Do you think that this variable negatively affects your performance?” in this study’s survey, the total percentage of those that answer YES [%] and NO [%] are considered. This allows knowing the level of influence of each variable on the individual WP.

Considering the percentages obtained, proportionality constants are built, to compare the total of the variables as a whole and each one, with their weight in importance.

What is presented in Figure 23 leads to the construction of the OWPI for OO (see Equation 1).

\[ IRLO = 0.23 \cdot Eq_{VRt} + 0.31 \cdot Eq_{VRA} + 0.19 \cdot Eq_{VRI} + 0.27 \cdot Eq_{VRr} \]

What is presented in Figure 24 leads to the construction of the OWPI for CO (see Equation 2).

\[ IRLO = 0.33 \cdot Eq_{VRt} + 0.36 \cdot Eq_{VRA} + 0.08 \cdot Eq_{VRI} + 0.23 \cdot Eq_{VRr} \]

As can be seen, the order of influence of the variables changes for both typologies. However, in both cases the CO₂ concentration appears as the one with the greatest influence.

The value obtained in Equation 1 and 2 is qualitatively translated, following Table 3.

OWPI validation-application

The OWPI tool is applied in this section, on two real OO and CO typology office cases, to validate the results (Table 8 and 9).

Case A - OO:
Table 8 shows the data obtained from measurements for each environmental variable and their valuation (EqN), following Figures 15, 17, 19 and 21.

As a result, the following OWPI value is obtained:

\[ IRLO = 0.23 \cdot 2 + 0.31 \cdot 1 + 0.19 \cdot 1 + 0.27 \cdot 2 = 1.50 \rightarrow Malo \]

Case B - CO:
Table 9 presents the data obtained from measurements for each environmental variable and its evaluation (EqN) as per Figures 16, 18, 20 and 22.
List of Abbreviations

CAI Calidad Ambiental Interior
CO2 Dióxido de Carbono
EqN Equivalente Numérico
IRLO Indicador de Rendimiento Laboral Óptimo
OA Oficina de Tipología Abierta
OC Oficina de Tipología Cerrada
RL Rendimiento Laboral
UMM Unidad Móvil de Medición
UT Usuarios-Trabajadores
VR Voto de Rendimiento
VRa Voto de Rendimiento de la Calidad de Aire
VRi Voto de Rendimiento del Nivel de Iluminación
VRr Voto de Rendimiento del Nivel de Ruido
VRt Voto de Rendimiento Térmico
Eq VRt Equivalente Voto de Rendimiento Térmico
Eq VRa Equivalente Voto de Rendimiento Calidad de Aire
Eq VRi Equivalente Voto de Rendimiento de Iluminación
Eq VRr Equivalente Voto de Rendimiento de Ruido

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CONCLUSION

Connecting the self-reported work performance vote with the levels of each environmental variable studied, allows getting to know optimal values and the most vulnerable values of operating temperature, air quality, light level, and noise level, to achieve a good WP in UW in a warm template area during the summer period.

The construction of ranges evaluated through the EqN, reports the WP level of users by open and closed office typology, varying from 1 (bad WP) to 5 (excellent WP). Thus, the valuation of an OWPI equal or close to 5, as well as indicating the best environmental conditions for the optimal performance of the UW considering the health, assumes a “beneficial” contribution to comfort conditions (thermal, visual, acoustic and air quality) of the UW. On the contrary, an OWPI equal or close to 1 indicates to the Building Manager about the need to address comfort related environmental solutions, and as a result, of the WP in the work setting.

Regarding the comparison between office typologies, it is confirmed that the UW develops a higher level of environmental adaptation in OO, so that said offices are a less advantage space on having a lower occupation factor, lack of windows, lack of total enclosure, and higher noise levels.

Finally, it highlights that the development of the OWPI tool characterizes WP conditions in offices for warm template climate regions during the summer. In future research, the idea is to extrapolate this progress for winter and transitory periods, as well as how to apply them in other local case studies.
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