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Presentation of the Content

In the first chapter we present, *Hilbert transform for modulation of interference fringes of liquid substances*, by GALVÁN-CHÁVEZ, Arturo, MORENO-MARTÍNEZ, Jatziri Yunuén, HERRERA-DIAZ Israel Enrique and PALACIOS-HERNÁNDEZ, Otoniel, with adscription in the Universidad Tecnológica del Norte de Aguascalientes and Universidad de Guadalajara, as next article we present, *Geometric analysis as a design base for implementing joints assisted for the displacement of components in tilting furnaces*, by TÉLLEZ-MARTÍNEZ, Jorge Sergio, KANTUN-UICAB, María Cristina, PINTOR-ESTRADA, Abel Alberto and RODRÍGUEZ-SÁNCHEZ, Isis, with adscription in the Tecnológico Nacional de México - Instituto Tecnológico de Morelia, Universidad Politécnica de Juventino Rosas and Instituto Politécnico Nacional; as next article we present, *Analyze vehicular flow at the intersection, Fernando Baeza avenues and Chuvíscar River, applying work sampling*, by AGUIRRE-OROZCO, Mario Abelardo, DELGADO-MARTÍNEZ, Martha Lilia, MÁRQUEZ-MONÁRREZ, Olivia and CONTRERAS-MARTÍNEZ, Jesús José, with adscription in the Tecnológico Nacional de México, Campus Delicias, as next article we present, *Historical interpolation repair: a new method for handling limits in differential evolution*, JUAREZ-CASTILLO, Efrén, DEL ANGEL-GERARDO, Rodrigo, HERNÁNDEZ-HERNÁNDEZ, Avelina and MARTÍNEZ-HERNÁNDEZ, Ángel Francisco, with adscription in the Universidad Tecnológica de la Huasteca Hidalguense, as last article we present, *Numerical study of the thermal characterization of transparent envelopes for buildings with high energy impact*, by CABRERA-CRUZ, Jafet Neftali, SERRANO-ARELANO, Juan, AGUILAR-CASTRO, Karla María and VERA-CÁRDENAS, Edgar Ernesto, with adscription in the Tecnológico Nacional de México - IT de Pachuca and Universidad Juárez Autónoma de Tabasco.

Content

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Hilbert transform for modulation of interference fringes of liquid substances

Transformada Hilbert para demodulación de franjas de interferencia de sustancias líquidas

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Abstract

The demodulation of interferometric signals presents a challenge in the study of object, especially when working in environments with disturbances, instability or noise. This document presents a procedure to demodulate a pair of highly noisy interferograms obtained with a fiber optic Mach Zehnder interferometer, the procedure is based on using the reconfiguration of the interference fringes as a result of Hilbert Transform. The method shown is fast, it does not present susceptibilities at high frequencies, it avoids demodulating interference patterns of closed fringes and with little carrier signal, in addition, it allows to verify the mathematical equivalence of the spectral analysis using Fourier Transform. As an application model, samples of liquid substances were used, where it was possible to know changes between substances according to their density.

Hilbert Transform, Interferometry, Circular fringes

Resumen

La demodulación de señales interferométricas presenta un reto en el estudio de los cambios de objetos, sobre todo cuando se trabaja en entornos con perturbaciones, inestabilidades o ruido. Este documento presenta un procedimiento para demodular un par de interferogramas altamente ruidosos obtenidos con un interferómetro Mach Zehnder a base de fibra óptica, el procedimiento se basa en utilizar la reconfiguración de las franjas de interferencia como resultado de un análisis Hilbert. El método mostrado es rápido, no presenta susceptibilidades en altas frecuencias, evita demodular patrones de interferencia de franjas cerradas y con poca señal portadora, además, permite comprobar la equivalencia matemática del análisis espectral utilizando Transformada de Fourier. Como modelo de aplicación se utilizaron muestras de sustancias liquidas, donde fue factible conocer cambios entre sustancias de acuerdo con su densidad.

Transformada Hilbert, Interferometría, Franjas circulares

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† Researcher contributing as first author.

Introduction

Several studies have been carried out to determine the physical properties of substances, which have relevance in the pharmaceutical industry, medicine, biology, engineering, among other areas, the advances in this study show a relationship between density and refractive index of the mixtures analysed through the physical and chemical characteristics of the substance, such as refractive indices, pressure, temperature, molar refraction and polarisability constant [1,2]. When the substance interacts with light, these parameters determine the change in optical path, thus developing techniques to determine changes in the properties of substances; This has given rise to non-invasive measurement methods, including expressions to determine the relationship between the density of the substance and the propagation of light in a medium, Newton-Laplace, Gladstone-Dale and Lorenz-Lorentz [3], to the integration of systems capable of detecting small displacements to determine refractive indices of gases [4], fibre optic sensors without physical contact with the material, [5], the use of interferometric refractometers [6-7], interferometers for temperature change and sample concentration [8-10].

However, the instruments and methodology reported so far require high stability and are also limited by the experimental set-up [3-4], this problem has been solved with the use of interferometers that provide the stability and measurement range that is not achieved with conventional refractometers and holographic techniques, among them the Jamin, Mach Zehnder and Michelson interferometers [4,10-11]. Despite the reliability that interferometers provide to the measurement, the problem of a later demodulation of the fringe pattern obtained arises, this pattern shows the changes before and after the deformation to later obtain the optical phase, commonly, by means of techniques based on Fourier Transform [12], Wavelet [13-18] and Hilbert [19-23], the problem increases if the interferograms obtained have a circular configuration, their carrier frequency is very low, and they also present several reflections caused by the arrangement of the instruments and the analysed material, requiring more computational work and the implementation of new spectral and temporal analysis techniques [24-32].

Although Hilbert analysis applied to closed fringes has already been studied [24], in this work we present the analysis of the difference of the reconstructed analytical signal, computationally redistribute the interference fringes in order to know the density change between substances and check the spectral dependence between the Fourier Transform and the Hilbert.

The method used is able to demodulate noisy interferograms, without carrier frequency and with high reflections, using liquid substances and with low stability.

Experimental method

To obtain the fringe pattern, a Mach Zehnder interferometer based on single-mode fibre optics, a coherent light source at 632.8 nm, a 20x microscope objective, Figure 1, was used. Where one end of the interferometer was taken as a reference, the other end is considered as the deflection which is incident on the diffusion cell, with a size of 25 cm3; both directed towards a beam splitter. The images were obtained using an XC-77 CCD camera with a pixel size of 11 × 13 μm and a computer to process the data.

For substance change analysis, water was used as the reference liquid and ethanol as the immersion liquid with 96% purity; ethanol was added into the water sample, changing its density between 0.9957 gr/cm3 and 0.8054 gr/cm3, for water and ethanol [1,33], respectively, Table 1.

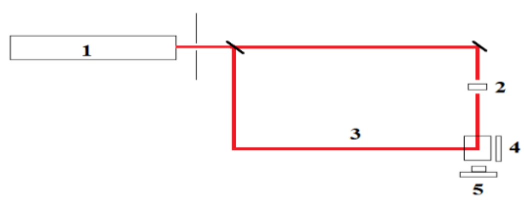

Figure 1 Mach Zehnder interferometer to obtain interference fringes of liquid substances (water-ethanol) with different density (1) He-Ne laser, (2) sample of liquid substance, (3) reference, (4) mirror, (5) CCD
Source: Own elaboration

Substance	water (ρ_1)	water-ethanol 5ml (ρ_2)	water-ethanol 10ml (ρ_3)	water-ethanol 15ml (ρ_4)	water-ethanol 20ml (ρ_5)	water-ethanol 25ml (ρ_6)	Ethanol (ρ_7)
Density (ρ) (gr/cm^3)	0.9957	0.9858	0.977	0.9689	0.9616	0.9549	0.8054

Table 1 Density of liquid mixtures
Source: [1,33]

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Theoretical model and experimentation

After obtaining the interferograms with the experimental arrangement of Figure 1, they can be mathematically expressed as:

$$I_n(r,t) = a(r,t) + b(r,t)\,cos\big(\phi(r,t)\big). \quad (1)$$

Where a(r,t) is the interferogram background illumination, b(r,t) is the modulation amplitude and □(r,t) is the interference term. Traditionally, the method to know the phase difference between two interferograms makes use of the direct and inverse Fourier Transform, filters, with a separation of the interferogram, Figure 2, to calculate the phase the *arctan* function is used, so the phase difference can be determined as:

$$\Delta\varphi = \cos\left(\phi_{wx_1} - \phi_{wx_0}\right) + \cos\left(\phi_{wy_1} - \phi_{wy_0}\right). \quad (2)$$

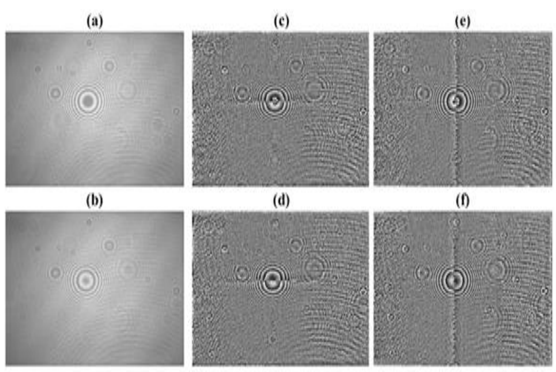

Figure 2. Optical phase of two interferograms (a) water interferogram, (b) ethanol interferogram, (c),(d) x-enveloped phase, for (a), (b), and (e),(f) y-enveloped phase, for (a), (b)
Source: own elaboration.

A normalised interferogram is achieved by eliminating the background and approximating the modulation to one, equation (3). Figure 3 illustrates the procedure to determine the phase difference Δφ using the Hilbert Transform, between two highly noisy interferograms, a bandpass filter ρ(x,y) is used first, in our case, the size that presented the smallest rms error is the full-field one. (a), (e) represent the normalised interferograms, (b), (f) the direct Fourier transform of each interferogram, (c), (g) the inverse transform of each interferogram and (d), (h) the absolute value of the Hilbert transform of the interferograms (a), (e), (i), (ii), (iii), (iv), (v), (vi), (vii), (viii), (viii), (viii), (viii), (viii), (viii) and (viii).

$$I_n(r,t) = b(r,t)\cos\big(\phi(r,t)\big). \quad (3)$$

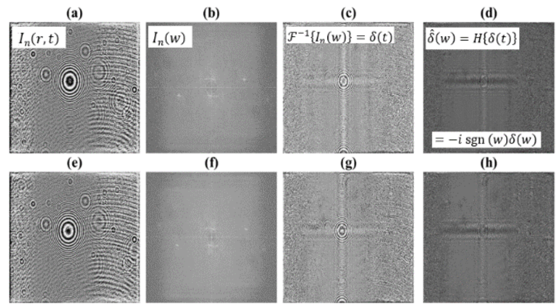

Figure 3 Process for analytical signal with Hilbert transform (a) standardised water interferogram, (e) standardised ethanol interferogram, (b), (f) Fourier transform of water and ethanol interferograms, and (c), (g) inverse Fourier transform of water and ethanol interferograms, (d) and (h) Hilbert transform of (c), (g)
Source: own elaboration.

To reconstruct the analytical signal of each interferogram we take the signal δ(t) and the absolute value of δ'(t), equation (4), Figure 4 (a), (b) represent the water and ethanol interferograms, while (c), (d) the enveloped phase for (a), (b), equation (7).

In order to determine the difference between the substances, the equation (7).

$$\mathcal{F}^{-1}\{\hat{\delta}\,(w)\} = \delta'(t) \quad (4)$$

$$\varphi(r,t) = \delta(t) + |\delta'(t)| \quad (5)$$

$$\varphi_w(r,t) = \tan^{-1}\left\{\frac{Im\{\hat{\delta}\,(w)\}}{Re\{\delta(t)\}}\right\} \quad (6)$$

$$\Delta\varphi(r,t) = \varphi_{w_A}(r,t) - \varphi_{w_B}(r,t) \quad (7)$$

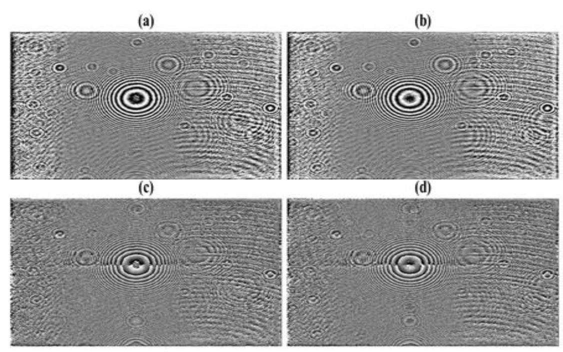

Figure 4 (a), (b) Reconstructed signal using Hilbert Transform of water and ethanol and (c), (d) Enveloped phases of (a), (b)
Source: own elaboration.

To determine the spectral dependence between Fourier Transform and Hilbert Transform, equations (2) and (5) were taken, Figure 5 shows the relationship between the phase difference taken between water and ethanol, using Hilbert Transform and Fourier Transform (a) and (b), respectively, in (c) shows the distribution profile of each fringe pattern obtained, the rms error is 0.0763 rad.

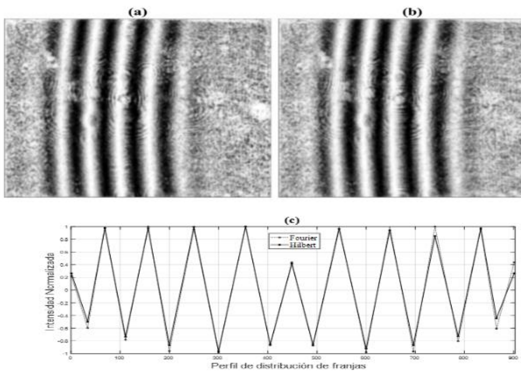

Figure 5 Phase difference water - ethanol, (a) Hilbert, (b) Fourier and (c) fringe pattern profile along the y-axis
Source: Own elaboration.

Applicability model

To evaluate the geometrical position change of the interference fringes, the differences between water and different values of immersion liquid (ethanol) were obtained, Table 1, the detection of the geometrical change was carried out with Hilbert Transform.

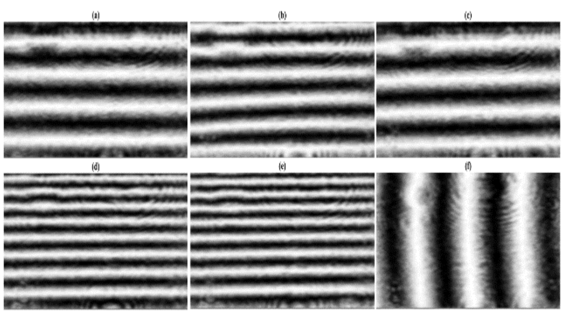

Figure 6. Geometric differences (a) ρ1- ρ2, (b) ρ1- ρ3, (c) ρ1- ρ4, (d) ρ1- ρ5, (e) ρ1- ρ6 and (f) ρ1- ρ7
Source: own elaboration.

Figure 6 shows the results obtained between each substance density change with a minimum value to detect phase change of 0.0099gr/cm^3 and maximum 0.1903 gr/cm^3 as indicated in Table 1, as the substance density changes, so does the amount of interference fringes, in Fig. 6 (a) and (f), the change of geometrical location of the fringes can be verified, for the case of (a), the optical phase change is at the x-position, for (f) the phase change is at the y-coordinate.

Conclusion

A procedure is described to determine the phase difference between two highly noisy, highly reflective, circular interferograms without the need for laborious techniques and using the Hilbert Transform. First, the spectral dependence between the Fourier Transform and the Hilbert Transform is shown, by comparing the phase difference with the conventional Fourier technique and the one proposed in this work, the results show an rms between the phase difference of two substances with different density of 0.0763 (water-ethanol), second, it is demonstrated that the interphase technique is capable of monitoring values in the order of microns without being affected by high frequencies as in the case of holography, obtaining a resolution in the measurement of 9.9-3gr/cm3. It can also be verified that by means of the phase difference of the analytical signals, it is possible to determine a change of substance, with the geometric rearrangement of the interference fringes.

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Geometric analysis as a design base for implementing joints assisted for the displacement of components in tilting furnaces

Análisis geométrico como base de diseño para la implementación de articulaciones asistidas para el desplazamiento de componentes en hornos basculantes

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Abstract

Various devices in productive chains implement parts that move through pneumatic, hydraulic, electrical systems, or some combination. Articulation-assisted displacement systems implemented by hydraulic systems are of particular interest, specifically, those used to lower bodies concerning support points with a structure of degrees of freedom of movement. An application in the metallurgical industry establish since processes at high temperatures and elements of great mass make human manipulation impossible. However, introducing these automation operations makes standardizing and controlling processing times possible. In this work, the procedure for the mathematical approach through principles of analytical geometry and trigonometry, to be develop as a contribution to the domain of knowledge for the design of articulated systems. The above applied to the displacement requirements in a melting furnace of metal alloys allowed selection of the characteristics of hydraulic components to implement in the consolidation of industrial equipment.

Angle Joint Design, Hydraulic Systems, Assisted Displacement

Resumen

Diversos dispositivos en cadenas productivas implementan partes que son desplazadas mediante sistemas neumáticos, hidráulicos, eléctricos o alguna combinación de éstos. Los sistemas de desplazamiento asistidos por articulaciones en las cuales se implementan sistemas hidráulicos son de interés particular. Específicamente, los que se utilizan para abatir cuerpos respecto a puntos de apoyo que cuenten con una estructura de grados de libertad de movimiento. Una aplicación es en la industria metalúrgica ya que existen procesos a elevada temperatura y elementos de gran masa que imposibilitan una manipulación humana. No obstante, la introducción de estas operaciones de automatización permite estandarizar y controlar los tiempos de procesamiento. En este trabajo se desarrollará el procedimiento para el planteamiento matemático, a través de principios de geometría analítica y trigonometría, como aporte al dominio del conocimiento para el diseño de sistemas articulados. Lo anterior aplicado a los requerimientos de desplazamientos en un horno de fusión de aleaciones metálicas correspondientes, permitió seleccionar las características de componentes hidráulicos para ser implementados en la consolidación de un equipo industrial.

Diseño de Articulaciones Angulares, Sistemas Hidráulicos, Desplazamiento Asistido

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December 2023, Vol.7 No.13 7-14

Introduction

There are various industrial furnace products for carrying out activities in high-temperature conditions. Metal alloy melting furnaces are an example of these devices (Nabertherm, 2023). These pyrometallurgical activities are essential to manufacturing processes (Mullinger & Jenkins, 2008). Therefore, there is relative interest in the design of assistance for moving rigid elements with a large mass. Hydraulic cylinder systems are ideal, thanks to their high load capacity, (DeKun, Yuan, SiYuan, Peng, & NianLi, 2023), (Drew, Edge, Barker, Darling, & Owen, 2005), (Janebrink, 2014), (Kwasi-Adzimah, Samuel-Akinwonmi, & Sebbeh, 2012).

In the case of furnaces, various displacement functions assisted by power systems implement rigid, articulated elements to perform controlled displacements. **Figures 1(a) and 1(b)** show images from different perspectives of non-ferrous metal fusion equipment used in the metallurgical industry to manufacture parts or pieces.

(a) (b)

Figure 1 Melting furnace implementing: a) joint for tilting, b) joint for opening the lid
Spurce: Images property of Mechatronics DDMI COMBUSTION. https://www.youtube.com/watch?v=LP3Wmo8rSlU

As can be seen, the hydraulic cylinders assist, with a possible speed adjustment, in the two main events: 1) the movement in the joint for opening the lid and 2) the tilting of the furnace, therefore, the determination of its adaptation according to the characteristics of the extension and retraction lengths of the commercialized elements.

This work analyzes the trajectories with geometric lines of the structural joints for a prototype of a non-ferrous metal smelting furnace. The objective of specifying the cylinders for each displacement function required the mathematical formulation of the load balances.

Methodology

In the methodology adopted, an analysis of the geometry of assisted joints implemented in collapsible melting furnaces allowed for establishing a design basis. In particular, without establishing an exclusive criterion for different similar devices, the following specific objectives were set:

- Mathematically pose the geometric problem considering the degrees of freedom of movement at the assembly points.

- Use a physical model's dimensions to verify the previous point's mathematical formulation and graphically show the displacement trajectories.

Figure 2 complements the visual information of **Figure 1(b)** with the schematization of the joint structure used to fold down the furnace lid.

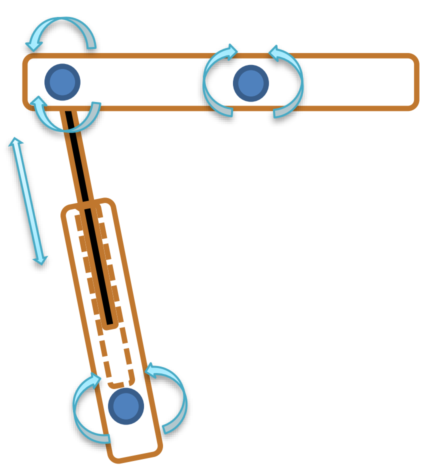

Figure 2 Schematization of elements in the joint of the mechanism for opening the furnace lid.
Source: Own elaboration in Microsoft PowerPoint 2016

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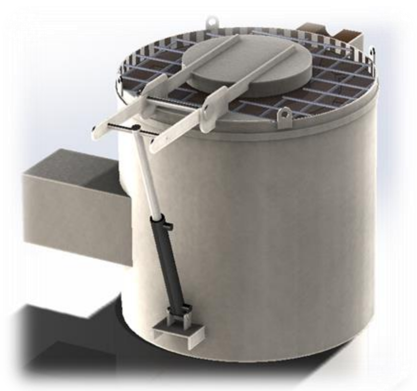
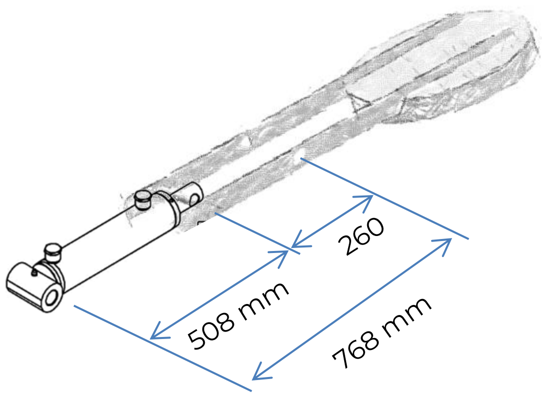
December 2023, Vol.7 No.13 7-14

The development of the design basis for the manufacture of each joint was born from an analysis of plane geometry and trigonometry. Therefore, each mathematical approach to the problems considered the degrees of freedom of movement at the assembly points (hinges). In the case of the lid, the dimensions of the physical model presented in **Figure 3** are the reference for the calculations. The results obtained from the displacement trajectories showed certainty once they were analyzed graphically.



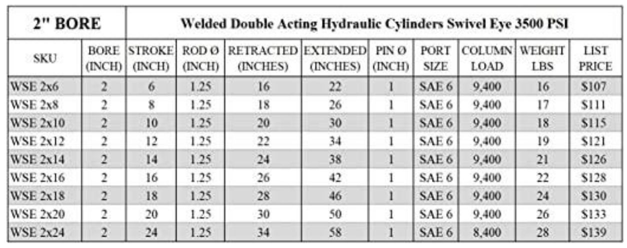
(a)



(b)

Figure 3 Specifications: a) of the CAD model of the furnace and b) of the hydraulic cylinder-lid arrangement used for the geometric analysis of the corresponding joint
Source: Own creation in SolidWorks 2018.

The specification of available cylinders was obtained from the Table in **Figure 4** from a commercial supplier (Magister_Hydraulics, 2015-2023). **Table 1** shows further specifications of the retraction and expansion length data.



2" BORE		Welded Double Acting Hydraulic Cylinders Swivel Eye 3500 PSI								
SKU	BORE (INCH)	STROKE (INCH)	ROD Ø (INCH)	RETRACTED (INCHES)	EXTENDED (INCHES)	PIN Ø (INCH)	PORT SIZE	COLUMN LOAD	WEIGHT LBS	LIST PRICE
WSE 2x6	2	6	1.25	16	22	1	SAE 6	9,400	16	$107
WSE 2x8	2	8	1.25	18	26	1	SAE 6	9,400	17	$111
WSE 2x10	2	10	1.25	20	30	1	SAE 6	9,400	18	$115
WSE 2x12	2	12	1.25	22	34	1	SAE 6	9,400	19	$121
WSE 2x14	2	14	1.25	24	38	1	SAE 6	9,400	21	$126
WSE 2x16	2	16	1.25	26	42	1	SAE 6	9,400	22	$128
WSE 2x18	2	18	1.25	28	46	1	SAE 6	9,400	24	$130
WSE 2x20	2	20	1.25	30	50	1	SAE 6	9,400	26	$133
WSE 2x24	2	24	1.25	34	58	1	SAE 6	8,400	28	$139

Figure 4 Specifications of hydraulic cylinders sold
Source: (Magister_Hydraulics, 2015-2023)

As specified in **Figure 3(b)**, a 508 mm (20 in) retracted cylinder coupled to a 260 mm straight section determines the position of the ball joint for the furnace lid opening and closing mechanism. **Figure 5** presents the geometric scheme of the joint in the closed lid position.

R, in	E, in	R, mm	E, mm
16	22	406	559
18	26	457	660
20	32	508	813
22	34	559	864
24	38	610	965
26	42	660	1067
28	46	711	1168
30	50	762	1270
34	58	864	1473

Table 1 Lengths of retracted and extended cylinders according to commercial models

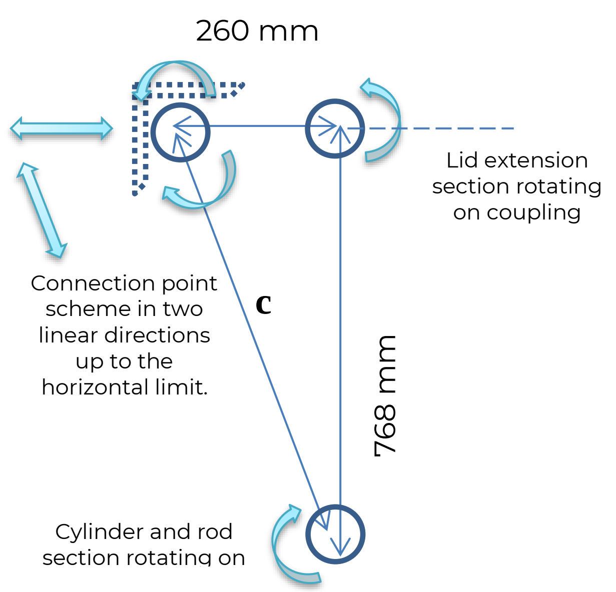


Figure 5 Geometric diagram of articulation in closed lid position with an extension of 260 mm
Source: Own creation in Microsoft PowerPoint 2016

Equation 1, defined by the Pythagorean Theorem, allowed us to calculate the length **c**. The result defines the maximum extension required in the cylinder.

$$\boldsymbol{c} = \sqrt{(260)^2 + (768)^2} = 811\, mm \qquad \textbf{(1)}$$

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The calculated magnitude of 811 mm is in the extension interval of the WSE 2x10 cylinder indicated in the Table of **Figure 4**, which has an extension limit of 812.8 mm according to the data reported in **Table 1**.

When the lid is in the path between the closed and fully opened position, the analysis of the geometric system changes to the scheme shown in **Figure 6**. In this new scheme, two right-angled triangles appear coinciding in the horizontal partition defined as **z**, representing the variable separation from the vertical concerning the position of the R_2 kneecap. The magnitudes of the distances **x** and **y** change because of the arc drawn in the lid's path due to the cylinder's retraction or extension determined by the magnitude **a**.

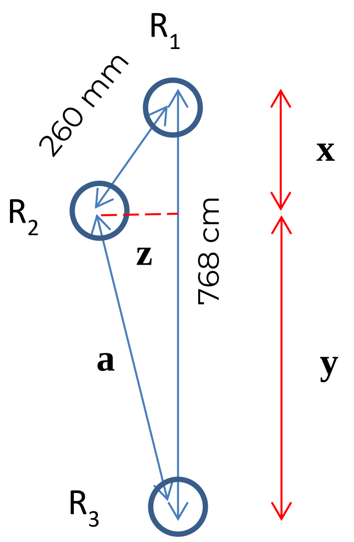

Figure 6. Diagram of the joint in an intermediate process of closing and total opening
Source: Own creation in Microsoft PowerPoint 2016.

The scheme also aims to define that the value of the length **x** is between 0 mm and 260 mm, while the length **y** is in an interval of 768 mm to 508 mm. Note that the sum of both magnitudes is constant (768 mm). In this way, based on the structure of **Figure 6**, **Equations 2 and 3** are defined, which, when equalized and developed, determine the relationship between the lengths **y** and **a** through **Equation 4**.

$$\mathbf{z}^2 = 260^2 - \mathbf{x}^2 \qquad \textbf{(2)}$$

$$\mathbf{z}^2 = \mathbf{a}^2 - \mathbf{y}^2 \qquad \textbf{(3)}$$

$$\mathbf{y} = \frac{\mathbf{a}^2 + 768^2 - 260^2}{2(768)} \qquad \textbf{(4)}$$

The corresponding clearances also lead to calculating the magnitudes **z** and **x**. Afterwards, the information generated determines the calculation of the angle ratio of the upper right triangle. In particular, the angle **β** is directly related to the degree of collapse of the lid, as shown in **Figure 7** in the geometric structure. As a result, the displacement relationship added to a moment at the support points will generate a slight deviation from a presumably linear relationship to represent the movement of the joint. However, the polynomial relationship of **a** concerning **x** and **y** is of second order.

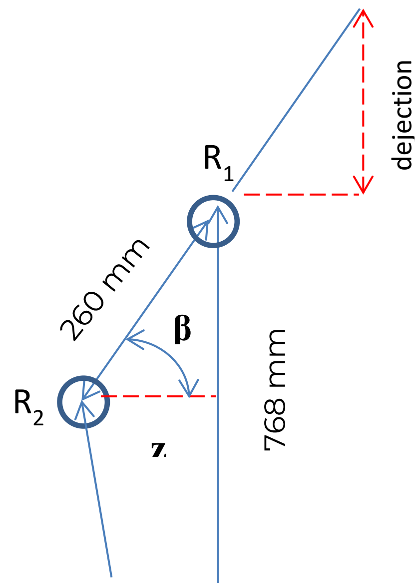

Figure 7 Diagram of the structure of the articulated lid defining the angle **β** with respect to the horizontal for its folding
Source: Own creation in Microsoft PowerPoint 2016.

The second joint required for the model furnace has a different movement relationship because displacement starts from a structure similar to a porch with vertical pillars and a horizontal beam. **Figure 8** presents the dimensions of the relevant sections.

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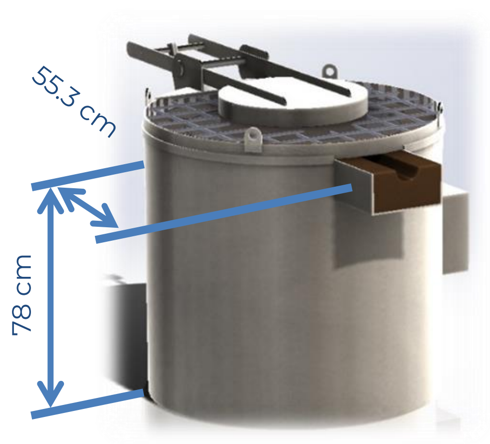

Figure 8 Furnace model for the implementation of the tilting system on each flank
Source: Own creation in SolidWorks® 2018.

According to **Table 1**, the best coupling for the joint corresponds to the cylinder with a length of 864 mm in the retracted state. The total tilt of the furnace, that is, the ability to rotate it 90° from the horizontal, must be developed during cylinder extension. A right triangle drawn in this last position demonstrates that the magnitude of the extended cylinder **c** is determined again with the Pythagorean Theorem expressed by **Equation 5**. **Figure 9** shows the implementation strategy of the cylinder.

$$\boldsymbol{c} = \sqrt{(133.3)^2 + (55.3)^2} = 144.3\ cm \qquad (5)$$

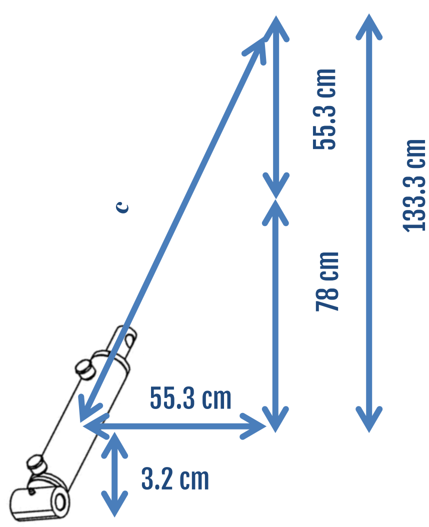

Figure 9 Diagram of the joint in the extended cylinder state for each flank of the furnace
Source: Own creation in Microsoft PowerPoint 2016.

Additionally, **Figure 10** represents the joint structure's geometric approach during the furnace's tilting. **Equations 6 and 7** emerged through the analysis developed for this system.

$$\boldsymbol{a}^2 = \boldsymbol{x}^2 + \boldsymbol{y}^2 \qquad \textbf{(6)}$$

$$L^2 = (\boldsymbol{y} - H)^2 + (L - \boldsymbol{x})^2 \qquad \textbf{(7)}$$

$\boldsymbol{a}$ represents the length of the extended cylinder or hypotenuse, in any scheme during the tilting of the furnace, associated with the right triangle that also defines the angle θ.

Equation 7, in a complementary manner, describes the relationship of distances formed by the right triangle formed by the displacement of the rigid section coupled to the furnace from its horizontal position until it reaches the vertical position. Obtaining **Equation 8** corresponds to developing **Equation 7** and substituting the solution for **x** from **Equation 6**.

$$y^2(4L^2 + 4H^2) - y(4H^3 + 4a^2H) + (2a^2H^2 - 4a^2L^2 + H^4 + a^4) = 0 \qquad \textbf{(8)}$$

The magnitudes of L and H can vary for different furnace dimensions; however, for the specific case under study, they have a magnitude of 55.3 cm and 78 cm, respectively, according to **Figure 9**.

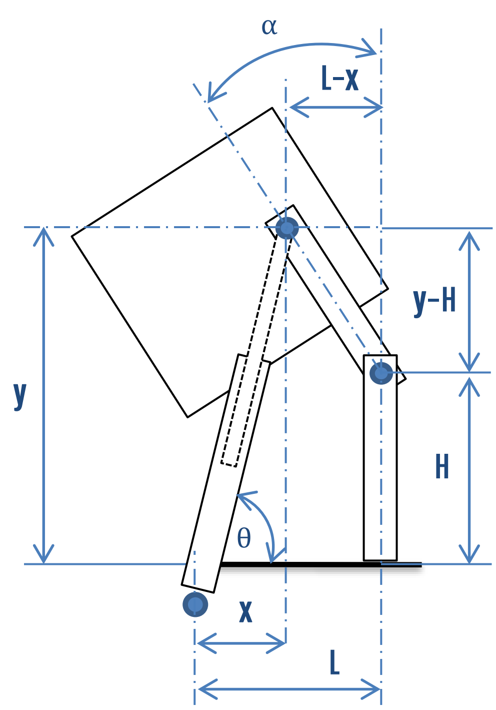

Figure 10 Geometric analysis of the joints for furnace tilting
Source: Own creation in Microsoft PowerPoint 2016.

Results

The analysis of the curves in **Graph 1** allows us to understand the variation of the lengths of **x**, **y**, and **z**, defined by **Equations 2 to 4**, for the opening hinge mechanism of the furnace lid.

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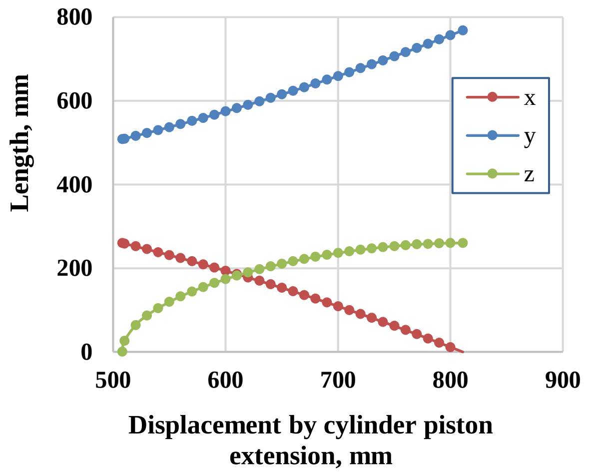
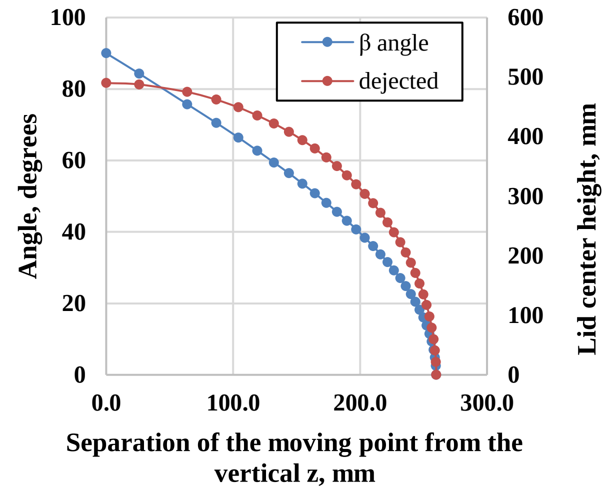


Graphic 1 Solution curves of **Equations 2 to 4** of the articulated system for opening the furnace lid according to **Figure 5**
Source: Own creation in Microsoft Excel 2016.

The trend of the magnitudes of the displacements for **x** and **y** are opposite, reaching the maximum and minimum length, respectively, in the fully open lid event (curves with blue and brown filled lines and circles). The opposite case occurs in the fully closed lid event where the length of **x** is zero.

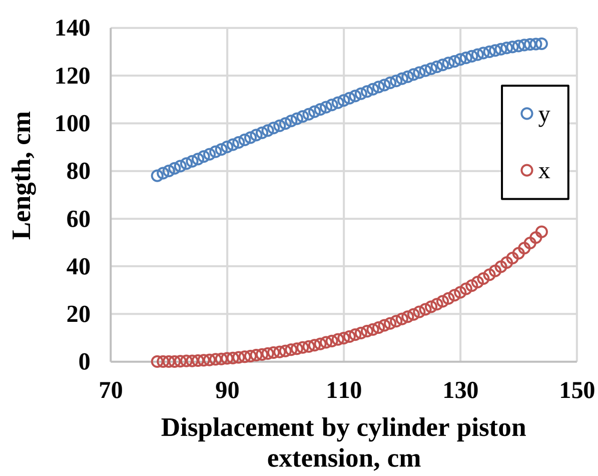
Note that the most significant parabolic behavior corresponds to the definition of the length **z** (curve with gray-filled lines and circles), which is related to the displacement of the patella R2 simultaneously in the vertical and horizontal directions.

On the other hand, the analysis of the trajectory of the lid during the collapse in the closing event determines that it falls rapidly, losing the angle concerning the vertical (curves with blue and brown lines with filled circles, respectively). The length of the stroke and the advance angle decreased as the cover reached the horizontal position according to the outline of the curves in **Graph 2**.



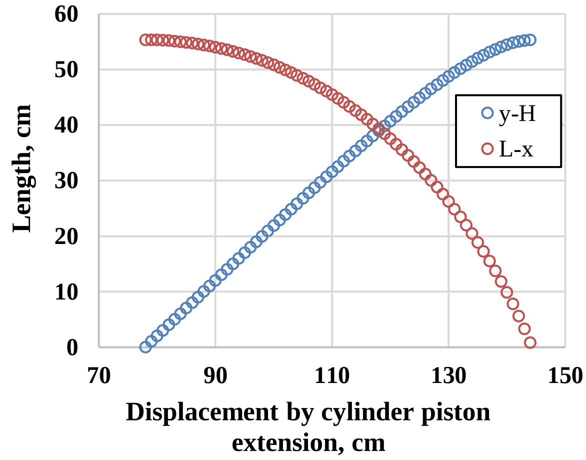
Graphic Curves of the evolution of the beta angle are defined in **Figure 6,** and the respective lowering of the furnace lid is according to **Figure 5**
Source: Own creation in Microsoft Excel 2016.

When tilting the furnace to empty the contents of the internal container or crucible, the curves in **Graph 3** correspond to **Equations 6 and 7** results, which define the trajectory on the vertical (**y**) and horizontal axes (**x**) of the coupling of the hydraulic cylinder with the furnace. Due to the effect of the scale, the displacement y (curve with empty blue circles) appears to have significantly linear behavior; however, by definition of **Equation 6**, the curvature in an interval around the maximum extension of the cylinder piston indicates that before From the 90° emptying position, the most relevant displacement takes place in the horizontal direction. The above is congruent with the behavior of the corresponding curve of **x** (curve with empty brown circles).



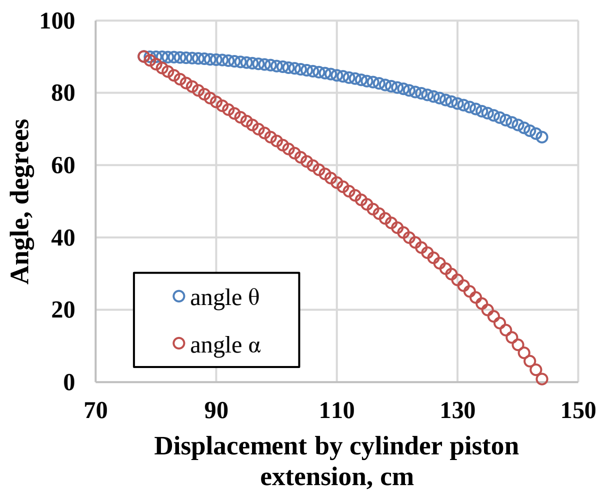
Graphic 3 Solution curves of **Equations 6 and 8** of the articulated system for tilting the furnace according to **Figure 10**
Source: Own creation in Microsoft Excel 2016.

As defined by the dimension of the diagram in **Figure 10**, the lengths specified as (y-H) and (L-x) have opposite magnitudes; that is, while one dimension is at the maximum, the other reaches a minimum of zero, as shown in the plot of the curves in **Graph 4** (blue and brown circles, respectively).



Graphic 4 Solution curves of **Equations 7 and 8** of the articulated system for tilting the furnace according to **Figure 10**
Source: Own creation in Microsoft Excel 2016.

The trends in the curves of **Graphs 3 and 4** correspond to the result of the solution of **Equation 8**, applying the solution method for a quadratic equation. In this way, it was also possible, through the translated angles technique, to determine the importance of the evolution of the angles θ and α for the tilting of the furnace, as shown with the corresponding curves in **Graph 5** (circles of blue and brown, respectively).



Graphic 5 Curves of the evolution of the angles α and θ defined in the scheme of **Figure 10**
Spurce: *Own creation in Microsoft Excel 2016.*

As can be deduced from the tilting of the furnace, the cylinder inclination angle θ only decreases from 90° to 68° (curve with empty blue circles). Not so for the angle α, which must evolve between 0° and 90° (curve with open brown circles).

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Conclusions

The analysis of displacements in the joints' elements allows for determining the cylinders' specifications that assist the fundamental movements, whether to lower a gate or perform a tilt, as in the case of the non-ferrous metal melting furnace prototype presented. n particular, with an approach of plane geometry and trigonometry tools, it was possible to determine an adequate approximation of the trajectory of the components of both independent systems. In this regard, a change in analysis strategy is emphasized depending on the structure of the joint and its position in a superimposed Cartesian plane. In this way, determining the load capacity in the rigid elements could be analyzed to establish the degree of force supported in each position during displacement.

Additionally, given the existence of similar systems applied to various industrial processing devices, the present development can be implemented in a computer application in which it would be possible to feed the magnitudes of the target cylinder and the rigid sections to establish a valid design basis.

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Analyze vehicular flow at the intersection, Fernando Baeza avenues and Chuvíscar River, applying work sampling

Analizar afluencia vehicular del cruce, avenidas Fernando Baeza y Río Chuvíscar, aplicando muestreo del trabajo

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Abstract

It is an innovative work to carry out this analysis of vehicular flow that will be very useful for the city of Delicias Chihuahua, this town is relatively young and lacks road engineering (traffic lights) in some specific points, given the demographic growth of the neighborhoods on the outskirts, this avenue has been a key point to vent the vehicular flow to the different neighborhoods. The continuous improvement technique was applied, which is work sampling, according to ILO establishes that Work sampling is a technique to determine, through statistical analysis and random observations, the percentage of appearance of a certain activity. It will be necessary to continuously observe each of the points in the area and record the moment, at a previously selected time in the same period of time, but at different random times provided by the work sampling. For this investigation, the general objective is: identify the vehicular flow at the intersection of Fernando Baeza and Río Chuvíscar avenues in Ciudad Delicias, Chihuahua. The contribution of this study will benefit more than 79,907 vehicles that are registered in the vehicle registry of the Revenue Collection Office (2022) in the town and in this way apply continuous improvement for the benefit of citizens, identifying the hours of more vehicle capacity and consequently take advantage of cutting-edge technology, and build a road engineering focused on traffic lights for the benefit of its entire population.

Vehicular flow, Traffic lights, Work sampling, Continuous improvement

Resumen

Es un trabajo innovador, el realizar este análisis de flujo vehicular que será de gran utilidad para la ciudad de Delicias Chihuahua, esta localidad es relativamente joven y carece de una ingeniería de vialidad (semaforización) en algunos puntos específicos, dado el crecimiento demográfico de las colonias de la periferia, esta avenida ha sido un punto clave para desfogar su flujo vehicular a las diferentes colonias. Se aplicó la técnica de mejora continua la cual es el muestreo de trabajo, de acuerdo con OIT establece que El muestreo del trabajo es una técnica para determinar, mediante análisis estadístico y observaciones aleatorias, el porcentaje de aparición de determinada actividad. Será necesario observar continuamente cada uno de los puntos de la zona y registrar el momento, en un horario previamente seleccionado en un mismo lapso de tiempo, pero en diferentes horarios aleatorios que arroje el muestreo del trabajo, para esta investigación, el objetivo general es: identificar la afluencia vehicular en la intersección de las avenidas Fernando Baeza y Río Chuvíscar en Ciudad Delicias, Chihuahua. La contribución de este estudio dará como beneficiarios a más de 79,907 automotores que tiene registrados el padrón vehicular de la Oficina de Recaudación de Rentas (2022) en la localidad y de esta manera aplicar una mejora continua en beneficio de la ciudadanía, identificando las horas de más aforo vehicular y por consecuencia aprovechar la tecnología de punta, y construir una Ingeniería de vialidad enfocada hacia la semaforización en beneficio de toda su población.

Flujo vehicular, Semaforización, Muestreo del trabajo, Mejora continua

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December 2023, Vol.7 No.13 15-24

Introduction

Work sampling is defined as a technique for determining by statistical sampling and random observations the rate of occurrence of a given activity. Work sampling is based on making observations on some activity at random intervals; if the sample size is adequate, and the observations are truly random, there is a high probability that, with a certain margin of error, the observations reflect the true situation of the observed event. The observed activity has to occur repeatedly in order for sampling to be carried out correctly.

Work sampling W Niebel Benjamin (1988) has advantages such as: it does not require continuous observations by an analyst, a single analyst can easily study what is required, the worker is not subjected to long periods of timed observations, the number of analyst-hours is less. In addition, this method is applicable in companies for the improvement of activities, evaluation of productive and unproductive periods, establishing production standards, work allocation, among other things. However, sampling also has several disadvantages, among them: For Hugo García Mancillas it is not economical for a single operation, as well as it is not economical for repetitive operation times with very short cycles, it does not provide a detailed record of the method used, among other disadvantages.

Description of the method

A nomogram, abacus or nomograph is a graphical calculating instrument, a two-dimensional diagram that allows the graphical and approximate computation of a function of any number of variables. It is an analogue calculation instrument, like the slide rule, because it uses continuous line segments to represent the discrete numerical values that the variables can assume. To develop this work, a straight line is drawn starting from the ordinate p (5-95) cutting the required ordinate error or precision (10%) and extending to the ordinate "number of observations", which cuts off at 10 for a confidence level of 90%. Table 1 below illustrates the above.

As mentioned by Manuel Mancilla in his book, random numbers are those that can be generated from sources of randomness which are generally physical in nature (dice, roulette wheels, electronic or mechanical mechanisms), and are governed by the laws of chance; they exhibit true randomness in the conduct of experiments. The sample size can be determined by applying the nomographic method most easily by directly reading the number of observations required in a nomogram as stated by W Niebel Benjamin (1988) as presented in figure 1. To determine the sample size, the nomographic method was used, with which the percentage of occurrence, the required precision and the number of observations were determined. Since the analysis was carried out to determine car traffic at the traffic light located at the Fernando Baeza Avenue - Rio Chuvíscar Avenue intersection, the data sampled were: number of cars travelling from North to South, South to North, Northeast to Southwest and Southwest to Northeast. When analysing the variables, the data will be recorded and summary tables will be made where the results obtained in the observations will be concentrated; also, in order to better understand, a graphic analysis of the data obtained (per day) will be formulated, and then a tabular and graphic concentration of all the sampled data will be made. The sampling, tables and graphs will help to predict the traffic flow, taking into account the data obtained from the observations, which will allow informed decisions to be made.

The sample size can be determined by applying the nomographic method most easily by directly reading the number of observations required in a nomogram according to W Niebel Benjamin (1988), as presented in table 1. The nomographic method was used to determine the sample size, with which the percentage of occurrence, the required precision and the number of observations were determined. Since the analysis was carried out to determine car traffic at the traffic light located at the Fernando Baeza-Av. Fernando Baeza-Av. Río Chuvíscar intersection, the data sampled were: number of cars travelling from north to south, south to north, northeast to southwest and southwest to northeast.

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Opportunity identified

A study of the nature of the present one had not been carried out previously in the City of Delicias, at the Avenida Fernando Baeza - Avenida Río Chuvíscar intersection, so this research is relevant given the current situation, as mentioned by Mądziel, M. and Campisi, T. (2023). A study by Skuza and Jurecki indicates that one of the most sought-after aspects of an electric vehicle is its energy consumption. This parameter is particularly important for electric vehicle users. It would be of great importance for the development of activities related to school, work, etc., are beginning to return to normal, so naturally, the traffic of cars is greater than what had been observed in recent years, hence the importance and relevance of this study, especially talking about a crossing as busy as the one studied in this research, in addition to abate pollution to the environment.

The creativity of this study lies in the fact that not only is traffic studied in terms of day and time, as expressed by; Kanawaty George, (1998), but also by including as variables of interest the direction in which automobile traffic flows: North to South and South to North along Avenida Río Chuvíscar, and Northeast to Southwest and Southwest to Northeast along Avenida Fernando Baeza; thanks to this, depending on the problem to be solved, a single direction can be selected, which is the one of interest for the question.

General objective

A general objective is one that indicates, in a global way, the purpose of the work to be carried out. It should be kept in mind throughout the research.

According to Arias Fidias (2006), a general objective expresses the concrete aim of the research in direct correspondence with the formulation of the problem.

According to Arias, the general objective is the one that gives meaning to the research, i.e. it is the one that defines the results to be obtained and the way in which it will be carried out in order to achieve these results. Therefore, the objective of this research is: To analyse the vehicular flow at the Fernando Baeza Avenue - Río Chuvíscar Avenue intersection. Applying the work sampling technique, with the aim of applying an improvement in road engineering to this strategic point.

Specific objectives

The specific objectives must be clearly expressed to avoid possible deviations in the quantitative research process and be achievable. According to Hernández et. al (2014), they are the guidelines of the study and must be kept in mind throughout its development, they need to be congruent with each other. To consider the contributions of the authors, subscribed throughout the research. These are mentioned below:

- Allocate the times at which the counting is to be carried out using the nomographic method and the random number table.

- Determine the synchronisation time of the traffic lights with the help of the stopwatch technique.

- Count the number of vehicles travelling in the four directions, i.e. north to south, south to north, northeast to southwest and southwest to northeast for five days at the intersection of Fernando Baeza Ave. and Rio Chuvíscar Ave.

- Construct (statistical tables), to record the results obtained in the sampling.

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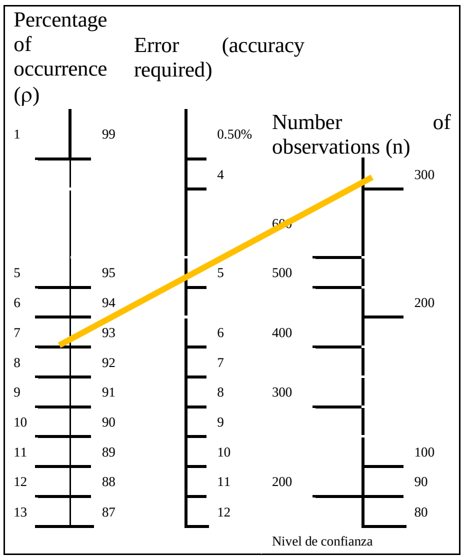

Table 1 Nomogram to determine the number of observations

49 54 33 54 82	17 37 93 23 78	87 35 20 96 43	84 26 34 91 64
57 24 55 6 88	17 4 74 47 67	21 76 33 50 25	83 92 12 6 76
16 95 55 57 19	98 10 50 71 75	12 86 77 58 7	44 39 52 38 79
78 64 56 7 82	52 42 7 44 38	15 51 0 13 42	99 66 2 79 54
9 47 27 96 54	49 17 46 9 62	90 52 84 77 27	8 2 73 43 28
44 17 16 58 9	79 83 86 19 62	6 76 50 3 10	55 23 64 5 5
84 16 7 44 99	83 11 46 32 24	20 14 85 88 45	10 93 72 83 71
82 97 27 77 81	7 45 32 14 8	32 98 94 7 72	93 85 79 10 75
50 92 26 11 97	0 56 76 31 38	80 22 2 53 53	86 60 42 4 53
83 39 50 8 30	42 34 7 96 86	54 42 6 87 98	35 85 29 48 39
40 33 20 38 26	13 89 51 3 74	17 76 37 13 4	7 74 21 19 30
96 83 50 87 75	97 12 25 93 47	70 33 24 3 54	97 77 46 44 80
88 42 95 45 72	16 64 36 16 0	4 43 18 66 79	94 77 24 21 90
33 27 14 34 9	45 59 34 68 49	12 72 7 34 45	99 27 72 95 14
50 27 59 87 19	20 15 37 0 49	52 85 66 60 44	38 68 88 11 80
55 74 30 77 40	44 22 78 84 26	4 33 46 9 52	68 7 97 6 57
59 29 97 68 60	71 91 48 67 54	13 58 18 24 76	15 54 55 95 52
48 55 90 65 72	96 57 69 36 10	96 46 92 44 45	97 60 49 4 91
66 37 32 20 30	77 84 57 3 29	10 45 65 4 26	11 4 96 67 24
68 49 69 10 82	53 75 91 93 30	34 25 20 57 27	40 48 73 51 92
83 62 64 11 12	67 19 0 71 74	60 47 21 29 68	2 2 37 3 31
6 9 19 74 66	2 94 37 34 2	76 70 90 30 86	38 45 94 30 38
33 30 51 26 38	79 78 45 4 91	16 96 53 56 16	2 71 50 95 98
92 38 97 1 50	87 75 66 81 41	40 1 74 91 62	48 51 84 8 42
96 44 33 49 13	34 86 82 53 91	0 52 43 48 85	27 55 26 89 62
64 5 91 95 86	11 5 65 9 68	76 83 20 37 90	57 16 0 11 66
75 73 88 5 90	52 27 41 14 86	22 98 12 22 8	7 52 74 95 80
33 95 2 75 19	7 60 62 93 55	59 33 82 43 90	49 37 38 44 59
97 91 40 14 2	4 2 33 31 8	39 54 16 49 36	47 95 93 13 30
15 5 15 93 20	1 90 10 75 6	40 78 78 89 52	2 67 74 17 33
22 35 85 15 33	92 3 51 59 77	59 56 78 6 83	52 91 5 70 74
9 98 42 99 64	61 71 62 99 15	6 51 29 16 93	58 5 77 9 51
54 87 66 47 54	73 32 8 11 12	44 95 92 63 16	29 56 24 29 48
58 37 78 80 70	42 10 50 67 42	32 17 55 85 74	94 44 67 16 94
87 59 36 22 41	26 78 63 6 55	13 8 27 1 50	15 29 39 39 43
71 41 61 50 72	12 41 94 96 26	44 95 27 36 99	2 96 74 30 83
23 52 23 33 12	86 93 2 18 39	7 2 18 36 7	25 99 32 70 23
31 4 49 69 96	10 47 48 45 88	13 41 43 89 20	97 17 14 49 17
31 99 73 68 68	35 81 33 3 76	24 30 12 48 60	18 99 10 72 34
94 55 28 41 36	45 37 59 3 9	90 35 57 29 12	82 62 54 65 60

1er día 2do día 3er día 4to día 5to día

Figure 1 Random numbers
Source: Mancilla

Development

The method is applied to find out the automobile traffic at the Fernando Baeza-Av. río Chuvíscar intersection. Ten observations were taken per day, with a duration of three minutes. The data analysed were: number of cars heading north-south, south-north, northeast-southeast and southeast-northeast. For the sampling, with an error percentage of 5%, and with a confidence level of 95%, 300 observations were obtained, and five of the preset schedules are attached in tables 3, 4, 5, 6 and 7.

The 300 observations are carried out in 30 days, giving a total of 10 observations per day. They were carried out in 3 shifts of 5 hours: from 7:00 am to 10:30 pm. 5 hours is 300 minutes, so there are 30 periods of 10 minutes.

- Choose a random number from the table: 37
- Pick a number from 1 to 10: 3
- Going down the column, select a number from each 3 and write it down: 37, 69, 0, 66, 41, 10, 8, 94, 33 and 47.
- Eliminate 69, 66, 41, 94, 33 and 47 because they are greater than 30.
- Eliminate 37 because it is the initial number.
- Using the same procedure, select 7 more digits to replace the previous ones: 9, 14, 3, 4, 6, 24 and 26.
- Eliminate digits in case of repetition.
- Sort in numerical order: 0, 3, 4, 6, 8, 9, 10, 14, 24, 26.

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(i) The smallest digit (0) represents 0°. Period of 10 minutes from the starting time.

Start of sampling	Multiplied by 10 min	Time of observation
0	0	7:00 + 0 = 7:00
3	30	7:00 + 30 = 7:30
4	40	7:00 + 40 = 7:40
6	60	8:00
8	80	8:20
9	90	8:30
10	100	8:40
14	140	9:10
24	240	10:50
26	260	11:10

Table 2 Timetables day 1, shift 1
Source: Own source

Start of sampling	Multiplied by 10 min	Time of observation
2	20	12:20
10	100	13:40
11	110	13:50
12	120	14:00
16	160	14:40
20	200	15:20
21	210	15:30
23	230	15:50
25	250	16:10
27	270	16:30

Table 3 Timetable day 1, shift 2
Source: Own source

Start of sampling	Multiplied by 10 min	Time of observation
4	40	17:40
5	50	17:50
7	70	18:10
15	150	19:30
16	160	19:40
23	230	21:50
24	240	22:00
27	270	22:30
29	290	22:50
30	300	22:00

Table 4 Timetables day 1, shift 3
Source: Own source

Start of sampling	Multiplied by 10 min	Time of observation
2	20	7:20
5	50	7:50
7	70	8:10
15	150	9:30
16	160	9:40
23	230	10:50
24	240	11:00
27	270	11:30
29	290	11:50
30	300	12:00

Table 5 Timetables day 2, shift 1
Source: Own source

Start of sampling	Multiplied by 10 min	Time of observation
3	30	12:30
6	60	13:00
10	100	13:40
12	120	14:00
16	160	14:40
18	180	15:00
21	210	15:30
23	230	15:50
26	260	16:20
27	270	16:30

Table 6 Timetables day 2, shift 2
Source: Own source

To carry out the sampling, 4 directions were taken into account: the section from Commscope to BBVA is considered to go from North to South, from BBVA to Commscope from South to North, from Alsuper to ADC Delicias from Northeast to Southwest and from ADC Delicias to Alsuper from Southwest to Northeast.

Sate: 25/03/22 Estudio: 1	Observador: M. L. O. I., A. E. P. L. y D. A. Q. P										Day 1	
Number of observations : 10 observaciones	16:30 hrs	17:00 hrs	17:10 hrs	17:30 hrs	17:50 hrs	18:00 hrs	18:10 hrs	18:50 hrs	20:30 hrs	20:50 hrs	Total	Percentage
North to South	15	9	15	7	11	13	10	2	14	14	110	11%
South to North	12	15	36	11	13	15	13	5	8	15	143	14%
Northeast to southwest	69	50	42	52	22	31	31	34	32	32	395	40%
Southwest to northeast	36	39	42	27	39	28	41	18	36	43	349	35%

Table 7 Sample example 1
Source: Own source

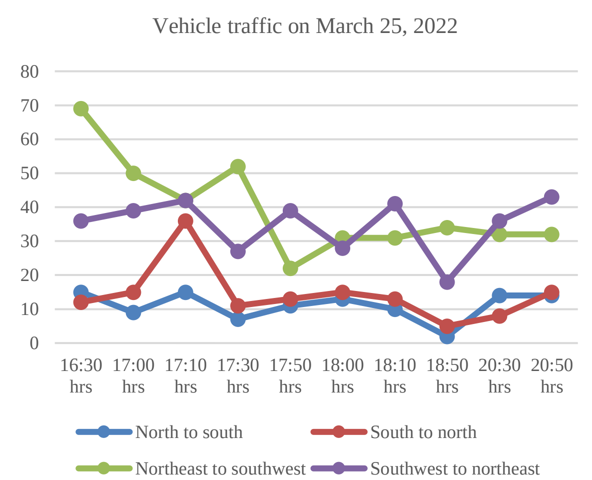

Figure 2 Sample example 1
Source: Own source

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Based on the data obtained on 25 March (afternoon shift) on vehicle traffic, table 8 it can be seen that the busiest hours for each direction are: from North to South, at 16:30 hrs and 17:10 hrs, with approximately 15 cars; from South to North, the busiest hour is at 17:10 hrs, with 36 cars; in the Northeast to Southwest direction, the busiest hour is at 16:30 hrs with 69 cars; and finally, in the Southwest to Northeast direction, the peak hour is at 20:50 hrs, with 43 cars.

DATE: 26/03/22 Estudio: 2	Observador: M. L. O. I., A. E. P. L. y D. A. Q. P										Day 2
Number of observations : 10 observaciones	16:50 hrs	18:10 hrs	18:20 hrs	18:30 hrs	19:10 hrs	19:50 hrs	20:00 hrs	20:20 hrs	20:40: hrs	21:00 hrs	Total	Porcentaje
North to South	11	15	4	1	7	13	10	10	16	10	97	12%
South to North	9	17	6	10	4	9	10	9	16	7	97	12%
Northeast to southwest	36	40	29	15	15	26	26	19	27	25	258	33%
Southwest to northeast	44	37	26	20	24	32	39	45	34	25	326	42%

Table 8 Sampling example1
Source: Own source

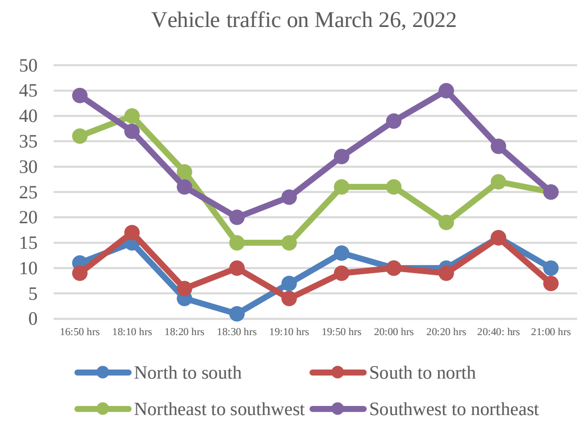

Figure 3 Sampling example 2
Source: Own source

According to the data collected on vehicle traffic on 26 March, table. 9, the peak hour of vehicular traffic in each direction studied is as follows: in the North to South direction this hour was at 20:40 hrs, with 16 cars; in the South to North direction, it is at 18:10 hrs, with 17 cars; in the Northeast to Southwest direction it is at 18:10 hrs, with 40 cars; finally, there is the Southwest to Northeast direction, in which the peak hour is at 20:20 hrs, with 45 cars; in the Southwest to Northeast direction, the peak hour is at 20:20 hrs, with 45 cars; in the South to Northeast direction, it is at 18:10 hrs, with 17 cars; in the Northeast to Southwest direction it is at 18:10 hrs, with 40 cars; and in the Southwest to Northeast direction it is at 18:10 hrs, with 40 cars.

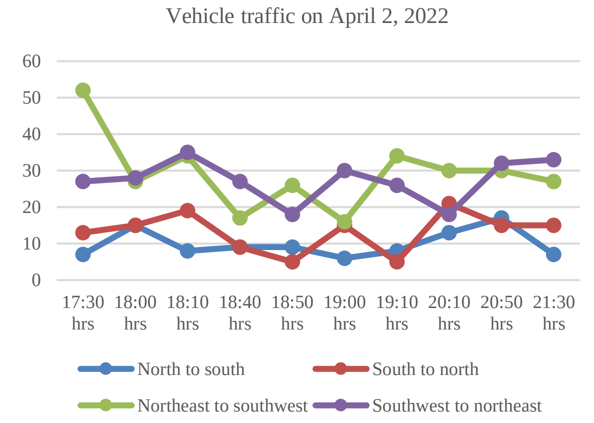

Figure 4 Sampling example 3
Source: Own source

DATE: 27/03/22 Estudio: 3	Observador: M. L. O. I., A. E. P. L. y D. A. Q. P										Day 3
Number of observations : 10 observaciones	17:10 hrs	17:20 hrs	17:40 hrs	19:00 hrs	19:10 hrs	20:20 hrs	20:30 hrs	21:00 hrs	21:20 hrs	21:30 hrs	**Total**	**Porcentaje**
North to South	15	12	13	2	15	15	14	15	17	9	127	15 %
South to North	18	8	17	15	8	10	8	10	9	13	116	13 %
Northeast to southwest	30	21	31	10	20	20	35	30	30	22	249	29 %
Southwest to northeast	52	38	46	33	25	41	37	22	41	36	371	43 %

Table 9 Sampling example 3
Source: Own source

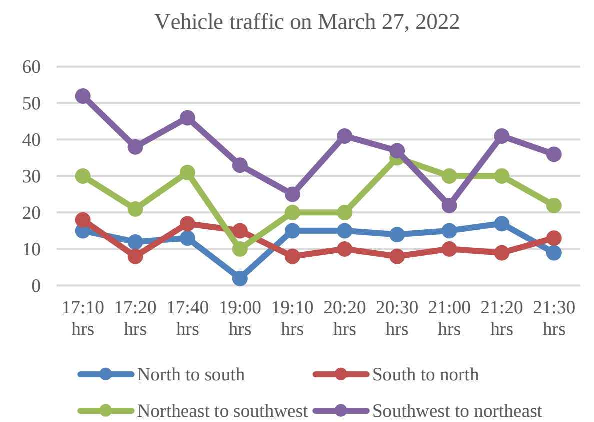

Figure 5 Sampling example 4
Source: Own source

With the above, in table 10 the vehicular affluence of the day March 27, it is perceived that, in the 4 directions, the hours in which the vehicular traffic is greater are those that are described next: for the direction North to south, it is at 21:20 hrs, with 17 vehicles; the case of South to north, it is at 17:10 hrs, with 18 automobiles; for the direction Northeast to southwest, it is at 20:30 hrs with 35 vehicles: 20 hrs, with 17 vehicles; the case of South to North, is at 17:10 hrs, with 18 cars; for the Northeast to Southwest direction, it is at 20:30 hrs with 35 vehicles; and finally the Southwest to Northeast direction, at 17:10 hrs, with 52 cars..

DATE: 02/04/22 Estudio: 4	Observador: M. L. O. I., A. E. P. L. y D. A. Q. P										Day 4
Number of observations : 10 observaciones	**17:30 hrs**	**18:00 hrs**	**18:10 hrs**	**18:40 hrs**	**18:50 hrs**	**19:00 hrs**	**19:10 hrs**	**20:10 hrs**	**20:50 hrs**	**21:30 hrs**	**Total**	**Porcentaje**
North to South	7	15	8	9	9	6	8	13	17	7	99	12%
South to North	13	15	19	9	5	15	5	21	15	15	132	17%
Northeast to southwest	52	27	34	17	26	16	34	30	30	27	293	37%
Southwest to northeast	27	28	35	27	18	30	26	18	32	33	274	34%

Table 10 Sampling example 4
Source: Own source

Based on the data in table. 11 on 2 April, the peak hours for each direction are as follows: in the North to South direction, it is at 20:50 hrs, with 17 cars; while in the South to North direction, it is at 20:10 hrs, with 21 vehicles; for the Northeast to Southwest direction, it is at 17:30 hrs, with 52 cars; finally, in the Southwest to Northeast direction, the peak hour is at 18:10 hrs, with 35 cars.

DATE : 03/04/22 Estudio : 5	Observador: M. L. O. I., A. E. P. L. y D. A. Q. P										Day 5
Number of observations : 10 observaciones	**17:00 hrs**	**17:30 hrs**	**18:10 hrs**	**18:30 hrs**	**19:10 hrs**	**19: 30 hrs**	**20:00 hrs**	**20:20 hrs**	**20:50 hrs**	**21:00 hrs**	**Total**	**Porcentaje**
North to South	11	8	15	8	9	4	10	7	15	10	97	12%
South to North	16	14	16	12	6	12	12	10	12	11	121	14%
Northeast to southwest	47	50	36	20	20	19	26	25	30	26	299	36%
Southwest to northeast	39	25	47	25	27	25	30	35	43	24	320	38%

Table 11 Sampling example 5
Source: Own source

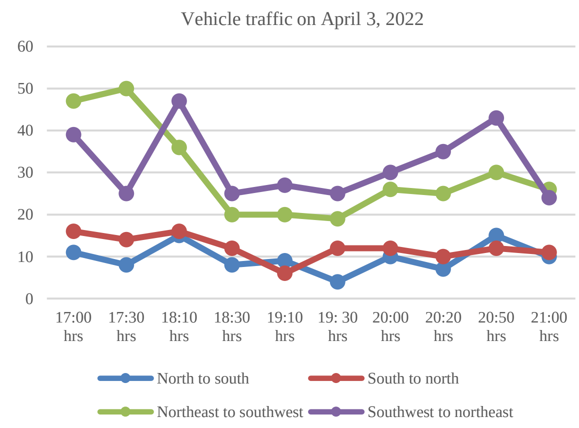

Figure 6 Sampling example 5
Source: Own source

Taking into account data from table. 12 for the sampling of the 3rd of April, on the vehicle flow, we have the following peak hours in the 4 directions observed: for the direction North to South, there are two different hours, and they are 18:10 hrs and 20:00 hrs: 50 hrs, with 15 cars; for the South to North, there are also two different hours, at 17:00 hrs and 18:10 hrs, with 16 vehicles; in the Northeast to Southwest direction, there is only one hour and that is 17:30 hrs, with 50 vehicles; and finally, Southwest to Northeast, at 18:10 hrs, with 47 cars.

Results

The following table 10 shows a general concentration of the data analysed during the sampling carried out, in order to reach a clear and well-founded conclusion on car traffic at the Fernando Baeza-Av. Río Chuvíscar intersection.

	North-South	South-North	North-East-South-West	Southwest-Northeast	Total
7:00–7:30	15	12	69	36	132
7:30-8:00	11	9	36	54	110
8:00-8:30	10	16	49	59	134
8:30-9:00	15	27	36	47	125
9:00-9:30	12	8	21	38	79
9:30-10:00	8	13	32	27	80
10:00-10:30	13	17	21	46	97
10:30-11:00	11	13	22	39	85
11:00-11:30	14	15	29	28	86
11:30-12:00	12	17	36	40	105
12:00-12:30	4	6	29	26	65
12:30-13:00	5	11	17	23	56
13:00-13:30	19	29	37	77	162
13:30-14:00	16	25	60	68	159
14:00-14:30	14	35	43	82	164
14:30-15:00	10	6	23	26	65
15:00-15:30	4	12	19	25	60
15:30-16:00	13	9	26	32	80
16:00-16:30	10	11	26	35	82
16:30-17:00	13	21	30	18	82
17:00-17:30	11	10	22	41	84
17:30-18:00	14	8	34	37	93
18:00-18:30	16	16	27	34	93
18:30-19:00	16	14	31	40	101
19:00-19:30	22	30	57	74	173
19:30-20:00	17	9	30	41	97
20:00-20:30	8	14	25	35	82
Total	**323**	**393**	**867**	**1178**	**2731**
Porcentaje	**10%**	**12%**	**30%**	**48%**	**100%**

Table 12 Concentrated data
Source: Own source

In order to create table 13 of the concentrate of the data obtained, the sampled schedules were compiled (daily registration tables see figure 7, which were created previously). To complete the filling of table. To complete the filling of table 13, the number of cars that travelled in the pre-established directions was also entered. For the schedules where more than one sampling had been performed, it was decided to average the data obtained on each of the days, as described by Hagen Kirk (2009), in case the result was a decimal number, it was rounded up to the next higher whole number.

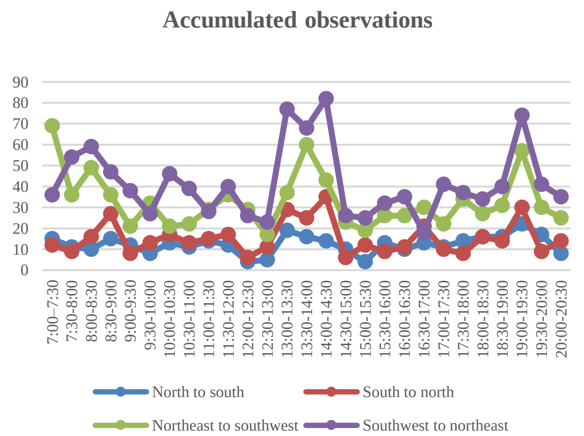

Figure 7 Data evaluated by hour
Source: Own source

After analysing the percentages in Fig. 7 and the graph, it can be seen that more cars travel from the Southwest to the Northeast, with a percentage of 48% of the total data sampled. According to; Rovetto, C., Cruz, E., Núñez, I., Santana, K., Smolarz, A., Rangel, J., & Cano, EE (2023). make reference that; Cities manage the different flows of cars at intersections in a static way, which makes the times assigned to traffic lights constant and not adaptable to changing traffic conditions at any given time, resulting in suboptimal performance. Given that a city has many intersections regulated by these systems, the inefficiency of these systems results in hundreds of hours wasted by citizens: This is because the Southwest part of the city has several subdivisions, so, when analysing an intersection that connects these subdivisions with a large part of the city (which is located to the Northeast), there is more traffic flow in this direction (Southwest-Northeast), which results in more traffic flow in the Southwest-Northeast direction).

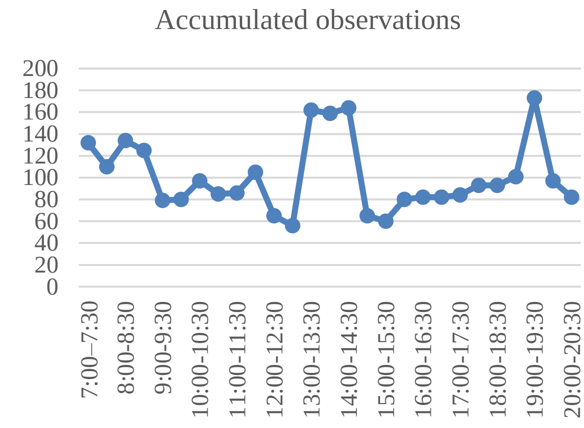

Figure 8 Data evaluated by hour
Source: Own source

It is also of interest to know the hours when there is more vehicular traffic at the Fernando Baeza-Av. Río Chuvíscar intersection, so the data for the total number of cars that pass through at the times analysed were also plotted, and it can be seen that the three times with the highest traffic flow between 7:00 and 22:00 hours are: between 7:00 and 9:00 hours, between 13:00 and 14:30 hours, and between 18:30 and 19:30 hours.

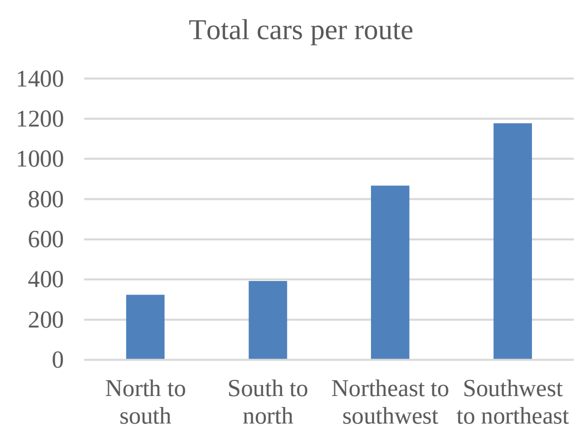

Figure 9 Data evaluated per route
Source: Own source

Conclusions

Following the analysis made in this fieldwork, a number of conclusions have been drawn. In order to present them more clearly, they have been divided into categories according to the context in which they were developed.

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Firstly, when sampling the Fernando Baeza-Av. Fernando Baeza-Av. Río Chuvíscar intersection, it was observed that the agglomeration that occurs in certain parts of the city can be measured thanks to analyses such as these. This type of analysis makes life easier, as it allows informed decisions to be made when travelling through the city in a vehicle. Importantly, this analysis can be applied to a myriad of activities, as pointed out by Mondal, S. and Gupta, A. (2023), related to a case study involving Shanghai that combines GPS-based bike sharing and road network data. First, spatio-temporal mobility patterns are visually analysed; then community sensing is used to divide the study area into management sub-areas according to mobility characteristics making it very technically functional. In addition, it was interesting to know that it is possible to identify the causes of congestion. And it is necessary to develop a road engineering focused on traffic lights at this strategic point. The application of this work sampling technique is of vital importance and its application is interesting. It is possible to have it in different areas, since they are very diverse places and have different purposes; from the traffic time that can be prevented when going to and/or returning from work to their homes, to being able to analyse the product that sells more in an establishment. This type of analysis not only yields a result, but also gives the possibility to act according to the information obtained, and in this way, to achieve technification by means of road technology.

According to; Palacios Acero Luis C, (2009), who mentions that the design in essence, is the solution of problems with methods that maximize the profit in the investment of time, money and other resources. a brief and general description of the characteristics of the problem, free of details and restrictions, includes at least: The input and output states: Another important possibility observed in this analysis study is the application of work sampling, which demonstrated the amount of analysis that can be done with a single sampling job; in this case, going to sample the number of vehicles transiting from North to South, South to North, Northeast to Southwest and Southwest to Northeast. It was of vital importance for both pedestrians and vehicle users to know the time of day when the most vehicles pass through the intersection, but it also provided more information, such as the direction in which there is the most traffic.

In general for any activity, work sampling is an engineering tool for continuous improvement of vital importance to determine the amount of time in activity or inactivity in a production process, since having established time standards helps to reduce labour costs, and also helps to improve areas of the company indirectly. Sampling results are used to determine tolerances or margins applicable to the work, to evaluate machine utilisation and to establish production standards, among other applications. To conclude, it is also interesting to note that there are already tools with established data for quality work, such as the nomogram.

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Historical interpolation repair: a new method for handling limits in differential evolution

Reparación por interpolación histórica: un nuevo método para el manejo de límites en la evolución diferencial

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Abstract

Differential Evolution (DE) is a population algorithm widely used in the solution of numerical optimization problems in continuous spaces. Sometimes, after mutation, DE generates solutions that exceed the search space, a requirement that justifies the implementation of Boundary Management Methods (BLM). This paper presents an innovative MML called "Historical Interpolation Repair", which relies on data from previous successful solutions to adjust those that deviate from the search space. Through a series of comparative experiments, it is shown that this approach outperforms other boundary handling methods. In fact, even under the most unfavorable conditions, the proposed method maintains high performance, suggesting that it is a solid choice for boundary management in DE.

Differential Evolution, Numerical Optimization, Boundary Handling, Boundary Constraints

Resumen

La Evolución Diferencial (ED) es un algoritmo poblacional ampliamente utilizado en la solución de problemas de optimización numérica en espacios continuos. En ocasiones, después de la mutación, ED genera soluciones que exceden el espacio de búsqueda, requerimiento que justifica la implementación de los Métodos para el Manejo de Límites (MML). Este artículo presenta un innovador MML llamado "Reparación por Interpolación Histórica", que se basa en los datos de soluciones exitosas anteriores para ajustar las que se desvían del espacio de búsqueda. Mediante una serie de experimentos comparativos, se demuestra que este enfoque supera a otros métodos de manejo de límites. De hecho, incluso en las condiciones más desfavorables, el método propuesto mantiene un alto rendimiento, lo que sugiere que es una opción sólida para la gestión de límites en ED.

Evolución Diferencial, Optimización numérica, Manejo de límites, restricciones de límites

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December 2023, Vol.7 No.13 25-32

Introduction

Evolutionary computation is a subfield of artificial intelligence, which includes heuristic search algorithms that are inspired by biological evolution and its processes, such as natural selection and genetics. Such algorithms simulate processes such as mutation, recombination (or crossover) and survival of the fittest (or selection).

Generally, evolutionary computational algorithms start from a set of possible solutions to a problem and 'evolve' them over many generations (Eiben & Smith, 2015). Those solutions that are most effective in each generation are selected and modified to constitute the next generation of possible solutions. This process is repeated until a sufficiently effective solution is found or until other termination criteria are met.

Evolutionary Algorithms (EA) have gained recognition by demonstrating their high ability to solve complex numerical optimisation problems, whether combinatorial or continuous (Zhang, Peng, Zhang & Wang, 2023). This has been achieved through the implementation of techniques such as genetic algorithms, genetic programming, evolutionary strategies and differential evolution, among others.

Despite their effectiveness, certain EAs, such as Differential Evolution, encounter a specific challenge when dealing with problems with boundary constraints on the decision variables. These algorithms were originally designed to operate in search spaces without boundary constraints.

Boundary management, i.e., the way in which the algorithm is kept within the valid ranges defined for each design variable in a continuous space (the search space), is an aspect that is still being explored. This mechanism is essential in algorithms such as Differential Evolution (DE) and Evolutionary Strategies (ES), since their variation operators (such as crossover and mutation) do not ensure that the generated solutions stay within the bounds of the search space.

To address this problem, in algorithms such as ED and EE, boundary management methods are used. These methods are responsible for fitting solutions that lie outside the search space. In recent years, several studies have been published that reveal how the choice of boundary handling method can have a major impact on the quality of the solutions generated by the DE algorithm (Nocedal & Wright, 2006).

It is understood that there is no universal method for boundary handling that is optimal for all problems. However, this is seen as an opportunity to develop new methods that can improve the performance of the DE algorithm. With this in mind, this paper proposes a new method called "Historical Interpolation Repair", which uses information from previous successful solutions to adjust solutions that lie outside the search space. This method has been designed to improve the handling of boundary constraints in the context of algorithms such as Differential Evolution (DE).

Problem statement

Numerical Optimization Problems (NOP) arise in a wide range of situations in science and engineering. Their objective is to determine the values of a specific set of decision variables, through the optimisation of an objective function, provided that both the limits set for the variables and the functional constraints are met (Storn & Price, 1997; Eberhart, Kennedy et al., 1995). This type of problem is defined as follows:

$$Minimizar: f(\vec{x}) \tag{1}$$

Subject to:

$$l_j \leq x_j \leq u_j \tag{2}$$

Where $\vec{x} = [x_1, x_2, \dots, x_n]^T \in R^n$ represents a solution vector and f(x ⃗) is the objective function.

Equation 2 sets the bounds on the variables in the solution vector, which restrict the possible values for the decision variables. Each variable x_j in x ⃗ is bounded by a lower and an upper bound, which together define the search space S.

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Numerical Optimisation Problems are often tackled by traditional mathematical methods, although these may be insufficient for large-scale or complex problems. In contrast, Evolutionary Algorithms such as Differential Evolution have proven to be powerful alternatives, especially in situations where detailed information about the objective function is limited or uncertain. This article focuses on the application and analysis of Differential Evolution to solve this kind of problems, detailing its implementation in the following section.

Differential evolution

Differential evolution (DE) is a population-based stochastic search algorithm for solving optimisation problems in continuous spaces (Storn & Price, 1997). The DE algorithm aims to evolve a population of n-dimensional NP-vectors representing candidate solutions in the generation g:

$$\vec{x}_i^g = \{x_{i,1}^g,\ x_{i,2}^g, \dots, x_{i,n}^g\}, i = 1, \dots, NP \tag{3}$$

Where $x_{i,j}$ represents the j-th component of solution i. The initial population is generated uniformly at random within the predefined lower l_j and upper u_j limits for each variable x_(i,j). The DE consists mainly of applying three operations that are repeated generation after generation until a termination criterion is satisfied. These operations are described below.

Mutation operator. For each target vector or "parent vector" x ⃗_i^(g-1) in generation g-1, a mutant vector v ⃗_i^gen generation g is created. The mutant vector can be created by some mutation strategy such as DE/rand/1/bin, described in Equation 4.

$$\vec{v}_i^g = \vec{x}_{r1}^{g-1} + F \times \left(\vec{x}_{r2}^{g-1} - \vec{x}_{r3}^{g-1}\right) \tag{4}$$

Where *r1≠r2≠r3≠i* are indices generated within the range [1,NP]. F>0 is a real value representing a mutation scaling factor. Other DE variants exist, such as DE/best/1/bin and DE/rand/1/exp (Mezura-Montes, Miranda-Varela, & Gómez-Ramón, 2010), however, the present study focuses only on the DE/rand/1/bin variant.

The mutation operator can generate vector values outside the limits of each variable. Therefore, it is necessary to apply some method for handling boundary constraints in order to keep the search within the space defined by the bounds of each design variable.

Crossover operator. The crossover operator generates a test vector (child) by recombining the target vector and its corresponding mutant vector, as shown in Equation 5.

$$u_{i,j}^g = \begin{cases} u_{i,j}^g & \text{if}\left(\text{rand}_j[0,1] \le \text{CR}\right) \text{ or j} = j_{rand,} \\ x_{i,j}^g & \text{de lo contrario} \end{cases} \tag{5}$$

Where $j = 1, \dots, n,\ CR \in [0,1]$ is a user-defined value indicating how similar the test vector will be with respect to the mutant vector, $randj$ is a randomly generated real value between 0 and 1, and $jrrand$ is a randomly generated integer within the range [1,n], its purpose is to avoid duplicates between the target vector and the test vector.

Selection operator. Finally, the selection operator is summarised in Equation 6, where the best vector is selected based on the fitness values between the target vector and its corresponding test vector. The vector with the best fitness value will remain in the next generation.

$$\vec{x}_i^g = \begin{cases} \vec{u}_i^g & \text{if } f\left(\vec{u}_i^g\right) < f\left(\vec{x}_i^{g-1}\right), \\ \vec{x}_i^{g-1} & \text{de lo contrario} \end{cases} \tag{6}$$

The Differential Evolution algorithm has consistently demonstrated its effectiveness in solving complex engineering problems and applications related to numerical optimisation in continuous spaces. However, as previously indicated, it experiences challenges in handling boundary constraints. It is common for its mutation operator to generate solutions beyond the defined search space, S, which implies the need to incorporate boundary constraint handling methods.

Boundary constraint handling methods

Boundary Constraint Handling Methods are used to ensure that all components of the solution vectors lie within the lower and upper bounds of the decision variables.

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These methods are fundamental in DE and other evolutionary algorithms to maintain population feasibility and convergence to optimal solutions. The choice of these methods can significantly influence the quality of the solutions produced. The following is a description of commonly used methods for boundary handling in DE.

Wrapping:

In this method, the search space is wrapped in each dimension (Purchla, Malanowski, Terlecki, & Arabas, 2004), i.e. the search space of each variable is simulated to have a periodic shape and can therefore be treated as a toroidal space (Zhang, Xie, & Bi, 2004). For this reason, values leaving the search space at the upper boundary are inserted at the lower boundary through Equation 7.

$$x_j^c \begin{cases} x_j & si\ l_j < x_j < u_j \\ u_j - (l_j - x_j)\%\ p & si\ x_j < l_j \\ l_j + (x_j - u_j)\%\ p & si\ x_j > u_j \end{cases} \quad (7)$$

Where % is the modulus operator and 〖p=||u〗_j-l_j | represents the range of the variable.

Reflection:

In this method, variables that violate limits (upper or lower) are reflected from the violated limit, by the number of violations (Robinson & Rahmat-Samii, 2004; Ronkkonen, Kukkonen, & Price, 2005). This method is described in Equation 8.

$$x_j^c = \begin{cases} x_j & si\ l_j \le x_j \le u_j \\ 2 \times l_j - x_j & si\ x < l_j \\ 2 \times u_j - x_j & si\ x_j > u_j \end{cases} \quad (8)$$

Where x_j^c is the corrected value, x_j is the value that violates some boundary constraint, l_j and u_j are the lower and upper bounds of variable j, respectively. This process is repeated until the generated value is within the bounds.

Boundary method:

In this method, also known as Bound or Projection, the value of the variable leaving the search space is reset to the violated bound (Brest, Greiner, Boskovic, Mernik & Zumer, 2006; Zhang, Xie, & Bi, 2004). This is expressed in Equation 9.

$$x_j^c \begin{cases} x_j & si\ l_j \le x_j \le u_j \\ l_j & si\ x_j < l_j \\ u_j & si\ x_j > u_j \end{cases} \quad (9)$$

In where x_j^c represents the corrected value x_j is the value that violates the bounds of the variable, l_j and u_j represent the lower and upper bounds of the variable respectively.

Random method:

This method replaces the values of the variables that are outside their bounds by random values within the lower and upper bounds (Lampinen, 2002; Price, Storn, & Lampinen, 2005) through Equation 10.

x_j^c=l_j+rand(0,1)×(u_j-l_j) (10)

Where rand(0,1) returns a random value between 0 and 1 with uniform distribution.

Centroid method:

The Centroid method relocates the invalid vectors within the search space to the centroid of an area formed by k+1 vectors, one of them taken from the population and k randomly repaired vectors (Juárez-Castillo, Pérez-Castro, & Mezura-Montes, 2017) by Equation 11.

The population vector biases the position of the corrected vector to an area with a good fitness value, while the k random vectors guide the position of the corrected vector to new areas in the search space.

$$\vec{x}^c = \begin{cases} \vec{x} & si \forall x_j : l_j \le x_j \le u_j \\ \frac{\vec{x}_{best} + \sum_{i=1}^{k} \vec{W}_{ri}}{k+1} & \text{en otro caso} \end{cases} \quad (11)$$

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Where $\vec{x} = [x_1, x_2, \dots, x_n]$ is the vector that violates the bounds, n represents the number of dimensions of the problem to be treated, x ⃗ is the corrected vector, x ⃗_best is the best solution of the current population. On the other hand, W ⃗_r1,...,W ⃗_rk are k random vectors (Juárez-Castillo, Pérez-Castro, & Mezura-Montes, 2015). The random vectors initially take the same values as x ⃗, and subsequently replace their invalid values by randomly chosen values between their lower bound l_j and upper bound u_j, in the same way that a repaired vector is generated by the Random method described in Equation 10.

It is important to note that the Centroid method, originally proposed by Juárez-Castillo et al. (2019), was designed to address problems with functional constraints, where feasible and infeasible solutions exist. However, in this case, we are dealing with optimisation problems without functional constraints. Therefore, minor adjustments have been made to the Centroid method to make it suitable for the problems presented in this paper.

Res&Ran method:

In the Res&Ran method, when the Differential Evolution (DE) mutation operator, described in Equation 4, produces an invalid solution, the mutation operator is reapplied with the expectation of generating a valid solution by recreating the random values r1≠r2≠r3. If a valid solution is not obtained, this procedure is repeated up to 3×n times, where n denotes the dimensionality of the problem. In case no valid solution vector is obtained after these iterations, the Random method is applied (Juárez-Castillo, Pérez-Castro, & Mezura-Montes, 2017), as described in Equation 10.

Proposed method:

In this paper we propose a new method for handling boundary constraints called "Repair by Historical Interpolation", this strategy uses historical knowledge of the best solutions found during the optimisation process to repair invalid solutions. While this involves keeping a memory of the best solution at each generation, this memory is commonly generated in order to generate the convergence graphs, so it does not involve keeping additional records.

The repair is performed by a weighted interpolation between two of the best past solutions, s_1 and s_2, those closest to the invalid vector, as shown in Equation 12.

$$\vec{x}^c = \begin{cases} \vec{x} & si\ \forall\, x_j : l_j \leq x_j \leq u_j \\ \alpha * s_1 + (1-\alpha) * s_2 : \ s_1, s_2\, \epsilon\, \mathcal{BS} & \\ & en\ cualquier\ otro\ caso \end{cases} \tag{12}$$

Where BS represents all the best solutions in each generation:

$$\mathcal{BS} = \{bs^1, bs^2, \dots, bs^g\} \tag{13}$$

Such that 〖bs〗^g represents the best solution in generation g. s_1 and s_2 are elements of BS, such that s_1 is the closest solution to x ⃗ and s_2 the second closest solution to x ⃗. To obtain the distance from 〖bs〗^g to x ⃗, the Euclidean distance formula is used. α is an interpolation parameter that takes values between 0 and 1 and determines the relative weighting of s_1 and s_1 at the interpolated point x ⃗.

Materials and methods

An experiment was conducted to assess the performance of the proposed Historical Interpolation Repair method by contrasting it against six other methods in solving a set of optimisation problems. This analysis took into account the following guidelines:
35 independent runs of the Differential Evolution (DE) algorithm were performed to address a benchmark consisting of 10 unconstrained continuous space numerical optimisation problems. The problems analysed, all of them minimisation problems, were: Ackley, Beale, Griewank, Michalewicz, Rastrigin, Rosenbrock, Schwefel, Schwefel_222, Sphere and Styblinski-Tang, all in 10 dimensions.

In each run of the ED algorithm, 100 generations were performed with the DE/rand/1/bin strategy, with F=0.7, CR=0.8 and population size NP=50, following the recommendations of the relevant literature (Zhang & Sanderson, 2009; Ronkkonen, Kukkonen, & Price, 2005).

December 2023, Vol.7 No.13 25-32

The same scheme was applied for each of the seven boundary management methods analysed: Wrapping, Reflection, Centroid, Res&Ran, Random, Bound and the Historical Interpolation Repair method, which will be referred to hereafter as Historic.

Results

Table 1 shows the average fitness value achieved over the 35 independent runs, highlighting in bold the best result for each of the 10 optimisation problems.

Additionally, the penultimate column shows the resultant value (H) of the Kruskal Wallis statistical test, while the p-value is presented in the last column.

As can be seen in Table 1, the Historic method obtained the best performance in all the problems treated, and as can be seen from the data generated by the statistical tests, the difference between the means is statistically significant.

Función	Historic	Wrapping	Reflection	Centroid	Res&Ran	Random	Bound	Kruskal Wallis (H)	Valor (p)
Ackley	**5.142**	16.576	16.566	13.130	15.501	15.197	17.401	193.584	**4.40E-39**
Beale	**0.018**	0.067	0.063	0.051	0.064	0.054	0.077	56.614	**2.19E-10**
Griewank	**3.665**	46.001	41.692	18.516	34.256	33.376	63.149	200.854	**1.25E-40**
Michalewicz	**-168.831**	-117.633	-118.981	-130.908	-121.558	-123.796	-110.725	144.214	**1.29E-28**
Rastrigin	**35.346**	75.256	75.280	55.344	67.785	66.679	82.513	173.391	**8.58E-35**
Rosenbrock	**2049.931**	18759.780	15727.982	6364.576	12673.040	11746.685	30470.934	177.004	**1.47E-35**
Schwefel	**710.249**	2024.166	2042.246	2443.639	2195.647	2198.008	2201.260	150.529	**5.98E-30**
Schwefel_222	**0.722**	3.947	3.918	2.340	3.240	3.372	4.529	200.344	**1.60E-40**
Sphere	**0.676**	13.716	12.241	4.999	9.894	9.159	16.695	206.042	**9.81E-42**
Styblinski-Tang	**-369.369**	-282.325	-283.791	-286.678	-291.923	-290.518	-255.152	137.659	**3.13E-27**

Table 1 Comparison of the performance of 7 boundary management methods for DE on 10 optimisation problems, with summary results of Kruskal Wallis statistical tests.

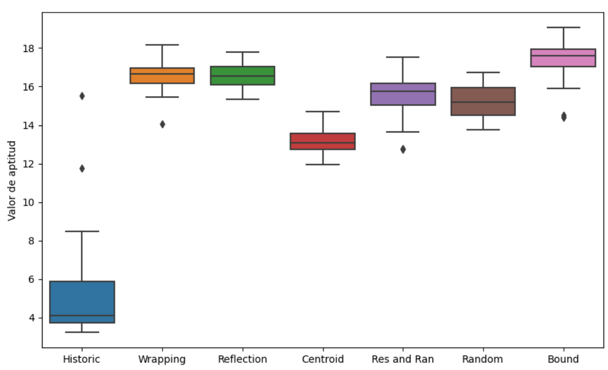

Figure 1 Comparison of methods for handling boundary constraints in DE: Distribution of fitness values obtained in 35 independent runs for the Ackley problem.

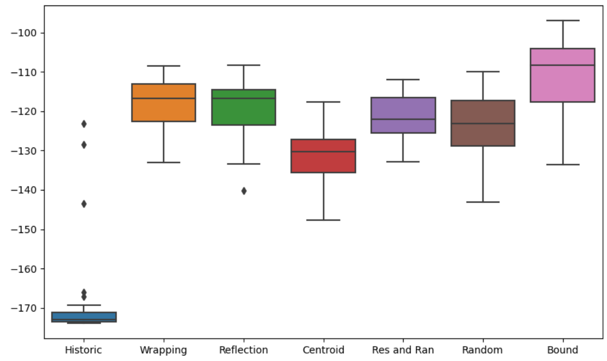

Figure 2 Comparison of methods for handling boundary constraints in DE: Distribution of fitness values obtained in 35 independent runs for the Michalewicz problem

After Historic, the second best performing method was Centroid, since it obtained the second best performance in 8 of the 10 problems treated, only being surpassed by Wrapping in the Schwefel problem and by the Res&Ran and Random methods in the Styblinski-Tang problem.

To complement the above, Figures 1 and 2 present two box plots illustrating the distribution of the fitness values achieved in the 35 independent runs for each of the 7 methods studied, in the Ackley and Michalewicz problems. For reasons of space, only 2 of the 10 problems evaluated are included, however, the rest of them show a similar trend.

In these graphs, a significant advantage of the Historic method for handling boundary constraints in the DE algorithm can be clearly observed when solving the Ackley and Michalewicz optimisation problems. In an optimisation scenario, a lower fitness value is preferable, which puts the Historic method in a prominent position. Not only does this method show a noticeably lower mean compared to the other methods, but also its highest values (represented by the upper "whiskers" in the box) are below the minimum values achieved by the other methods. This suggests an exceptionally consistent and efficient performance of the Historic method in terms of handling boundary constraints during optimisation, even in its worst-case performance scenarios. These observations highlight the effectiveness of Historic and set a strong precedent for its use in future DE applications.

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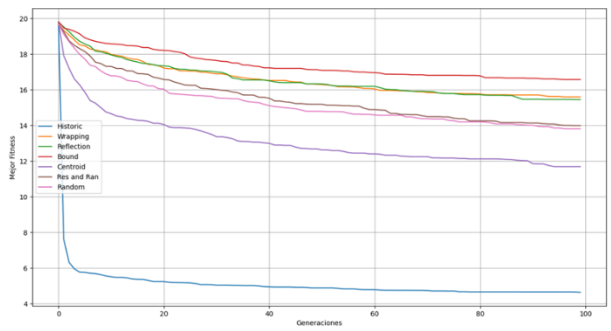

Figure 3 Comparison of Convergence of Methods for Handling Boundary Constraints in the Ackley Problem using Differential Evolution.

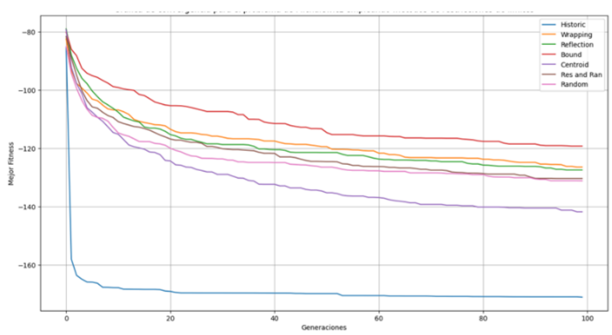

Figure 4 Comparison of Convergence of Methods for Handling Boundary Constraints in the Michalewicz Problem using Differential Evolution.

Finally, Figures 3 and 4 present two convergence plots for each of the seven methods compared in the Ackley and Michalewicz functions, which show the progress of the objective function over the generations for each method. Looking closely at these graphs, it is clear that the Historic method shows a much steeper downward trend than the other methods. Its rapid and steady decline indicates an effective convergence to optimal solutions. In addition, it is noted that the Centroid method was the second best, although its convergence rate is considerably slower compared to the Historic method.

In the last generation represented in the graphs, the results confirm the superiority of the Historic method over the others. While the other methods are in relative proximity in terms of objective function values, the Historic method stands out by being significantly below the other methods, thus demonstrating its effectiveness in obtaining more optimal solutions compared to the alternative approaches.

Conclusions

The handling of boundary constraints in Differential Evolution (DE) is a crucial challenge that affects the quality of solutions. This paper proposes a new method for handling boundary constraints, called "Historic Interpolation Repair" (Historic), which uses information from successful solutions to correct those that fall out of the search space, significantly improving the performance of DE.

The study's findings, based on tests covering ten numerical optimisation problems, indicate that the Historic method outperforms six methods tested, with its worst results still outperforming the best of the other methods, showing remarkable robustness and reliability.

The second best performing method was Centroid, which, like Historic, uses information from other solutions to guide the correction of invalid solutions.

The above seems to suggest that repair methods that employ some kind of information regarding the evolutionary process might show better performance, leaving open the possibility of exploring new, informed methods that employ information from solutions, either from the current population or from previous generations.

In summary, "Repair by Historical Interpolation" represents a breakthrough in the handling of boundary constraints in DE, improving its effectiveness and efficiency and providing valuable guidance for future proposals for repair methods.

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Numerical study of the thermal characterization of transparent envelopes for buildings with high energy impact

Estudio numérico de la caracterización térmica de envolventes transparentes para edificaciones de alto impacto energético

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Abstract

This research article presents the results of the energy simulation of a computer room with transparent windows located in the “Y” building of the Technological Institute of Pachuca. To carry out the energy simulation, the EnergyPlus program was used, which is a program to find the energy consumption of buildings. The methodology took into account the real operating conditions of the Computer Center, it was found that it has 20 desktop computers for students with computer spaces of 0.8m x 0.5m for each computer and the space for the teacher and his computer of 1m. x 1.3m, two office computers, an air conditioner with basic level climate control characteristics that ensures an average temperature between 64.4 degrees Fahrenheit and 86 degrees Fahrenheit, with variations of less than 4.1 degrees Fahrenheit per hour. The climate data of the City of Pachuca de Soto Hidalgo were taken into account. In this study the methodology is described, an achievement of a significant decrease in energy expenditure was shown.

Energy plus, Energy efficiency, Envelope, Building

Resumen

En el presente artículo de investigación se presentan los resultados de la simulación energética de una sala de cómputo con ventanales transparentes localizada en el edificio “Y” del Instituto Tecnológico de Pachuca. Para realizar la simulación energética se empleó el programa de EnergyPlus, que es un programa para encontrar el consumo energético de edificios. En la metodología se tomó en cuenta las condiciones reales de operación del Centro de Computo, se encontró que tiene 20 computadoras de escritorio para estudiante con espacios de las computadoras de 0.8m x 0.5m de cada computadora y el espacio del profesor y su computadora de 1m x 1.3m, dos computadoras de oficina, un aire acondicionado de características de nivel básico de climatización que asegura una temperatura promedio comprendida entre los 64.4 grados Fahrenheit y los 86 grados Fahrenheit, con variaciones inferiores a 4.1 grados Fahrenheit por hora. Se tomaron en cuenta los datos del clima de la Cd. de Pachuca de Soto Hidalgo. En estes estudio se describe la metodología, se mostró un logro de la disminución significativa del gasto de energía.

Energy plus, Eficiencia energética, Envolvente, Edificio

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Introduction

What is energy efficiency?

Overheating in buildings with transparent building envelopes is a growing problem in many countries with different climates, improving the thermal performance of buildings during the heating season has led to overheating problems, making it increasingly important that buildings are optimised for heating and cooling efficiency [1].

As society is advancing at a high speed, the production of all kinds of products is increasing day by day and although it is now becoming a habit to recycle, there is another method of contributing to the sustainability of the planet: energy efficiency. We are not fully aware of how much energy we waste on a daily basis and where this energy comes from. However, we are aware of how important it is to reduce our consumption in general and how much we humans pollute.

Figure 1 World Energy Efficiency Day
Source: Mutua Universal

Technological advances have changed the way human beings work in general. In the past, all procedures had to be carried out personally and took a long time, but with the evolution of the computer, it has been possible to minimise the effort and time required to carry out tasks and processes. In recent years, important experiments have been carried out to incorporate technology in education, with the aim of improving the teaching-learning process, which is one of the essential variables to take into account when we want to achieve significant learning in students, and it is important to be aware that the classroom is one of the most important factors that will greatly influence whether the objective is achieved or not. When planning a class or designing a syllabus, the available infrastructure must be taken into account, because without it there is no point in having the best syllabus.

To such an extent, it can be affirmed that there are very few institutions, both public and private, where computers are not at the service of teaching practice.

And because computers have become an indispensable tool for any professional and even for everyday life, as well as the importance of computer centres in any educational institution, there are also several problems in these computer centres, as the cost of having a computer centre in optimal conditions is currently very high. Periodic updates and maintenance of the equipment are required, as well as having a person who is continuously performing these functions, which leads many educational centres to offer slow and obsolete equipment to the student. Another very important expense is the use of electrical energy; on average, a CPU uses 500 W, which has a considerable impact on the electricity bill, as well as the acclimatisation and uniformity of the interior temperature of some schools.

The temperature uniformity inside some computer centres, which is necessary for the proper functioning of the computer equipment, should ideally have equipment that is not noisy, with a capacity to support the heat produced by all computers, as well as the occupants to have and thus have a certain degree of thermal comfort.

Figure 2 School control system
Source: SisteMéxico

Therefore it is very important to take into account the Energy Plus software as it gives details of the thermal behaviour in a building and thus it is possible to avoid overheating by reducing the thermal loads and to obtain energy efficiency.

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Theoretical framework

In the following, we are going to present several studies that have been found in the literature that are related to the topic of this research report. The first article shown is the one reported by Xie, et al. [2], in which they show a method to simulate occupancy and air conditioning that integrates the occupant behaviour model with a modified distributed air conditioning system in Energy Plus.

They used the Markov Chain method and a stochastic Monte-Carlo model to simulate occupancy and set-point adjustment. The results of their study show that significant differences (7.86%) in energy consumption results can be observed between the original and the modified model.

In the study by Uribe et al. [3], they investigated that in an academic building of a higher education institution they carried out a detailed study of lighting intensities or the correct location of the intensities, so an architectural survey of the building was carried out in order to analyse it through a simulation. The lighting intensities were found in all areas of the academic building using the luminaire simulation program. The results showed that energy consumption could be reduced by 15%. This represented a large reduction in electrical energy consumption.

In the case of Nelson et al. [4] they studied the Energy Initiative for Sustainability at the University of Coimbra, Portugal. They conducted a monitoring campaign to measure and disaggregate electricity consumption. It also evaluated natural gas and water consumption. They also evaluated the building envelope and the heating and lighting systems. They investigated some patterns of environmental energy behaviours of the academic community through a web-based survey. The results showed a reduction in consumption of about 26,123 kWh/year, avoiding the emission of 3,704 kgCO2/year, with an initial cost of 9,920 euros.
In the study by Lores et al. [5] they analysed multi-way principal components. This approach allows defining simple statistical indices T2 and SPE to be used in monitoring charts. These indices are used to detect abnormal behaviour on time scales.

After detection, a contribution analysis is performed to isolate the variables responsible for the misbehaviour. The exploitation of such models, obtained under normal operating conditions, can be used to detect both sensor failures and misbehaviour in energy consumption patterns in the case study focused on academic buildings located on the University of Girona Campus.

The need to reduce the energy requirements of lighting systems should provide engineers with a more mature and conscious vision during planning and this means that their main objectives should be visual comfort and energy efficiency. In the study by Ferdinando et al. [6] he examines the case study of a classroom located in the Faculty of Engineering of the Sapienza University of Rome and, in order to evaluate the possibility of combining natural and artificial light, he focuses on the realisation of a new lighting system. This new solution is made up of LED sources and control systems, resulting that there are payback periods that justify the higher costs presented by the electronics that characterise the control logic system.

Researchers Amy et al. [7] in their study comment that educational buildings, the third largest consumer of energy in the United States, provide significant opportunities to reduce greenhouse gas emissions by increasing energy efficiency because heterogeneous buildings consume a lot of energy, such as laboratories, medical research facilities, sports facilities and food. They deduced that there is a great opportunity to conserve energy by retrofitting these buildings. They concluded that through content analysis of the data they identified decision factors that fall into five main categories: economic feasibility, environmental impact, institutional characteristics, occupant impact and technical practicality, for retrofitting these buildings.

In the study of Joonho et al. [8] they estimated the energy efficiency of educational buildings with the case study of buildings in City University of Hong Kong by constructing a stochastic frontier model of energy demand. The model was estimated using university statistical data from 2011 to 2015.

December 2023, Vol.7 No.13 33-42

For a constant data frequency among the variables, they adopted the quadratic sum method to convert the annual university report data into a monthly dataset. With results showed that the average energy efficiency is 0.87, which implies that 13% of the total energy consumption can be saved.

Indoor air quality is an issue of great concern for human health, as people spend most of their lives indoors in the study by Ayesha et al. [9] aimed to investigate and compare the air quality and thermal comfort in classrooms of four buildings of an educational institute that have different types of heating, ventilation and air conditioning systems. Through simultaneous measurements of outdoor temperature and relative humidity and statistical analysis. As a result, it was found that the exceedance in CO2 levels of ASHRAE standards was higher in buildings with non-centralised systems compared to buildings with centralised systems during the occupational period. In addition, it found that thermal comfort parameters are influenced by outdoor climatic conditions and building orientation.

In the work of Mohd et al. [10] he presents the potential savings for achieving energy efficiency in academic building through optimisation and operational strategies. He used several existing analytical tools, such as ASHRAE CLTD/CLF, lumen method, net present value and cost benefit ratio. Its results showed that the use of air conditioning, lighting and appliances can be reduced by 12%, 52% and 40%, respectively.

Energy efficiency has now become one of the most challenging tasks for academic and commercial organisations, and this has prompted research in novel fields. In the study by A. De Paola et al. [11] they addressed the issue of timely and ubiquitous monitoring of building complexes, in order to optimise their energy consumption, with an intelligent user-driven system, and concluded with a design of a three-tier architecture to detect the user's presence of inhabitants in the building and understand their preferences regarding environmental conditions in order to optimise the overall energy efficiency of buildings.

In research by Mehreen et al. [12] conducted a pilot study to analyse the relationship between electricity demand profiles and the activities of the users of a university building. To obtain information on how the building is used, operated and managed on a daily basis, an online questionnaire was distributed to staff and students, as well as interviews conducted with key management personnel. And conducted an analysis of half-hourly electricity demand data for the case study building to identify key trends and patterns in energy use. It concluded that detailed information on occupancy patterns could help the management team redesign control strategies for optimal building energy performance.

Energy efficiency as a concept brings together actions that are taken on both the supply and demand side, without sacrificing welfare or production, allowing for improved security of supply. It also achieves savings both in energy consumption and in the economy of the general population. Simultaneously, reductions in greenhouse gas emissions and improvements in the finances of energy companies are achieved [13].

The researchers A. Boyano, et al. [14] presented energy usage figures and gave a potential energy saving strategy for office buildings. By simulating various scenarios. With their results of Energy Plus simulations of an office building which can be considered as a representative office building in the whole of Europe.

According to the mentioned research a good energy efficiency study can give a certain % of savings and this percentage can be higher by using, implementing passive elements and a % in decreasing the 〖CO〗_2. Also, it could be observed that in the analysed works, some strategies are proposed to improve the efficiency of HVAC systems such as the use of energy technologies, the improvement of control systems, the use of energy efficiency control systems and the use of passive elements.

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Energy Plus Methodology

In academic institutions there are buildings that consume more energy, for example, computer centres, in most cases there is no adequate study to have the highest energy efficiency of these facilities therefore there is a certain deficit in electricity consumption and at the same time thermal comfort. In the present research report, the aim is to reduce the energy consumption in the study laboratory and to improve the thermal conditions of the space occupied by the students, as well as the office attached to the computer centre.

Several computational energy tools have been found that allow the energy consumption of buildings to be established from detailed architectural models, taking into account information on equipment including computers, air-conditioning, lighting, etc. In this way, it is possible to modify the models for more efficient operation of the buildings prior to their construction.

One of the best computational tools used for this purpose is Energy Plus, which has been found to be a whole-building energy simulation program that is used by various professionals such as engineers, architects and researchers to model energy consumption for heating, cooling, ventilation, lighting, process and unregulated loads as well as water use in buildings.

What is Energy Plus?

The Energy Plus software is a calculation engine used to run energy simulations of buildings, it is a structured collection of analytical modules that evaluate the different associated models of a building, the analytical modules were developed by researchers for private and governmental institutions worldwide, through these procedures it is possible to take highly detailed descriptive input data of a building and generate data of the thermal conditions of the building and its surroundings, Energy Plus performs 2 types of simulations the simulation of mass and heat balance and simulation of building systems as shown in figure 3.

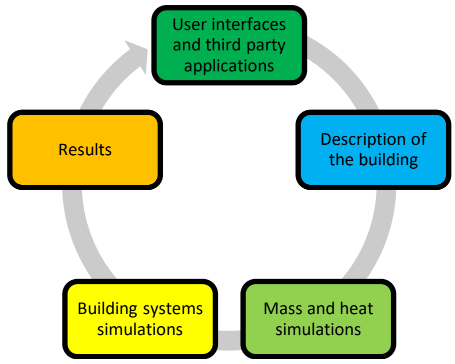

Figure 3 Energy plus simulation types
Source: (own figure)

Energy Plus is for modelling both the energy consumption of heating, cooling, ventilation, lighting, process and unregulated loads and water use in buildings of its most widely used and notable capabilities:

Simultaneous and integrated solution for heat zone conditions and HVAC system response.

Solution based on thermal balance of radiant and convective effects producing surface temperatures, thermal comfort and condensation calculations.

Combined heat and mass transfer model that considers air movement between zones.

Lighting and glare calculations to inform visual comfort and driving lighting controls.

Component-based HVAC that supports standard and novel system configurations.

Energy Plus is a console-based program that reads its input data and writes the results (output) via text files. In addition, it uses the Garbage in, Garbage out philosophy, which refers to the fact that the quality of the output depends on the quality of the input data. Thus, for example, if a program is fed with incorrect information, it is unlikely that its output will be useful or even informative.

Study geometry

The geometry should be built in 3D using the tools of Open Studio and Energy Plus through the software Sketch Up in this study should be made of a computer centre for academic purposes in which should have 20 computers 8 windows and have an office and have 2 computers, as well as having a HVAC system.

At the beginning, the computer centre space should be 10m x 6m and the office space should be 3m x 3m.

With the Open Studio tool, the elevation is made by selecting the area of the computer centre and the office and indicating that it should be 3m high.

We start with the computer centre and select to build the main door of 2.5m x 1m with the Sketch Up tool and in turn the 8 windows of 1m x 2m, as well as the door to the office of 2.5m x 1m and the computer spaces of 0.8m x 0.5m for each computer and the space of the teacher and his computer of 1m x 1.3m as shown in Figure (4).

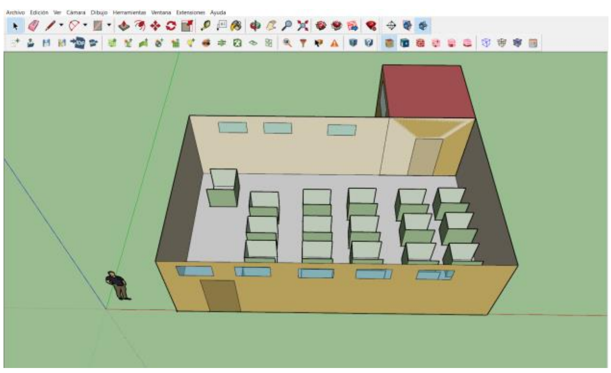

Figure 4 computer room space

In the office part of the office, the surfaces must first be matched with the Energy Plus tools so that the software takes into account the interaction of the door between the computer area and the office and does not take it as if it were outside, then the two windows of 2.5m x 2m are added with the Open Studio tools and the space of the two computers of 1m x 0.8m as shown in figure (5).

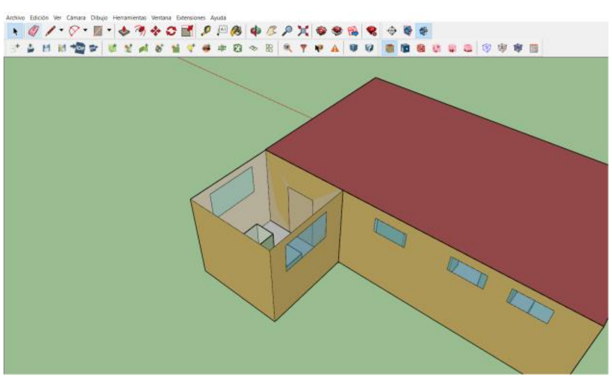

Figure 5 office space

Figure 6 shows the complete geometry as seen from the outside of the analysis building.

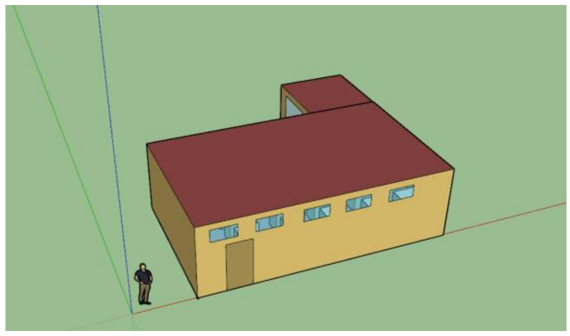

Figure 6 Complete geometry

Supplementary data for the simulation

The program is run with the climate data for the year in the desired region and displays the series of calculations in the form of tables and graphs of the 3D geometry, as well as the data entered.

Climate file

First you must add the desired climate data in an annual period in epw format as shown in figure 7, in this case the climate data for Pachuca de soto, Hidalgo for the year 2020 was used.

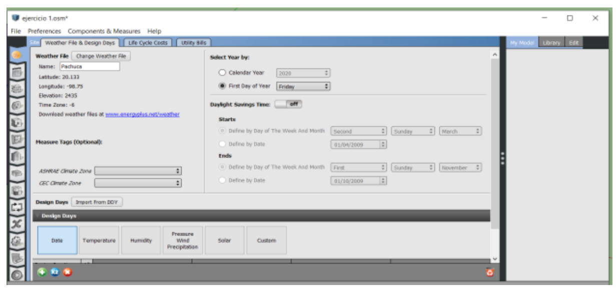

Figure 7 Climate Data Archive Addendum.

Input data

For electrical equipment, the data should be inserted either in general or per unit for the consumption of the computers, which is approximately 500w per computer, as well as for the luminaires, HVAC, etc. As shown in figure 8.

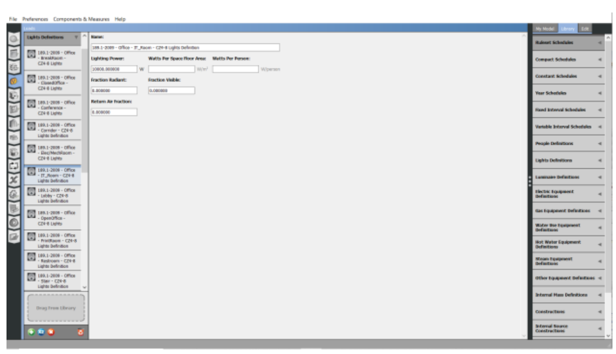

Figure 8 consumption data of computers in the computer room and in the office

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Analysis of results

Once the simulation is finished and verifying that there is no error, we will obtain a report of the geometry performed, as well as detailed graphs.

The first graph in figure 9 shows the behaviour of the air temperature in the student area of the computer centre during the period from January to December 2020 in Pachuca de Soto Hidalgo. It is worth mentioning that this area is conditioned with an HVAC. In the side section of figure 9, the range of temperatures reached is shown, which varied from approximately 71.5°F to 73.3°F and it can be observed that in some weeks, in March and May, the maximum temperature was obtained.

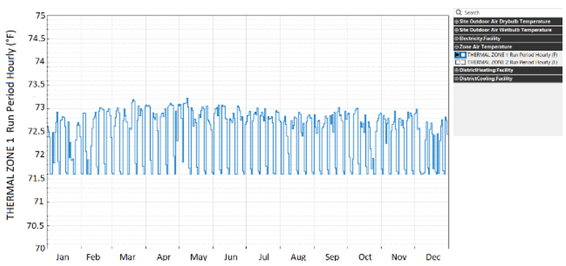

Figure 9 Approximate air temperature in the computer centre on a weekly basis

In figure 10, the behaviour of the air temperature in the student area of the computer centre is presented in a monthly average and it is worth noting that in the year 2020 in the computer centre the highest temperatures were in April and May with an average temperature of 72.6 degrees Fahrenheit and it can be observed that January and December were the months with the lowest average temperature with 72.3 degrees Fahrenheit.

Figure 10 Approximate air temperature in the computer centre on a monthly basis

As can be seen in figure 11, it gives the data in the form of a graph of the air temperature in the office attached to the computer centre, this office is not air conditioned, so it can be seen that there is a much more significant variation in the weekly temperatures of approximately 59.8 degrees Fahrenheit to 78 degrees Fahrenheit over the period January to December.

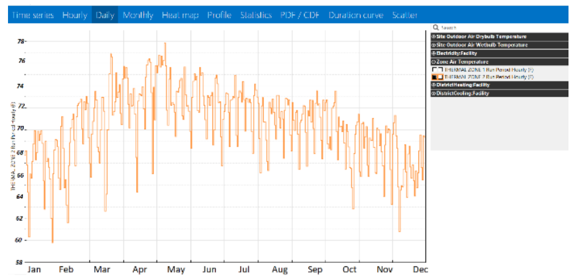

Figure 11 Approximate office air temperature on a weekly basis

With the graph in figure 12, the monthly temperatures were arranged and it was observed that the month with the highest temperature in the office was May with an average temperature of approximately 73.5 degrees Fahrenheit, while January and December had the lowest temperature with an approximate 66.9 degrees Fahrenheit.

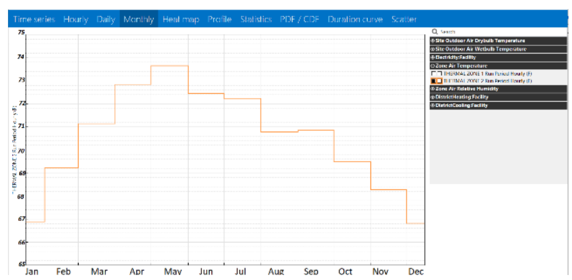

Figure 12 Approximate office air temperature on a monthly basis

As you can see in Figure 13, and Figure 14, a 24-hour heat map for the period January to December 2020 yielded an image in which it is possible to distinguish different shades of colour depending on the relevance of the area.

Normally, warm colours are always used for their representation, which usually follows the following criteria:

Red, orange and yellow tones for the areas with the highest temperature. The higher their intensity, the higher the temperature at that time of day.

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Green and blue tones for areas with lower general temperature.

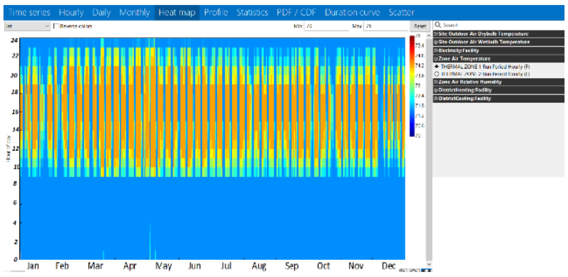

Figure 13 computer centre heat map.

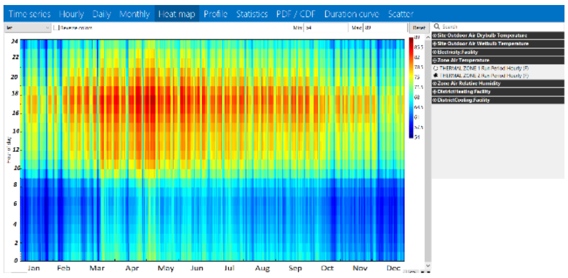

Figure 14 office heat map.

In figure 15, the total average weekly energy consumption of the building in the period January-December can be observed and can easily be seen to vary from 4500 Wh to 16100 Wh.

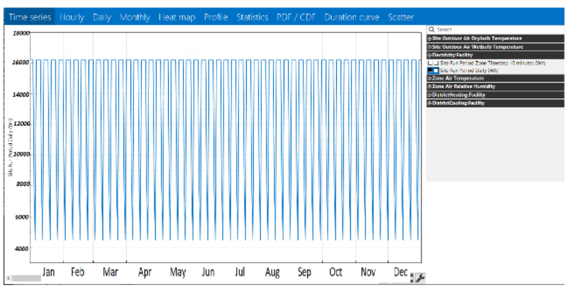

Figure 15 total average weekly energy consumption of the building

Figure 16 shows the total monthly average energy consumption of the building and shows that the month of May together with July, which had the highest temperature, had the highest consumption with an average of 13600 Wh and the lowest consumption was June with an average of 12,900 Wh.

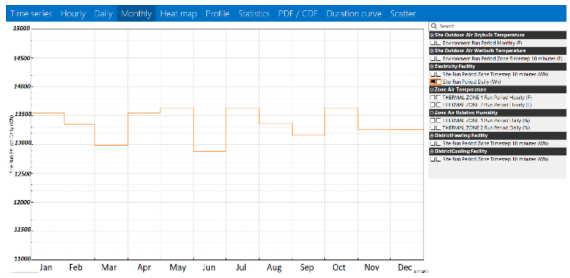

Figure 16 total average monthly energy consumption of the building

Proposed improvement

In figures 17 and 18 we added 4 small windows that can be opened to the computer centre and 2 to the office to add more ventilation and by being close to the floor we can have some ventilation near the CPUs of the computers and therefore avoid that they heat up and that the internal fans of each computer do not work at their maximum power.

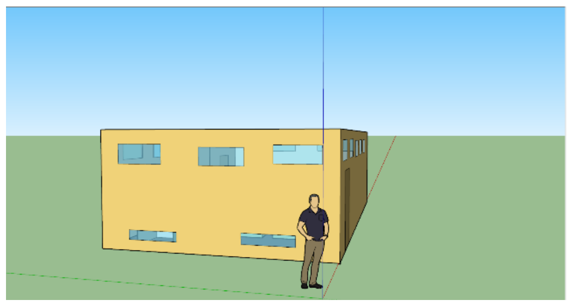

Figure 17 view of 2 additional windows to the computer centre.

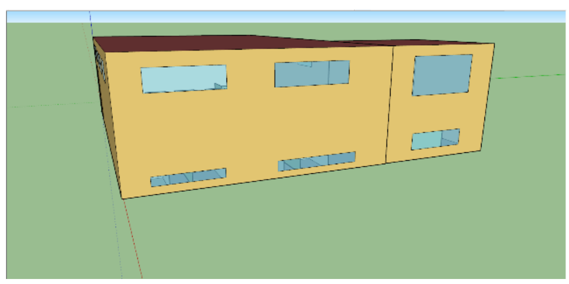

Figure 18 view of the extra windows in the computer centre and the office

Analysis of the results of the improvement proposal

Figure 19 shows the graph of the energy consumption with the extra windows per week in total for the building in the period from January to December and shows that it ranges from 4400 Wh to 14900 Wh on average.

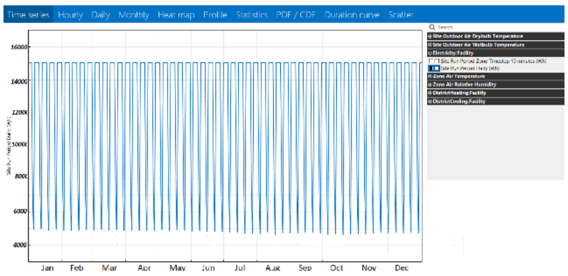

Figure 19 energy consumption with the extra windows weekly in total building

Figure 20 shows the energy consumption with the extra windows on a monthly basis and shows that there is a small but significant reduction in the hottest months and where the most energy was consumed now on average was 12800 Wh and the months with the lowest consumption was 12000 Wh on average for the total building.

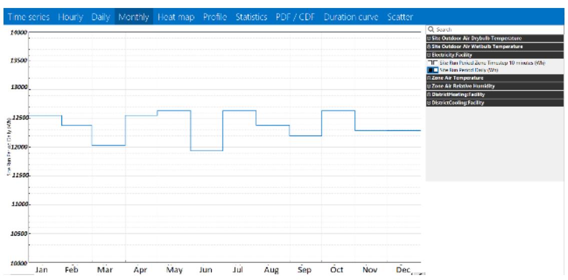

Figure 20 energy consumption with extra windows per month

In figure 21, a comparative graph of the monthly energy consumption of the study building can be seen on the left side the consumption of the building without the proposed improvement and on the right side the consumption with the proposed improvement of the extra windows for better ventilation and it is shown that there is a reduction of 1000Wh per month with the improvement.

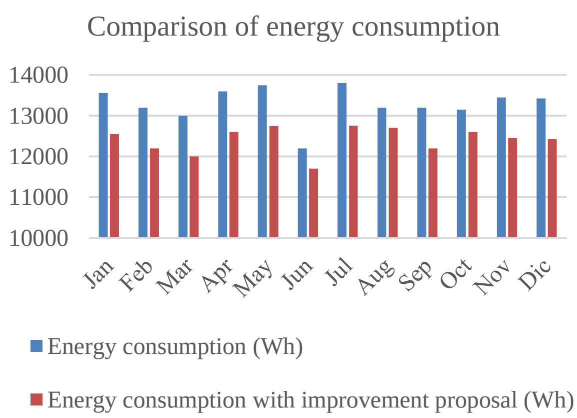

Figure 21 Comparative graph of energy consumption on a monthly basis

Conclusions

With the above studies, the use of the Energy Plus software becomes relevant as it showed that there are reductions in energy costs and significant savings, as well as a detailed demonstration of the behaviour of air conditioners and transparent envelopes as they affect thermal comfort.

The hottest month was May in both the computer centre with 73.3 degrees Fahrenheit. In the office with 78 degrees Fahrenheit. The total consumption was 13600 Wh. And the month with the lowest temperature was December with 72 degrees Fahrenheit in the computer centre and 66.9 degrees Fahrenheit in the office, with a total consumption of 12,900 Wh. The computers as a whole have the highest consumption at 500W per computer.

There are different ways to reduce the energy consumption, for example, if possible add more windows, change the windows for double glazed ones, change the lighting for the latest LED technology, change the old computer equipment, usually basic computer equipment, for better equipment with good internal ventilation systems. All this reduces energy consumption during periods of use.

This was demonstrated with the proposed improvement by adding extra windows, which provided better ventilation to the CPU's of the computers and prevented them from heating up to the point where the internal fans had to work at maximum power and a reduction of 1000 Wh per month was observed.

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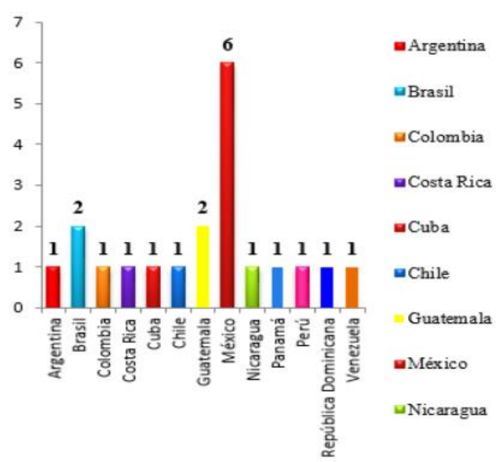

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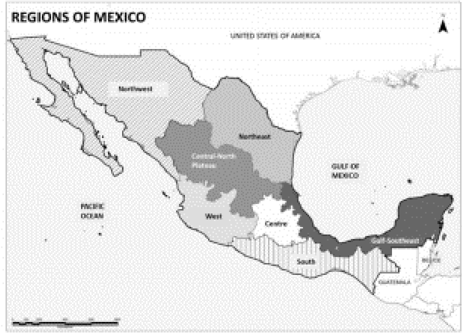

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