ISBN: 978-628-96613-3-0. ISSN: 2414-6390. Digital Object Identifier: https://dx.doi.org/10.18687/LACCEI2026.1.1.1661

Intelligent Control for Office Climate Conditioning Using Low-Enthalpy Wells

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Abstract— AbLow-enthalpy systems for building climate conditioning, such as Canadian wells based on ground–air heat exchange, offer a sustainable alternative for improving indoor thermal comfort by exploiting the thermal inertia of the subsoil. However, their performance strongly depends on the control strategy used to manage air injection and extraction under variable temperature and humidity conditions. This work presents the implementation of an intelligent control system for a low-enthalpy Canadian well installed in an office environment. The proposed solution is based on a small-scale programmable logic controller (PLC) integrated with industrial temperature and humidity sensors, enabling real-time monitoring and adaptive process control. Sensor data are visualized through a web-based interface, while the PLC executes a control algorithm designed to regulate ventilation according to thermal comfort requirements during occupied periods. Baseline measurements of thermal comfort and electrical energy consumption were first obtained. Subsequently, improvements were introduced, including upgraded ventilation equipment, higher-precision sensors, surface insulation measures, and refined control parameters. System performance was evaluated through a comparative analysis of temperature, relative humidity, and electrical energy consumption before and after automation. The results show improved stability of indoor temperature and humidity conditions, at the expense of increased electrical energy consumption. These findings highlight the trade-off between thermal comfort and energy use and demonstrate the relevance of intelligent control strategies to achieve controlled and predictable operation of low-enthalpy systems in office environments.

Keywords— ***Low-enthalpy geothermal systems, Earth–air heat exchanger (Canadian well), PLC-based control, Thermal comfort control, Energy–comfort trade-off.***

I. INTRODUCTION

Building air conditioning accounts for 40% of global energy consumption [1]. Canadian wells offer an efficient alternative by leveraging the thermal inertia of the ground to precondition air [2]. However, manual operation limits their potential. This work explores intelligent automation through real-time monitoring with industrial SIEMENS temperature and humidity sensors and process control using a LOGO! 8.4 micro-PLC, integrating existing air conditioning systems.

Studies such as [3] use PLCs with PID to control air flows but lack adaptability to seasonal changes. Modern approaches (IoT and AI) [4] propose IoT systems with machine learning to predict thermal efficiency. [5] implements low-cost sensors (NodeMCU) for remote monitoring. Not only for cooling but also for heating [6], where Christian (2024) proposes reducing greenhouse gas emissions and the carbon footprint in buildings, as they are responsible for more than 10% of these emissions. Charry [7] suggests incorporating IoT for automation, but in practice, there is still a significant gap between IoT and PLCs, especially regarding industrial safety and noise response, where development boards often fail in harsh environments.

II. METHODOLOGY

A. General Project Description

This study is based on the report by Valdizon and Merlos (2023) [8], where the system is based on a low-enthalpy Canadian well designed to thermally condition an office space through ground–air exchange. The main objective was to evaluate and improve thermal comfort (temperature and relative humidity) within the enclosure using automatic control and forced ventilation with low energy consumption.

B. Initial Conditions

Initially, the system included:

- SIEMENS equipment such as the LOGO! 8.4 programmable relay module with AM2 analog input expansion modules.
- An 8-inch, 80 W fan with a maximum thrust of 7.5 m/s for air injection from the well to improve indoor temperature.
- A similar fan in a window for extracting indoor air to remove excess humidity.
- Basic temperature and humidity sensors: PT100 and an embedded system with a DTH11 sensor.
- Threshold-based temperature or humidity control.
- An elbow-type air intake chimney without coating.
- A 3.2 m deep inspection well with an uncoated metal cover.

C. Thermal Comfort

Data collection was performed using a Datalogger for temperature values, while humidity data were collected manually in 9 periods throughout the day, as the embedded system used did not provide an analog response [9], complicating data capture. Manual measurements were taken with FLUKE 62 MAX+ and FLUKE 971 for humidity and temperature, and wind speed was measured with the HER-445 from Steren.

From these measurements, the following humidity and temperature graphs were generated, considering winter and summer readings.

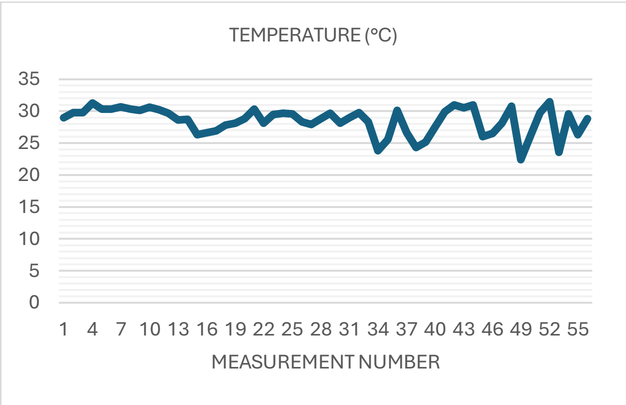

Fig. 1 Initial Temperature Graph

From the first graph, it is evident that there are ranges above 30°C, which are clearly undesirable. The second graph indicates that the humidity level is low.

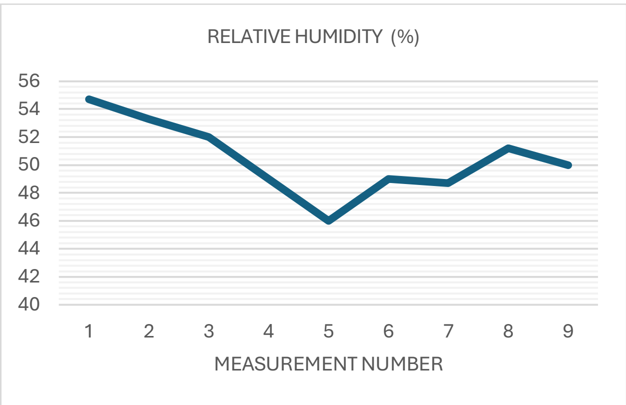

Fig. 2 Initial Relative Humidity Graph

This graph indicates that the humidity level is low.

These graphs show the baseline of the proposed research. With the obtained information, the control systems were configured with LOGO! and a basic web page was created for remote monitoring without interfering with office activities.

D. Energy Efficiency

Simultaneously, a Fluke 1736 network analyzer was installed for 5 days to obtain data on power, current, and energy consumption, establishing a baseline for the relationship between thermal comfort and energy use.

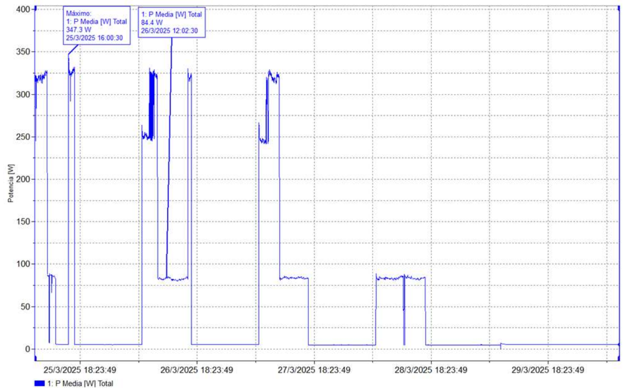

Fig. 3 Initial Power Graph

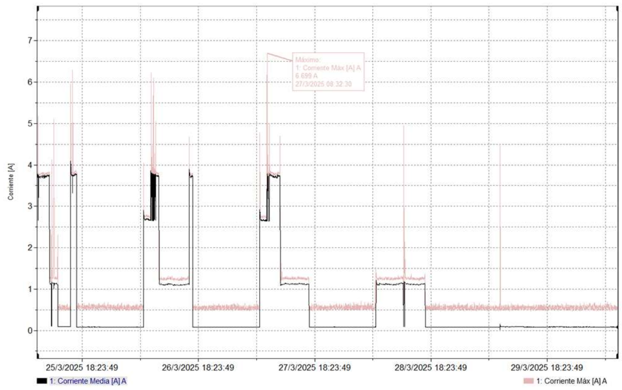

Fig. 4 Initial Current Graph

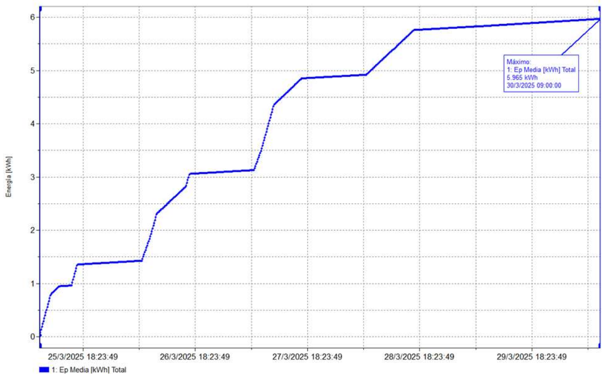

Fig. 5 Initial Accumulated Energy Graph

During this stage, the records showed:

- Energy consumed in 5 days: 5.9 kWh.
- Maximum power: 347.3 W.
- Minimum power: 84.3 W.

It is essential to note that only four days were most relevant, and that frequent fan startup currents may be affecting system efficiency.

Thus, the average daily energy consumption is inferred to be 1.4 kWh on working days.

E. Implemented Improvements

Based on performance analysis and measurement results, the following changes were made:

- Replacement of the 80W fan with a 13-inch, 150W fan, with a flow rate of 28.88 m³/min, thrust of 12 m/s, and drag of 10 m/s, to improve humidity extraction.
- Addition of a similar capacity fan for injecting humidity from outside into the office, placed in another window.
- Replacement of sensors with the industrial SIEMENS QFA20, with variation ranges of 0.1% for temperature and 3% for humidity, already configured for use with the LOGO! module, requiring only calibration (performed with the FLUKE 971).
- Improved control parameters based on temperature or humidity [10].
- Addition of aluminum coating to the chimney to reduce solar radiation heating and improve air intake.
- Addition of wood and polyethylene coating to the inspection well, identified as a hot spot [11].
- Integration with a remote monitoring web page.

F. Control Algorithm

The PLC was programmed using LOGO! SOFT COMFORT version 8.4, and the web page was developed with Siemens LWE software.

The program is based on the following process integration:

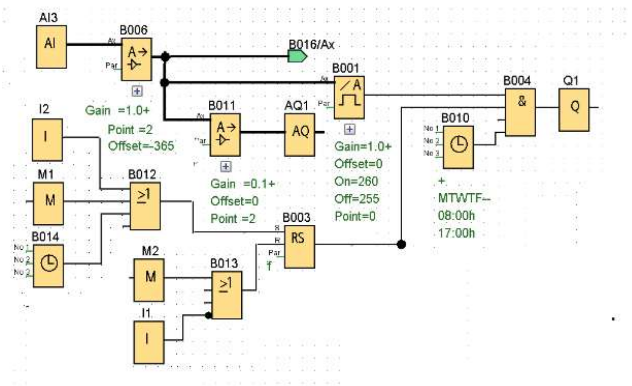

Fig. 6 LOGO! Block Diagram

Where I2, M2, and B014 are input variables for process activation; I1 and M2 are process stops; AI3 is the analog input for the temperature sensor in the current configuration (4–20 mA) [12].

Q1 represents the turbine that injects air and humidity from the well at 7.5 m/s, i.e., at full turbine power.

The figure lacks the humidity part and its working components, as well as the control algorithm for both the extraction and injection of humidity.

B006 is the input conditioner to eliminate signal offset, validated with FLUKE equipment to ensure the temperature–current relationship of the sensor.

B011 displays the temperature value in two digits for web page monitoring and online monitoring.

B010 and B014 are calendar clocks for automatic system activation; B014 is set to turn on the system Monday to Friday during office hours, ensuring it does not operate when the office is empty, but allowing web activation (M2 or manual, I2).

System shutdown is controlled by I1 or M1, which is the web page control variable.

B010 is the calendar clock that delays the activation of the air injection turbine until 9 am, to take advantage of the morning coolness and for energy efficiency. The control algorithm ensures the system does not inject air if humidity is above 80% or if temperature is below 26.5°C, aiming to save energy since under these conditions, recommended thermal comfort can be achieved [13].

After 9:00 am, the system initiates monitoring of ambient humidity and temperature to determine whether air injection from the geothermal well is required. Around 11:00 am, humidity levels tend to stabilize while ambient temperature rises, if humidity remains elevated, an extractor fan is activated to circulate air at a velocity of 5 m/s, enabling precise control over airflow and process dynamics. In cases where the temperature continues to increase and the well is unable to supply sufficient cool air, a secondary turbine is engaged to inject air from the building´s central way, an area shown to contribute positively to both temperature and humidity regulation.

Graphical data indicate that the predominant issue during morning hours is excessive humidity, whereas elevated temperature becomes more critical in the afternoon. To address this, a third turbine is employed to increase air volume and enhance thermal comfort. It initially operates at 5 m/s; however, if environmental conditions fail to improve and critical thresholds persist, the turbine switches to maximum power to optimize indoor working conditions.

Thermal Comfort Improvements

Below are the temperature and humidity graphs with the implemented improvements:

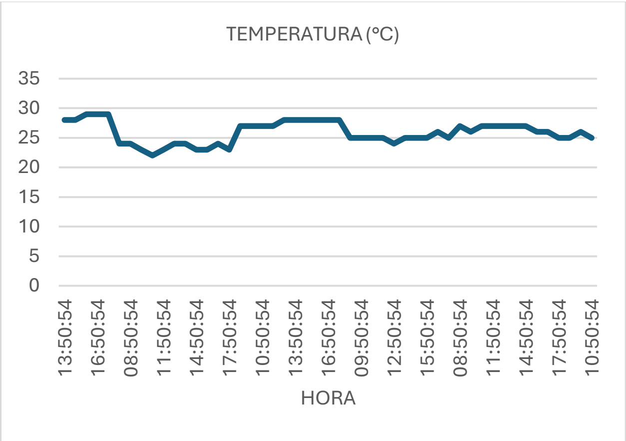

Fig. 7 Modified Temperature Graph

Although the value is more stable, there are moments when the turbines cannot maintain the expected temperature values, resulting in peaks between 28 and almost 30°C, though these do not occur frequently, which is a positive point for the process. Efficiently managed, the well can be an alternative for thermal comfort, with an average daily temperature of 25°C.

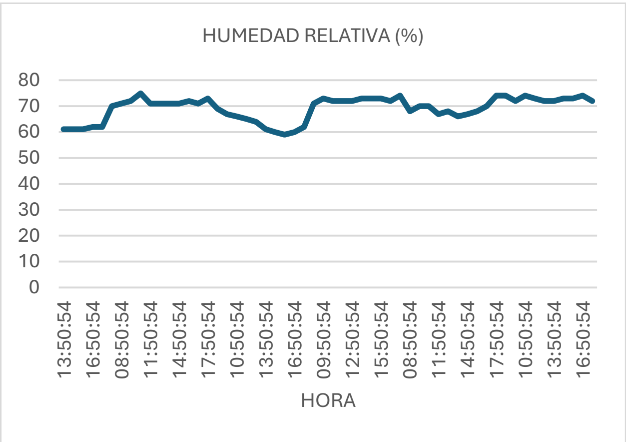

Fig. 8 Modified Relative Humidity Graph

The graph clearly shows how the algorithm seeks to control temperature by extracting humidity. Peaks above 70% occur at the start of the workday; on average, humidity is 69%, which is within expectations. The peaks were anticipated and allowed to reduce energy consumption, as will be seen in the before-and-after analysis of the automation process.

G. *Energy Efficiency Improvements*

To evaluate system performance, the Fluke 1736 network analyzer was reinstalled for 7 days to obtain power, current, and energy data, comparing the relationship between thermal comfort and energy consumption.

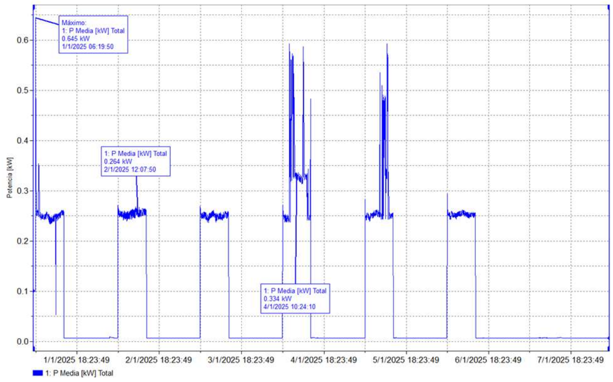

Fig. 9. Modified Power Graph

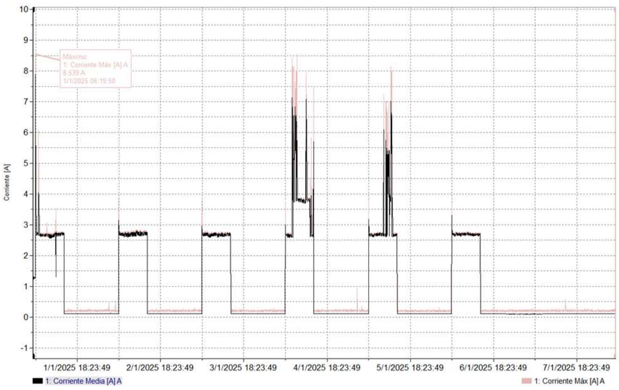

Fig. 10 Modified Current Graph

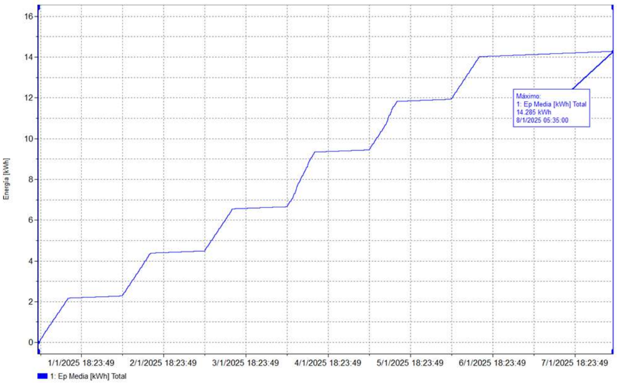

Fig. 11 Modified Accumulated Energy Graph

During this stage, the records showed:

- Energy consumed in 7 days: 14.28 kWh.
- Peak power: 645 W.
- Maximum power: 334 W.
- Minimum power: 264 W.

It is important to note that only six days were most relevant and that frequent fan startup currents could be affecting system efficiency. This is evident when observing the peak power, which exceeds 600W, while the maximum stable power is 334W.

Thus, the average daily energy consumption is inferred to be 2.35 kWh on working days.

III. CONCLUSIONS

The implementation of the automated control system resulted in more stable indoor thermal conditions, characterized by reduced temperature and humidity fluctuations during working hours. The controlled operation of the ventilation turbines improved indoor air circulation, making the office environment more tolerable during periods of high thermal load.

A low-enthalpy system leverages the temperature difference between the ground surface and the subsoil to generate thermal gradients that can improve indoor conditioning without reaching conventional air conditioning levels. The results obtained in this study show that the improvement in thermal comfort stability was achieved at the expense of increased electrical energy consumption, mainly associated with higher-capacity ventilation equipment and more frequent system operation. This behavior reflects a clear trade-off between thermal comfort and energy use, inherent to low-enthalpy systems operating under real conditions. While these systems are not necessarily more energy-efficient than traditional air conditioning systems, they may contribute to reducing the carbon footprint by avoiding the continuous use of high-power refrigeration equipment [14].

The use of sensor-based automation and PLC control algorithms proved effective in achieving more stable and predictable operation, allowing the system to respond dynamically to variations in temperature and humidity during occupied periods. Rather than minimizing energy consumption, the automation strategy enabled controlled operation focused on maintaining acceptable comfort conditions within the office space.

According to the thermal comfort ranges reported by the Center for the Built Environment at the University of California, Berkeley, the average temperature and relative humidity values obtained in this study fall within acceptable comfort zones for office environments, which supports the technical validity of the implemented control strategy (Fig. 12).

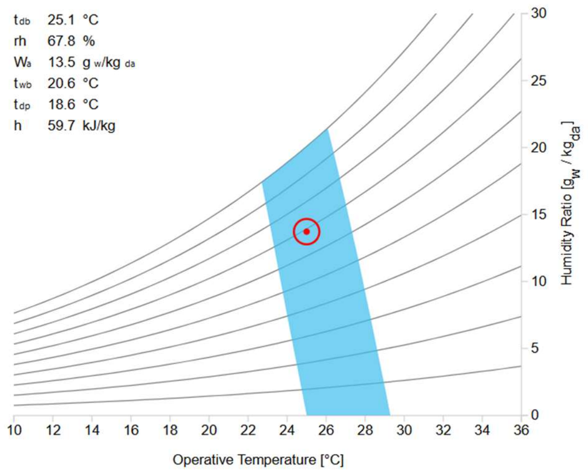

Fig. 12 Thermal Comfort Graph

While PLCs or RLCs provide robust solutions for automated process control in industrial environments, IoT-based approaches remain a potential area for future exploration, provided that adequate measures are taken to ensure sensor protection, electrical robustness, and system reliability.

Future research could focus on:

- Exploring deep learning techniques for long-term thermal behavior prediction.
- Controlling the speed of both extraction and injection fans to better manage startup currents and reduce energy consumption.
- Integrating photovoltaic power systems to supply the control and ventilation circuits, aiming for partial or full self-sustainability and applicability in rural environments.

The present study was focused on short-term experimental evaluation under real office operating conditions. Future work should incorporate long-term seasonal monitoring, adaptive or predictive control strategies, and variable-speed ventilation systems to improve energy efficiency and reduce startup current effects while maintaining thermal comfort conditions.

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