Máster Universitario en Ingeniería Informática – Curso 24/25

Inteligencia Computacional (IC)

Fuzzy control: Indoor Environment Quality (IEQ)

Marina Jun Carranza Sánchez

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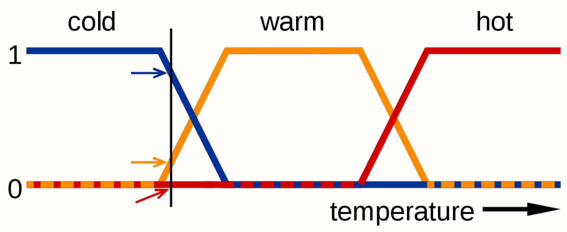
01

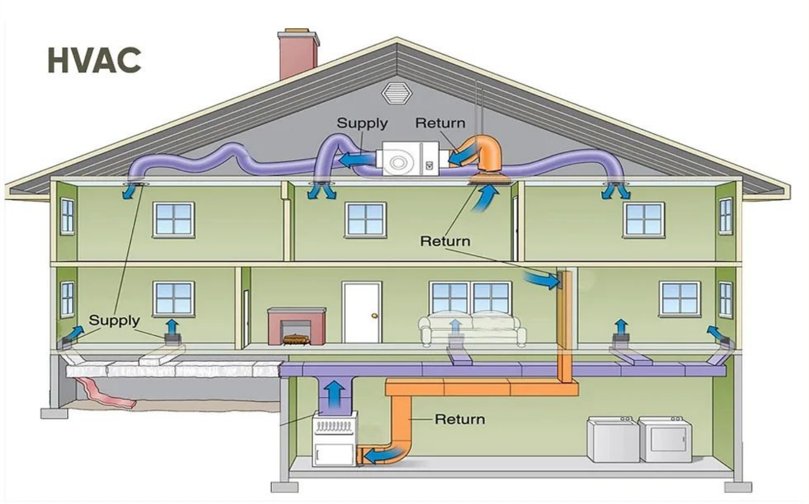
Introducción y análisis del problema

Introducción: motivación y contexto

- Mejorar el rendimiento de sistemas HVAC

- Abordar esta complejidad con **lógica difusa**.





Análisis del problema

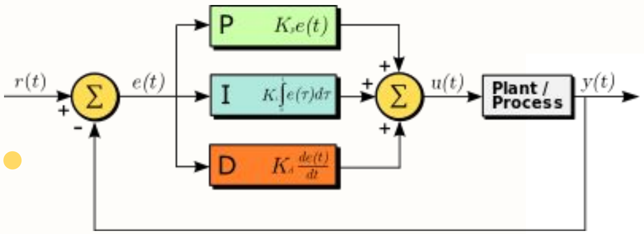
- IEQ → Interacción de diversos factores.

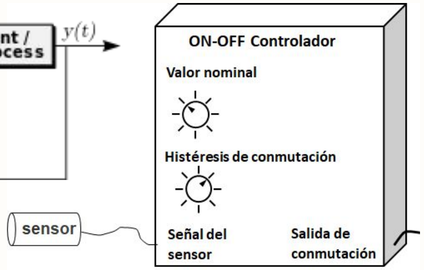
- Controladores tradicionales operan de forma aislada.

Importancia:

- Bienestar y salud de los ocupantes.

- Alineación con objetivos climáticos de la UE.





Objetivos

Diseño de un FLC para optimizar la IEQ, manteniendo **niveles adecuados de confort.**

Optimizar consumo energético	Reducir el consumo energético
Integrar múltiples sensores	Varios datos (temperatura, humedad, CO_2 ...)
Mejorar estabilidad del sistema	Reducir oscilaciones

02

Desarrollo del caso práctico

Descripción del caso práctico

- Controlador difuso unificado

Molina-Solana, M., Ros, M., & Delgado, M. (2013). Unifying fuzzy controller for indoor environment quality. *2013 Joint IFSA world congress and NAFIPS annual meeting (IFSA/NAFIPS)*, 1080-1085.

Unifying Fuzzy controller for Indoor Environment Quality

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***Abstract*—Optimizing energy consumption while maintaining an appropriate level of comfort is one of the current challenges in the Indoor Environment Quality (IEQ) field. In this paper, we propose an unified fuzzy controller for managing the different aspects involved in IEQ, overcoming the potentially inefficient interactions between several traditional controllers. We also describe the implemented web simulator to test the controller, and the results of applying the controller to a pilot room, measuring the air quality over a period of a month. Even though, further research and experimentation should be done, specially with the experts in order to fine tuning the rules and the controller, initial results are promising enough and the ease of use is quite remarkable by users.**

I. Introduction

Indoor Environment Quality (IEQ) has lately emerged as ...vance once the presence of HVAC (heating, ...air conditioning) systems has been popularized ...gs. IEQ tries to go beyond traditional control ...ducing the comfort of the users in the game. ...energy consumption of those systems, while ...appropriate comfort level is an issue of great ... not yet been fully addressed. Not in vain, energy consumption by the HVAC equipment in residential, commercial and industrial buildings represent about 40%

Although traditional PIDs could provide reasonable solutions, they are not enough to control the uncertainty of the dynamics of HVAC systems, which are more easily characterised using linguistic labels and rules [2], [3]. Fuzzy Logic Controllers (FLCs) appear as a viable alternative to conventional controllers, since they do not required a mathematical modelling [4] and they are prepared to handle different criteria, as they represent the dynamic of the HVAC system according to the knowledge of a human expert. Moreover, their efficiency and lower energy consumption (while satisfying the indoor comfort requirements) comparing to PID controllers, has been completely demonstrated [5].

In the literature, an extensive variety of proposals in this direction can be found. For instance, Calvino et al. [6] focus on the development of a fuzzy controller for the control of the indoor thermal-hygrometry comfort conditions, allowing a better adjustment of the indoor micro-climate conditions.

The focus of the FLC is not only maintaining the thermal environment, but also optimizing other parameters if necessary. Becker et al. [7] propose a fuzzy controller for temperature and relative humidity (RH) in refrigeration systems, by considering their thermodynamic coupling. In [8], authors develop a rule-based fuzzy controller to control and provide thermal comfort

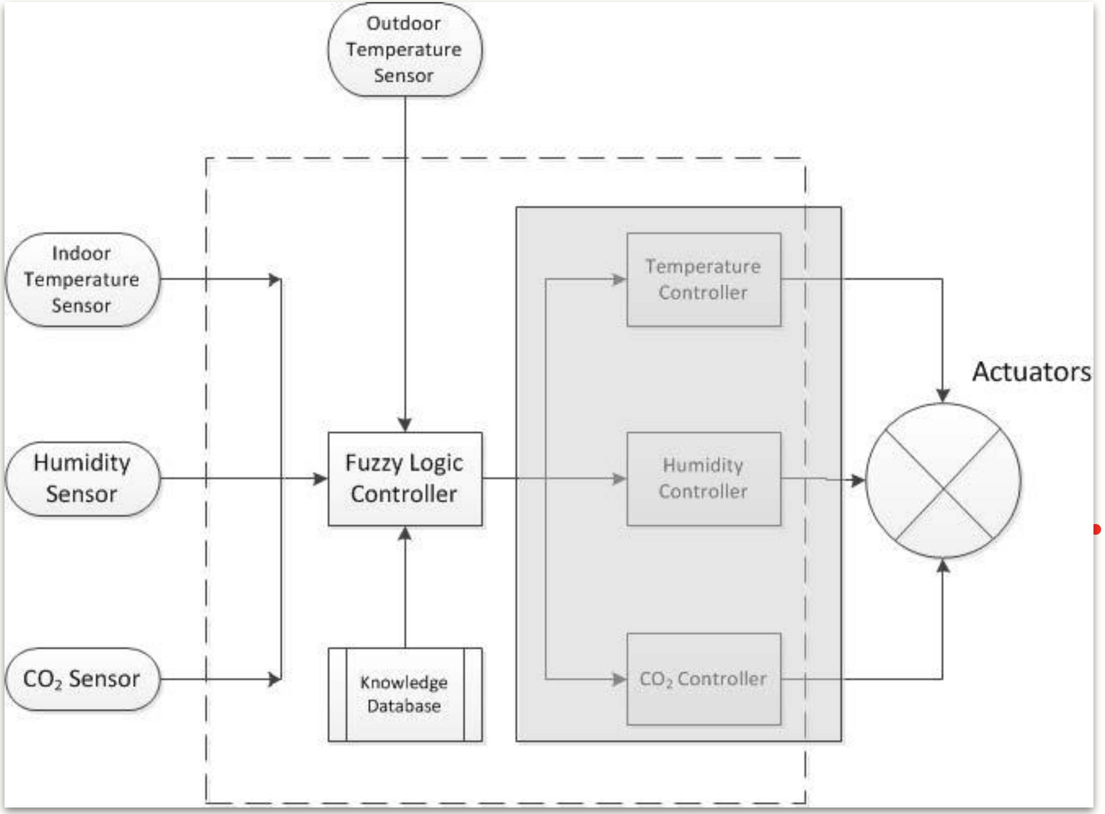
Diseño del controlador difuso

Entradas:

- Temp. interna/externa
- Humedad relativa
- Concentración CO_2
- Iluminación

Salidas:

- Nivel de temperatura
- Nivel de humedad
- Nivel de iluminación
- Programa de aire acondicionado

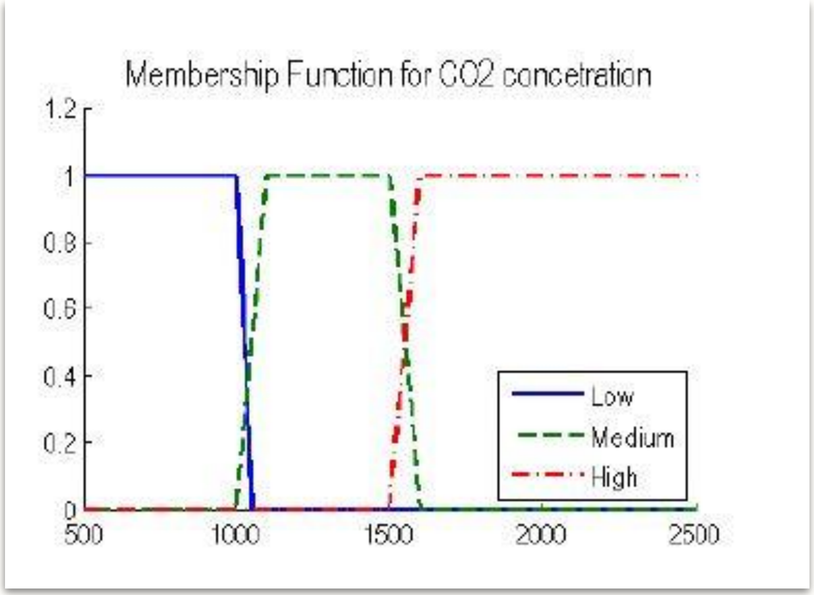


Diseño del controlador difuso

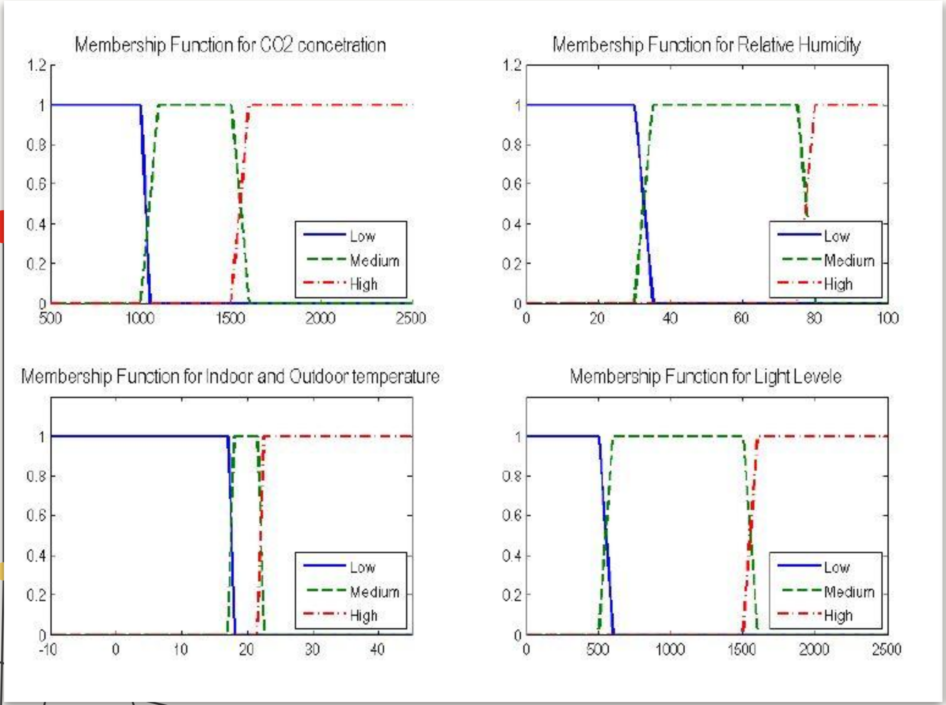
Base de conocimiento:

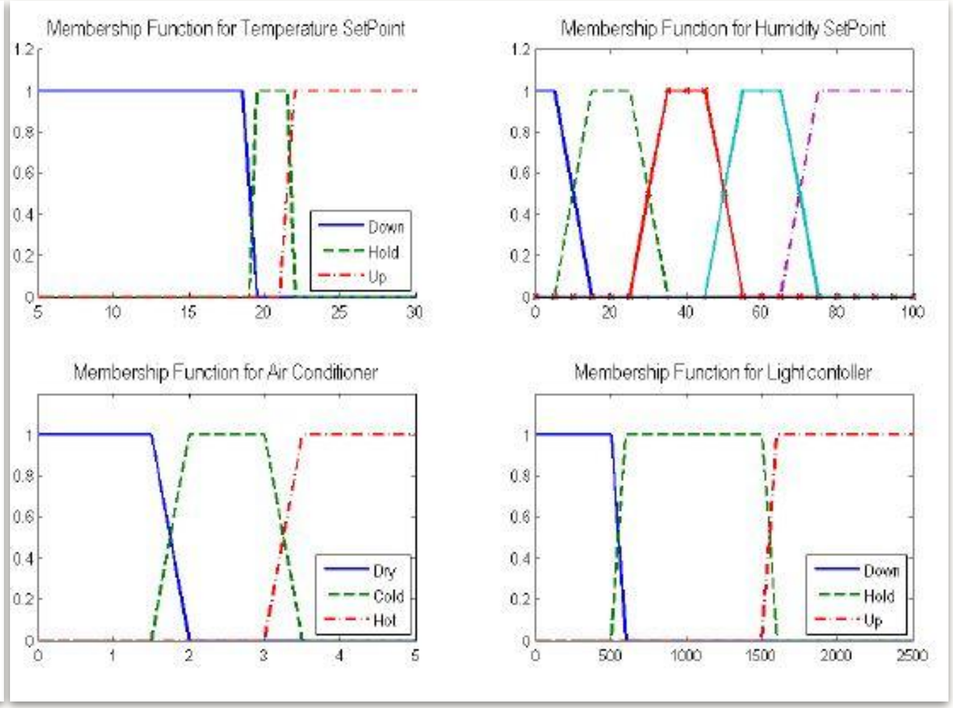
- Funciones de pertenencia (*trapezoidales*)

$$\mu_L(x_i) = \begin{cases} 0 & \text{si } x_i < a \text{ o } x_i > d, \\ \frac{x_i - a}{b - a} & \text{si } a \leq x_i \leq b, \\ 1 & \text{si } b \leq x_i \leq c, \\ \frac{d - x_i}{d - c} & \text{si } c \leq x_i \leq d. \end{cases}$$



Diseño del controlador difuso





Diseño del controlador difuso

Base de conocimiento:

- Conjunto de reglas difusas (*IF-THEN*)

IF $S_{temp_{indoor}}$ IS Medium AND $S_{temp_{outdoor}}$ IS High THEN $A_{temp_{level}}$ IS Hold AND $A_{h_{level}}$ IS Standard
IF S_{RH} IS Low AND $S_{temp_{indoor}}$ IS Low THEN A_{Air} IS Hot AND $A_{h_{level}}$ IS High AND $A_{temp_{level}}$ IS Up
IF S_{RH} IS Medium AND $S_{temp_{indoor}}$ IS Medium THEN $A_{h_{level}}$ IS Standard
IF S_{RH} IS High AND $S_{temp_{indoor}}$ IS Medium THEN A_{Air} IS Dry AND $A_{h_{level}}$ IS Continuous

Diseño del controlador difuso

Motor de inferencia:

- *Mamdani Max-Min*

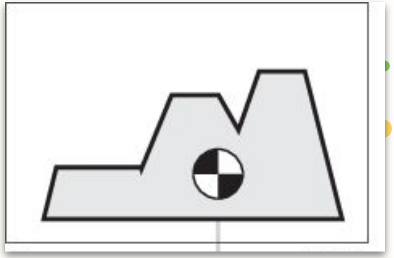
$$\mu_{R_i}(x) = \alpha_{i1} \wedge \alpha_{i2} \wedge \alpha_{i3} \wedge \alpha_{i4} \wedge \alpha_{i5}$$

$$\mu_{Output_i}(x) = max \mu_{R_1}(x), \mu_{R_2}(x), \ldots, \mu_{R_{17}}(x)$$

Defuzzificación:

- *Modo A - FATI*
- Método del *centroide*

$$d_{CA}(C) = \frac{\int_{-c}^{c} C(z) z \, dz}{\int_{-c}^{c} C(z) \, dz}$$



Pruebas en el simulador

Definition of comfort parameters

Lighting level (lux): **300 - 1500**

CO2 concentration (ppm): **0 - 1000**

Relative Humidity (%): **30 - 70**

Temperature (°C): **18 - 21**

Inputs

Indoor lighting level (lux): **132**

Outdoor lighting level (lux): **257**

Indoor CO2 concentration (ppm): **588**

Indoor relative humidity (%): **19**

Indoor Temperature (°C): **16**

Outdoor Temperature (°C): **12**

Actions


Increase Lighting (65 %)

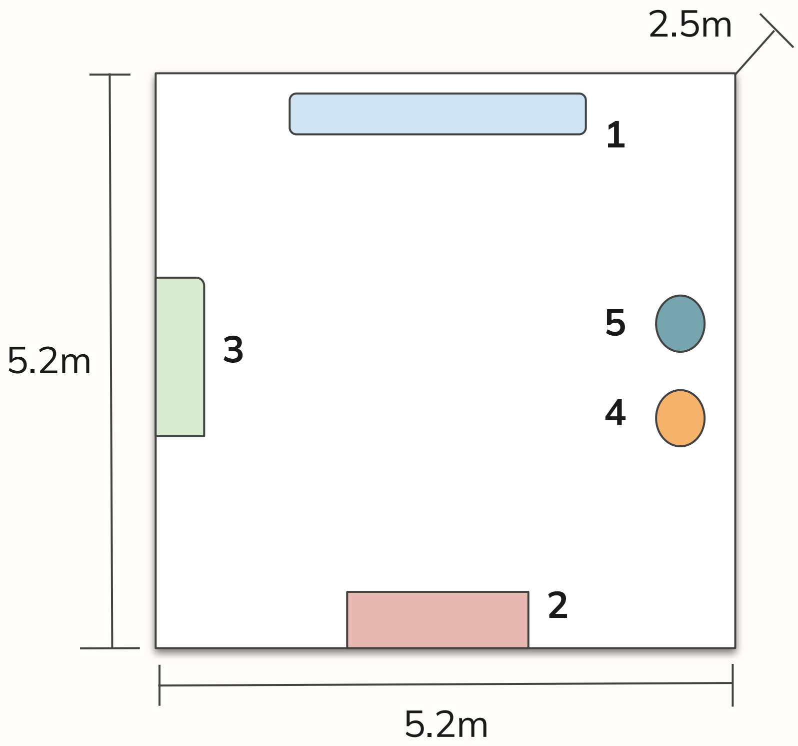

Close windows


Increase Humidifier (83 %)

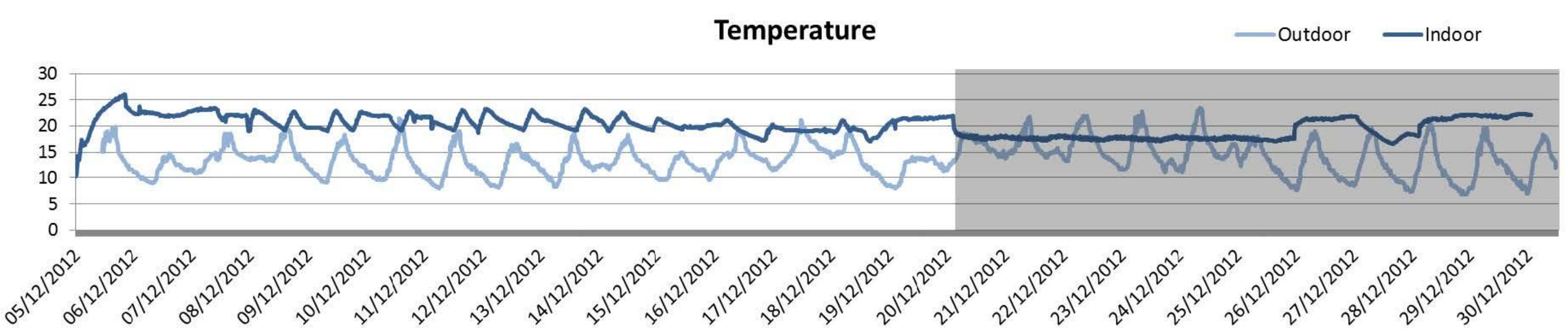

Increase Temperature (65 %)

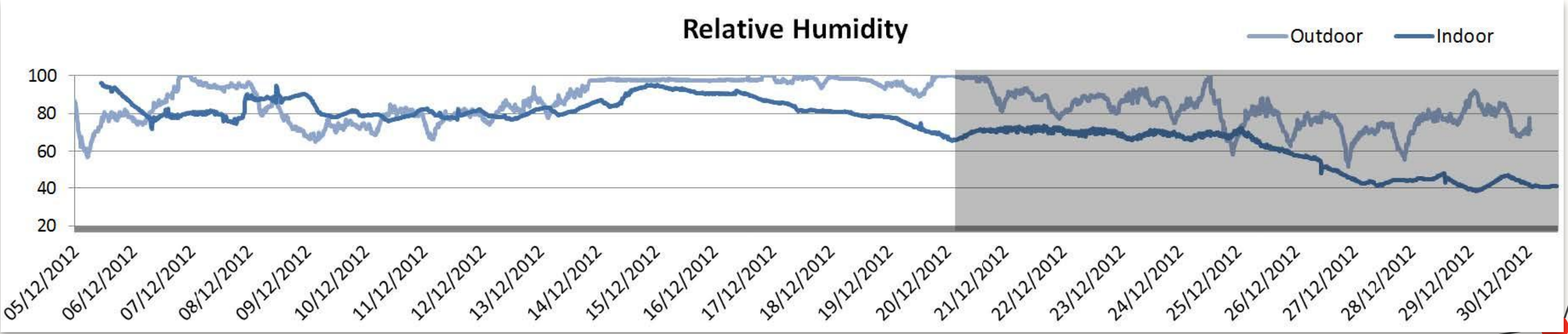
Pruebas en un entorno real

1) Ventana
2) Puerta
3) Sistema HVAC
4) Sensor de temperatura
5) Sensor de humedad
6) Ausencia de muebles y personas*



Resultados y conclusiones





03

Estudios y enfoques alternativos

FLC optimizado con algoritmos genéticos

- **AG** para optimizar los parámetros del controlador.

Applied Intelligence 18, 155–177, 2003

Fuzzy Control of HVAC Systems Optimized by Genetic Algorithms

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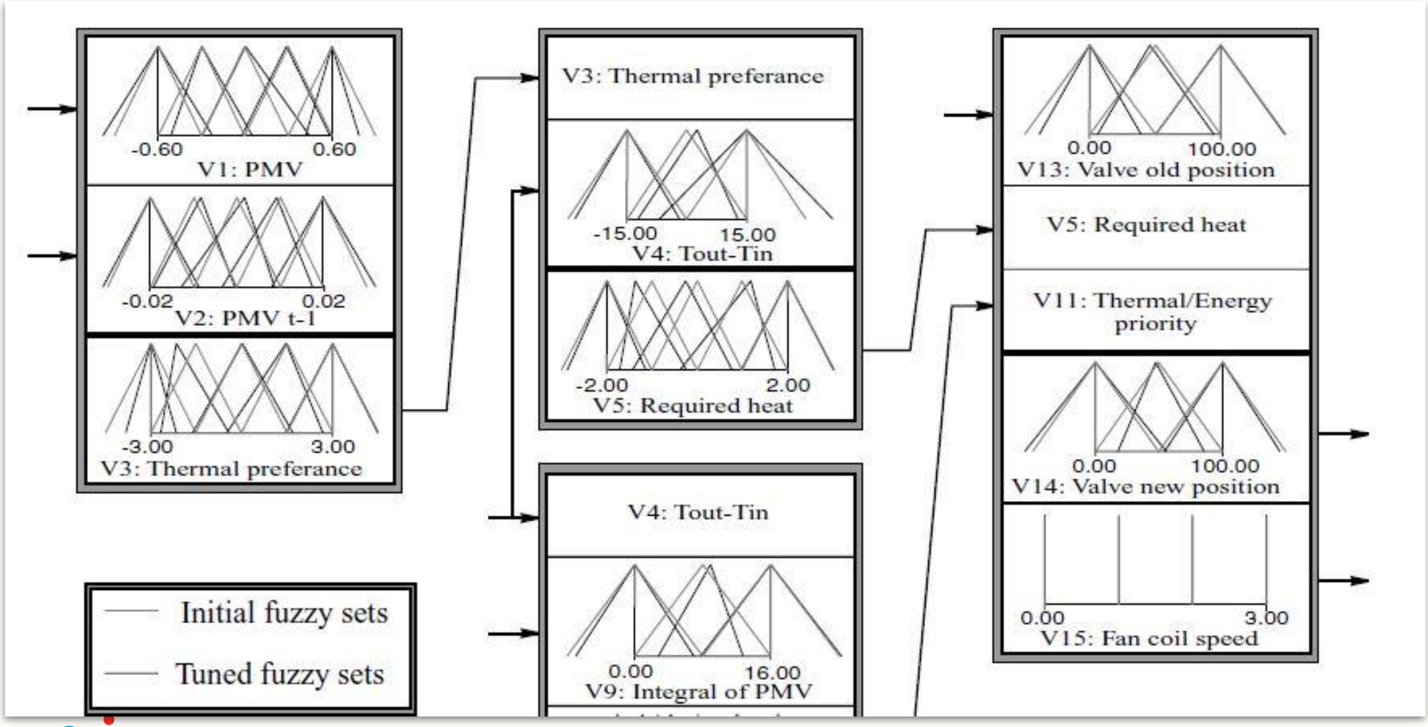
Abstract. This paper presents the use of genetic algorithms to develop smartly tuned fuzzy logic controllers dedicated to the control of heating, ventilating and air conditioning systems concerning energy performance and ...nts. This problem has some specific restrictions that make it very particular and complex ... requirements existing due to the need of considering multiple criteria (which enlarges the ...d to the long computation time models require to assess the accuracy of each individual. ...ions, a genetic tuning strategy considering an efficient multicriteria approach has been ...ogic controllers have been produced and tested in laboratory experiments in order to check ...trol and tuning technique. To do so, accurate models of the controlled buildings (two real test sites) have been provided by experts. Finally, simulations and real experiments were compared determining the effectiveness of the proposed strategy.

Keywords: HVAC systems, fuzzy logic controllers, genetic tuning, multiple criteria

Alcalá, R., Benítez, J. M., Casillas, J., Cordón, O., & Pérez, R. (2003). Fuzzy control of HVAC systems optimized by genetic algorithms. *Applied Intelligence*, *18*, 155-177.

FLC optimizado con algoritmos genéticos



FLC optimizado con algoritmos genéticos

Motor de inferencia:

- *Mamdani Max-Min*

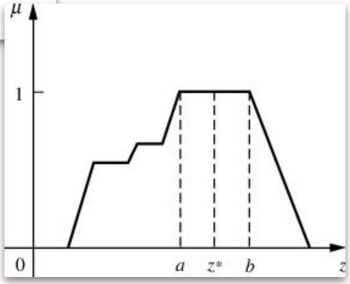
$$\mu_{R_i}(x) = \alpha_{i1} \wedge \alpha_{i2} \wedge \alpha_{i3} \wedge \alpha_{i4} \wedge \alpha_{i5}$$

$$\mu_{Output_i}(x) = max \mu_{R_1}(x), \mu_{R_2}(x), \ldots, \mu_{R_{17}}(x)$$

Defuzzificación*:*

- *Modo B - FITA*
- *MOM (Mean of Maxima)*

$$d_{MM}(C) = \frac{\sum_{z_k \in M} z_k}{|M|}$$



FIS centrado en la evaluación de IEQ

- Qué parámetros constituyen y/o afectan a la IEQ.
- Factor **humano.**

Original Paper

Indoor and Built Environment

Indoor and Built Environment
2018, Vol. 27(10) 1415–1430

DOI: 10.1177/1420326X17728097
journals.sagepub.com/home/ibe
SAGE

Fuzzy inference system for the assessment of indoor environmental quality in a room

Karol Jabłoński and Tomasz Grychowski

Abstract

The aim of the project presented in this article was to design a system which allows for assessment of indoor environmental conditions, with a special consideration regarding the comfort of occupants. The system consists of two microprocessor devices with numerous sensors, as well as a PC application which includes fuzzy inference module. Fuzzy inference algorithm allows for comfort assessment based on data gathered by sensors. It can also help to analyse the efficiency of HVAC systems. The article includes description of the system's functions and selection criteria for sensors taking into ... measurands. Also described in this paper is the construction of knowledge base, based on ... from environmental standards and experts' statements. The constructed system was tested ...ed, to confirm its application in practical comfort assessment and to highlight the advantages ...zy logic in the process of analysing measured parameters and inference, which captures the ...eings process data.

Keywords

Fuzzy logic, Indoor air quality, Environmental comfort, Microcontroller systems, Building control system, Knowledge-based systems, Multisensor system, Measurement system, Fuzzy inference

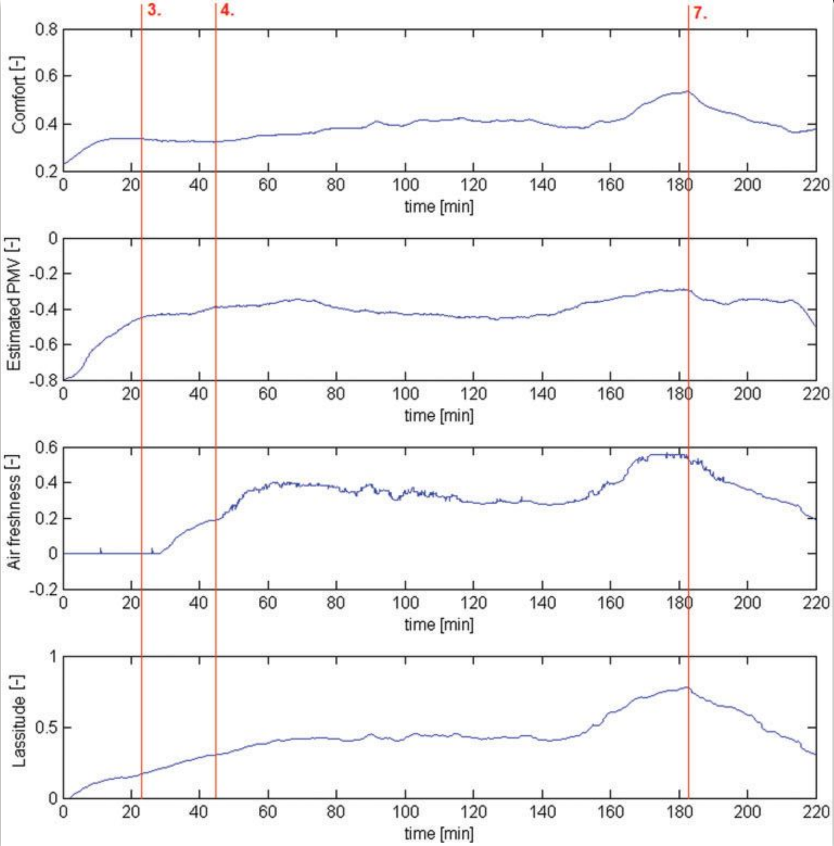
Accepted: 31 July 2017

Jabłoński, K., & Grychowski, T. (2018). Fuzzy inference system for the assessment of indoor environmental quality in a room. *Indoor and Built Environment*, *27*(10), 1415-1430.

FIS centrado en la evaluación de IEQ

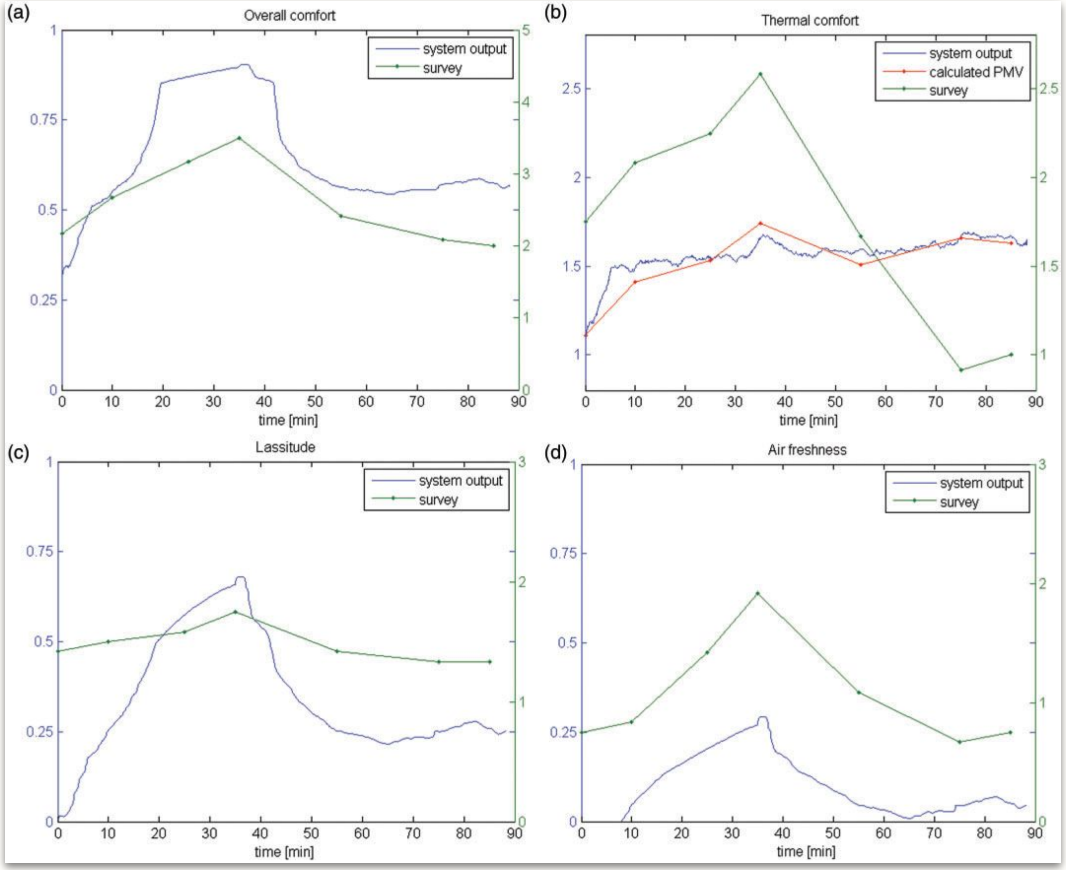
- Pruebas en **entornos reales** y transitados.

N	Time (min)	Event
0	000	Closing windows after venting and start of measurement
1	006	Leaving room by 1 person
2	020	Return of 1 person
3	022	Beginning of a meal
4	045	End of the meal
5	065	Leaving room by 1 person
6	140	Return of 1 person
7	182	Opening trickle vent in window
8	220	End of measurement



FIS centrado en la evaluación de IEQ

- **Encuestas** para la percepción humana del confort.



Comparaciones

- *¿Qué enfoque es el más adecuado?*

Aspecto	Controlador difuso unificado	Controlador con algoritmos genéticos	Sistema de inferencia difusa
Variables controladas	Temperatura, humedad, CO2, iluminación	Temperatura, humedad, CO2, consumo energético...	Temperatura, humedad, CO2, iluminación, ruido, olores...
Enfoque metodológico	Controlador difuso clásico con reglas definidas por expertos. FLC supervisa PIDs para HVAC	Integración de algoritmos genéticos para optimizar automáticamente reglas y funciones de pertenencia	Arquitectura modular con subsistemas independientes. Implementación en LabVIEW
Pruebas y validación	Pruebas en una habitación piloto controlada, comparando con controlador reactivo	Simulaciones y pruebas en múltiples entornos reales bajo diferentes condiciones estacionales	Pruebas en entornos ocupados reales, correlacionando resultados con encuestas de usuarios
Objetivo principal	Optimizar el confort interior y la eficiencia energética en sistemas HVAC	Equilibrio dinámico entre confort y eficiencia energética	Evaluación integral del confort interior basado en múltiples índices
Aplicación recomendada	Escenarios con reglas de confort bien definidas, simplicidad y robustez	Entornos donde se requiere máxima eficiencia energética y optimización precisa	Edificios donde la percepción humana del confort es crítica

04

Conclusiones y posibles mejoras

Consecución de objetivos

Optimizar consumo energético	Mejor eficiencia energética del sist. HVAC	✔
Integrar múltiples sensores	Temperatura interior y exterior, humedad…	✔
Mejorar estabilidad del sistema	Reducir oscilaciones (suaviza cambios)	✔

Posibles mejoras

Flexibilidad y escalabilidad	Ampliar el número de sensores y variables de estudio	🤔
Control predictivo y preventivo	Anticipar cambios y tomar medidas correctivas	🤔
Personalización del confort	Tener en cuenta preferencias y actividades de los usuarios	🤔

Gracias por vuestra atención