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A Modified Approach for Forecasting Relative Humidity in Indoor Premises

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***Abstract* – In order to forecast certain microclimatic parameters in a room, such as relative humidity, it is necessary to collect a large amount of data. For this reason, an electronic system for providing comfortable conditions in a room has been developed, which is based on the becoming largely popular Internet of Things (IoT) technology. On the basis of the obtained data, the future change of the relative humidity in a room can be forecasted, which aims to ensure the health and well-being of its inhabitants. It should be noted that working with large datasets requires more sophisticated methods for prediction, and for this reason, this paper presents results obtained from a modified ordinary differential equation approach for forecasting relative humidity. For the purposes of the study, a program code was developed in Matlab. The resulting predicted relative humidity values are comparable to actual measured values, which would help to improve indoor air quality and provide thermal comfort to occupants.**

***Keywords* – Relative humidity, microclimatic parameters, forecasting, IoT.**

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1. Introduction

Maintaining an appropriate indoor microclimate is essential for the health, comfort and well-being of occupants. The increase in health problems in people who spend more time indoors highlights the need to find solutions to improve microclimate quality control systems. The ability to monitor air quality and thermal comfort in real time would help to detect problems early and take adequate measures to prevent human health problems [1].

In their study, the authors of [2] focused on the microclimatic conditions in a hospital and found that controlling the temperature was the only factor that was considered important for regulating the environment. However, the researchers observed that this approach led to low relative humidity levels, which caused a range of health issues such as nasal irritation, dry nose, runny nose, eye irritation, cough, chest tightness, fatigue, headaches, and skin irritations, all of which are symptoms of Sick Building Syndrome.

Figure 1, [3] provides evidence that low relative humidity is responsible for these health problems.

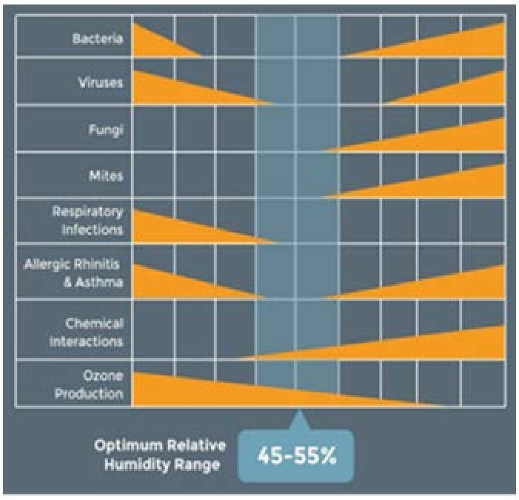

Figure 1. Sick building syndrome

The reason for this is that low humidity levels can impact the rate of water evaporation in the air and disrupt an individual's energy balance, which ultimately affects their thermal comfort. Therefore, it is crucial to consider both temperature and humidity levels when regulating the environment in buildings to avoid Sick Building Syndrome.

Research conducted in a hospital in Thailand [4] demonstrated that dramatic changes in relative humidity could both directly and indirectly cause symptoms of sick building syndrome. It was also found that alterations in relative humidity can intensify chemical air pollution by altering the speed of gas diffusion from building materials and the reaction between water and chemical compounds in the air.

Air conditioning and ventilation typically comprise a majority of a building's operational energy use. Studies have further revealed that those working in a building with inadequate internal environmental quality are likely to suffer from reduced well-being and productivity. Furthermore, buildings with more optimal microclimate quality are typically valued between 3-7% higher when sold or rented, and operating costs are 13-15% lower [5].

Throughout the world, there is a growing trend of promoting energy-efficient and environmentally-friendly technologies through various legislative measures. In line with this, the Energy Performance of Buildings Directive (EPBD) 2002/91/EG was established, and the European standard EN 15232 was created to support it.

This standard provides a framework for evaluating the impact of building automation, control, and management on energy consumption in buildings. By categorizing buildings into corresponding classes (A, B, C, or D) after being equipped with automation and control systems, it becomes possible to estimate potential savings in heat and electricity usage for each type and purpose of the building.

The impact of moisture on heat exchange is largely determined by the humidity levels of specific organs such as the eyes, lips, and respiratory tract. Although the transfer of heat at this level may be relatively small, it is still noticeable. However, at the skin level, the regulation of sweating plays a critical role in producing evaporative heat losses (E) as represented by equation (1) [6]:

$$E = h_e(P_{a_{H2O}} - P_{sk_{H2O}})A_e F_{pcl} \qquad (1)$$

This equation considers several factors including the evaporative surface heat transfer coefficient (h_e), the water vapor pressure in the ambient air (Pa_{H2O}), the water vapor pressure in saturated air at skin temperature (Psk_{H2O}), the evaporative surface area (Ae), and the clothing permeability coefficient (Fpcl).

The evaporative surface area can be expressed as the product of the ratio w=Ae⁄Ad and the area of dry skin (Ad) where Ae=(Ae/Ad)Ad=wAd_e. The ratio w represents skin humidity, which is a physiological index calculated as the ratio of the actual rate of sweating to the maximum rate of sweating. Skin humidity is a critical factor in determining heat loss through evaporation.

In summary, the effect of moisture on heat exchange depends on the humidity levels of various organs and the regulation of sweating at the skin level. Skin humidity plays a crucial role in determining heat loss by evaporation, and is, therefore, an essential factor to consider when evaluating thermal comfort.

The amount of water vapor present in the air affects how humid it feels to occupants in a space. When air is warmer, it can hold more water vapor, making it feel more humid. For instance, at 20°C, one cubic meter of air can hold up to 18 grams of water, while at 25°C, it can hold up to 22 grams of water. To create comfortable conditions for occupants in a room, it is essential to maintain a specific level of humidity. For example, to achieve optimal comfort at 25°C, one cubic meter of air should contain around 12-13 grams of water, which corresponds to about 60% relative humidity. When the temperature in a room is 21°C and the relative humidity is only 10%, it feels like the temperature is lower, around 18°C.

Conversely, a relative humidity of 70% can make the temperature feel higher, around 24°C. Maintaining an optimal relative humidity level is crucial for creating a comfortable and healthy indoor environment. According to various standards, regulations, and scientific studies, the ideal range for relative humidity is between 40-60%. This range is associated with a reduced risk of health problems, such as respiratory infections, as well as improved comfort and productivity for occupants in the space.

The focus of this paper is to forecast the relative humidity in a room, with the intention of providing comfortable conditions and safeguarding against unhealthy conditions for its occupants.

2. Theoretical Justification

The modified approach was used to forecast the temperature in a room for 06.01.2018. Precisely for this reason, the object of prediction is the relative humidity for the same date, since the obtained temperature predictions at six geometrically arranged points in the room demonstrate that the forecasted results closely align with the actual measured temperatures [7].

Various methods can be used to predict parameters, as detailed in [8], [9], [10]. Although each methodology has its advantages and limitations, the studies in references [11], [12] provide valuable insights into different approaches to parameter estimation. It is important to select the appropriate method to meet the specific requirements and characteristics of the problem being studied. It is suggested to arrange the moments in ascending chronological order and take into account the temperature/humidity readings at these moments in this sequence:

$$\tau_0, \tau_2, \dots, \tau_n. \text{ and } t_0, t_2, \dots, t_n \qquad (2)$$

Where: $\tau_0, \tau_2, \dots, \tau_n$ – time, $t_0, t_2, \dots, t_n$ – temperature / relative humidity

Comparison of this time series with an ordinary differential equation of the form [13, 14]:

$$t'(\tau) = g(\tau, t),\ t(\tau_0) = t_0, \qquad (3)$$

This simple differential equation approximates the time series values at specific moments in time, where the function $g\ (\tau, t)$ being largely arbitrary. A more general variant of $g\ (\tau, t)$ is proposed in [13], taking the form:

$$g(\tau, t) = \left(\sum_{i=0}^{M} a_i \tau^i\right) t + b_0 +$$

$$+ \sum_{j=1}^{N} b_j \sin\left(\frac{2\pi j}{\theta} t + c_j\right) \qquad (4)$$

Using expression (4), equation (3) is transformed into the following form:

$$t'(\tau) = \left(\sum_{i=0}^{M} a_i \tau^i\right) t + b_0 +$$

$$+ \sum_{j=1}^{N} b_j \sin\left(\frac{2\pi j}{\theta} t + c_j\right) \qquad (5)$$

The values of the coefficients in equation (6) that need to be determined are:

$$a_0, a_1, \dots a_M, b_0, b_1, \dots, b_N, c_1, c_2, .., c_N, \theta\ . \qquad (6)$$

The number of coefficients is $2N + M + 3$. The numerical methods that can be used are single-step, multi-step as well as explicit and implicit methods (7) to find these coefficients if the number of measured temperatures / relative humidity and is $n \geq 2N + M + 4$, which is assumed to always be fulfilled.

$$\frac{(t_{k+1} - t_k)}{h} = Z(g) \text{ or } t_{k+1} = t_k + hZ(g) \qquad (7)$$

Where $Z(g)$ represents the implementation of a particular numerical method.

The LSM can also be applied with a weighted function, which assigns a value to each element. The most recent values are assigned a higher weight relative to the older ones. This means that the weight function is monotonically non-decreasing.

A power function, with degree α, is chosen as the weight function. When α>1 is chosen, the weight function is convex. When α<1, the weight function is concave, and when α=1, it is linear [13], [14], [15].

3. Results

The forecasted figures and "marginal errors" for specific *M*, *N*, and α parameter values are showcased in a table format. From the data procured in Table 1 and Table 2, after weighting averages inversely relative to the value "end errors", a predicted humidity value of Pr=47.9224% was derived for a particular geometric point.

Table 1. Forecasted values of relative humidity at parameters M, N and α

Weight function, at α=1.25				
Values of M/N	***N=2***	***N=3***	***N=4***	***N=5***
M=0	47.89221	47.80871	48.03520	48.82210
M=1	47.92802	47.96803	47.97029	47.96898
M=2	46.47309	47.33924	47.47384	47.50070
M=3	45.88665	45.38513	47.32596	49.19450

Table 2. "End Errors" forecasted values of relative humidity at parameters M, N and α

Weight function, at α=1.25				
Values of M/N	***N=2***	***N=3***	***N=4***	***N=5***
M=0	0.0423	0.1122	0.0448	0.2160
M=1	0.0536	0.0372	0.0409	0.0403
M=2	1.2604	0.3836	0.4815	0.3304
M=3	1.5222	1.8354	0.3490	1.8619

Table 3. Forecasted values of relative humidity at parameters M, N and α

Weight function, at α=1				
Values of M/N	***N=2***	***N=3***	***N=4***	***N=5***
M=0	47.97807	48.20379	47.91932	47.59147
M=1	47.99142	47.98403	48.00347	47.97238
M=2	35.81173	46.98884	47.53256	47.40791
M=3	-19.8758	46.37048	47.57570	47.40683

Table 4. "End Errors" forecasted values of relative humidity at parameters M, N and α

Weight function, at α=1				
Values of M/N	***N=2***	***N=3***	***N=4***	***N=5***
M=0	0.3095	0.2332	0.0319	0.4353
M=1	0.0350	0.0463	0.0389	0.0422
M=2	0.9861	0.8379	0.5119	1.0592
M=3	2.9274	1.0669	0.7007	1.0391

Table 5. Forecasted values of relative humidity at parameters M, N and α

Weight function, at α=0.75				
Values of M/N	***N=2***	***N=3***	***N=4***	***N=5***
M=0	46.59276	47.76488	47.90893	48.01785
M=1	47.84635	47.99071	47.98944	47.97617
M=2	46.34518	47.41502	47.86433	48.09331
M=3	51.80924	47.49903	49.21892	50.04031

Table 6. "End Errors" forecasted values of relative humidity at parameters M, N and α

Weight function, at α=0.75				
Values of M/N	***N=2***	***N=3***	***N=4***	***N=5***
M=0	0.2458	0.2137	0.0634	0.0913
M=1	0.0490	0.0500	0.0422	0.0449
M=2	2.3957	0.61659	0.1396	1.0230
M=3	12.982	4.5138	1.3157	2.4677

When processing the results of Table 3 and Table 4 for the forecasted value of humidity, 30 minutes later a forecasted value of Pr= 47.7007% was obtained. From Table 5 and Table 6 an estimated value for humidity Pr= 47.9044% was obtained.

Figures 2 - 7 depict the proportion of the predicted relative humidity compared to the actual recorded humidity for the specified point, as well as the ultimate forecasted humidity for the same point.

The graphs show that the forecasted relative humidity values at six points in a room match the real relative humidity measurements taken by the electronic system designed to ensure a comfortable environment.

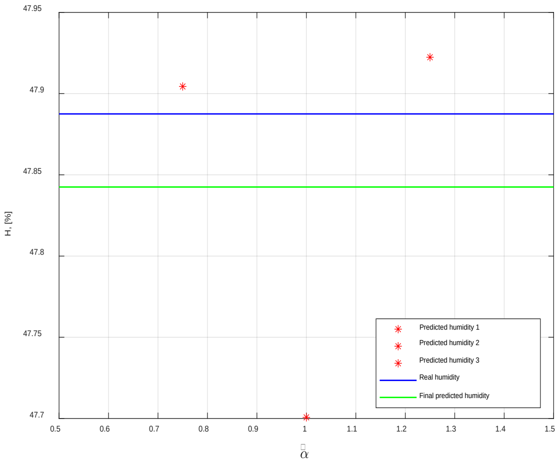

Figure 2. Forecasted, final forecasted and real relative humidity at point 1

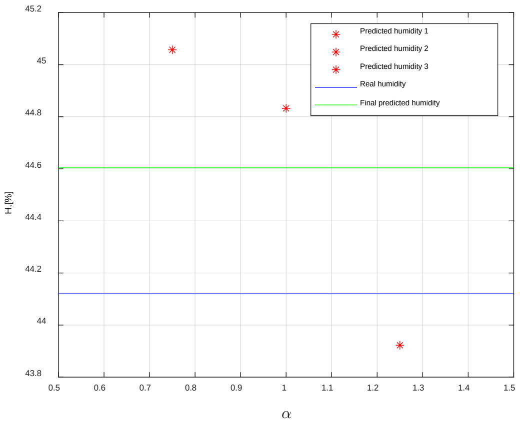

Figure 3. Forecasted, final forecasted and real relative humidity at point 2

The calculated errors demonstrate that the predictions are similar to the actual readings. This modified numerical differential equation technique is an effective way of forecasting microclimatic parameters so that rooms can be kept in comfortable conditions. All algorithms are implemented in the Matlab programming environment, as this environment has its own programming language and a diverse set of functions implementing the least squares method (LSM).

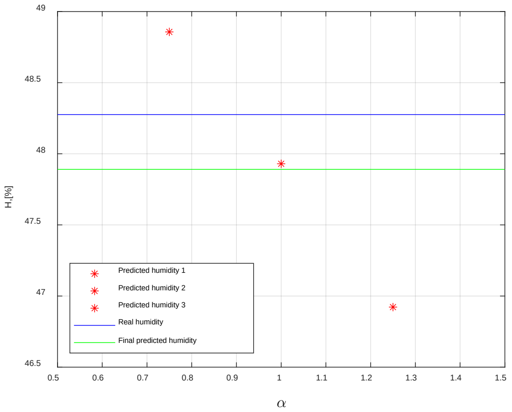

Figure 4. Forecasted, final forecasted and real relative humidity at point 3

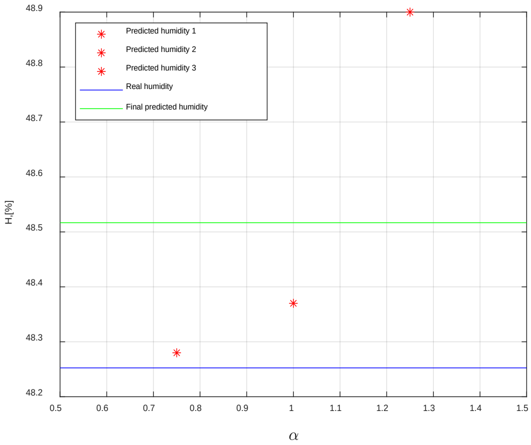

Figure 5. Forecasted, final forecasted and real relative humidity at point 4

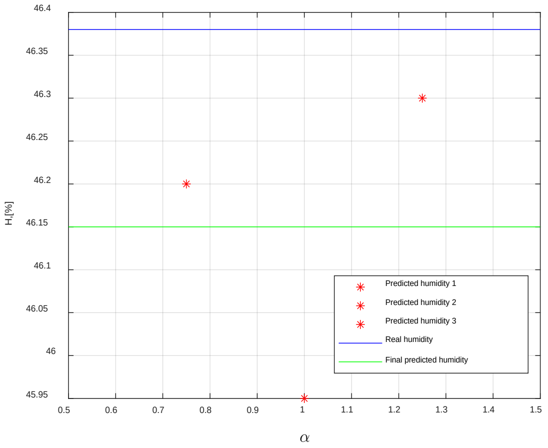

Figure 6. Forecasted, final forecasted and real relative humidity at point 5

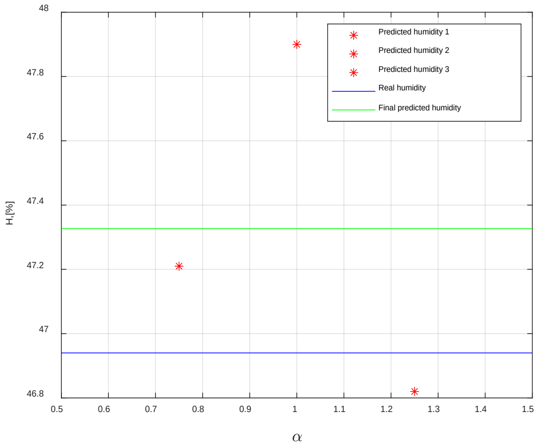

Figure 7. Forecasted, final forecasted and real relative humidity at point 6

The final forecasted values and calculated relative errors, compared to the actual measured relative humidity in the geometric points from 2 to 6, are given in Table 7.

Table 7. Final forecasted values and calculated relative errors, compared to the actual measured relative humidity

Points	Forecasted relative humidity, %	Relative error, %
2	*44.613*	*1.0879*
3	*47.911*	*0.8078*
4	*48.517*	*0.5596*
5	*46.150*	*0.4959*
6	*47.327*	*0.8306*

4. Conclusion

In recent years, IoT has undergone an evolution that is currently finding applications in various fields. For the future development of IoT technology, predictive models will play a key role.

The implementation of predictive models would help to utilize the developed IoT devices and systems more efficiently, thus smart automation can be achieved. This would inevitably enable better resource planning, optimization of energy efficiency and intelligent decision-making through which improvements in productivity, convenience and efficiency of various areas of life and business can be achieved.

The change in relative humidity in a room affects the perception of the microclimate by its inhabitants. Temperature and relative humidity are part of the microclimatic parameters that are used to assess air quality and thermal comfort conditions, and their maintenance in certain ranges would lead to the reduction of energy consumption.

The results obtained from the presented modified approach for the prediction of relative humidity show that the largest relative error is just over 1% and the smallest is approximately 0.5%. These results give reason to conclude that the obtained forecasted relative humidity is comparable to the actual measurement.

The revised methodology was primarily crafted empirically, utilizing Matlab, making it particularly suitable for predicting various microclimatic parameters, aiming to ensure comfortable conditions in diverse rooms.

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References:

[1]. Zaharieva, S., Stoev, I., Borodzhieva, A., & Petrova, T. (2023). Assessment of Gross Errors and Uniformity of Readings of Sensors for Relative Humidity Measurement in Indoor Premises. *22nd International Symposium INFOTEH-JAHORINA (INFOTEH)*, Jahorina, RS, East Sarajevo, 1-5. Doi: 10.1109/INFOTEH57020.2023.10094132

[2]. Hwang, R. L., Lin, T. P., Cheng, M. J., & Chien, J. H. (2007). Patient thermal comfort requirement for hospital environments in Taiwan. *Building and environment*, *42*(8), 2980-2987.

[3]. Arundel, A. V., Sterling, E. M., Biggin, J. H., & Sterling, T. D. (1986). Indirect health effects of relative humidity in indoor environments. *Environmental health perspectives*, *65*, 351-361.

[4]. Sookchaiya, T., Monyakul, V., & Thepa, S. (2008). A study and development of temperature and relative humidity control system in hospital buildings in Thailand. *EDU-COM 2008 International Conference, Edith Cowan University*, Perth Western Australia.

[5]. Rahman, M. M. G. M. A., Kasim A. C. & Raid M. M. (2015). Impacts of Indoor Environmental Quality (IEQ) Elements on Residential Property Market: A Review. *Jurnal Teknologi*, *73*(5), 99-106.

[6]. Candas V. (2000) Techniques de l'Ingénieur, traité Génie énergétique. *Doc. BE,* 9, 085.

[7]. Zaharieva, S., Georgiev, I., & Stoev, I. (2021). Modified Approach for Predicting the Temperature in Residential Premises. *29th Telecommunications forum TELFOR*, 1-4,
Doi: 10.1109/TELFOR52709.2021.9653330

[8]. Zaharieva, S. L., Georgiev, I. R., Borodzhieva, A. N., & Mutkov, V. A. (2021). Classical Approach for Forecasting Temperature in Residential Premises. *20th International Symposium INFOTEH-JAHORINA*, 1-6,
Doi: 10.1109/INFOTEH51037.2021.9400519

[9]. Zaharieva, S. L., Georgiev, R. I., Mutkov, V. A. & Neikov, Y. B. (2021). Arima Approach for Forecasting Temperature in a Residential Premises. *20th International Symposium INFOTEH-JAHORINA*, 1-5,
Doi: 10.1109/INFOTEH51037.2021.9400674.

[10]. Georgiev, S. G. & Idirizov, B. B. (2020). Predictive analysis and evaluation of the Bulgarian economy's most significant indicators. *Proc. University of Ruse and Union of Scientists*, *59.*

[11]. Georgiev, S. G. & Idirizov, B. B. (2021). TSA & DL predictive modelling of Bulgarian financial and economic indices as a part of EU. In *AIP Conf. Proc*.

[12]. Georgiev, S. G., & Idirizov, B. B. (2022). Jump-diffusion modelling of the gold and crude oil futures prices and predictive analysis of their economic impact. In *AIP Conf. Proc.*

[13]. Xue, M., & Lai, C. H. (2018). From time series analysis to a modified ordinary differential equation. *Journal of Algorithms & Computational Technology*, *12*(2), 85-90.
Doi: 10.1177/1748301817751480

[14]. Lascsáková, M. (2018). The Analysis of the Numerical Price Forecasting Success Considering the Modification of the Initial Condition Value by the Commodity Stock Exchanges. *Acta Mechanica Slovaca 22*(3), 12–19.

[15]. Georgiev, I., Centeno, V., Mihova, V., & Pavlov, V. (2022). A Modified Ordinary Differential Equation Approach in Price Forecasting. *AIP Publishing*, *2459*, 030008-1–030008-7. Doi: 10.1063/5.0083542