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Performance Comparison of Indoor Humidity Modeling: A Novel Hybrid Model vs. the Simplified Calculation Model by EN ISO 13788

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Abstract. Ventilation is essential for maintaining indoor air quality and human comfort, particularly in buildings with mechanical ventilation systems. However, modeling the complex relationship between ventilation rate and measurable indoor environmental parameters, such as humidity, poses significant challenges. Current methods for modeling this relationship are often inefficient. For example, data-driven models frequently require sufficient information on ventilation, which may not be available for constant air volume (CAV) systems. On the other hand, simulation programs can be time-consuming and require expert engagement. In this study, we present two simplified calculation models, including a hybrid model developed by the authors, and a well-known model introduced by EN ISO 13788. We compare their performance in evaluating the impact of ventilation rate on indoor humidity. The hybrid model uses a novel analytical method to upgrade a single-input regression model (which considers only outdoor humidity as input) to enable the evaluation of indoor humidity based on both outdoor humidity and ventilation rate. We used the commercial TRNSYS program to model two scenarios: increasing the reference ventilation rate and decreasing the reference ventilation rate. The results showed that both models matched TRNSYS simulations with satisfactory accuracies, but the hybrid model demonstrated superior performance to the EN ISO 13788 model in both scenarios. The hybrid model's higher accuracy and hybrid features make it better suited for big data analysis and field studies.

1. Introduction

Ventilation plays a crucial role in controlling indoor air quality (IAQ) and human thermal comfort, and indoor humidity is an essential indicator of IAQ [1]. Mechanical ventilation is the most significant factor affecting indoor humidity [2]. State-of-the-art methods typically use physics-based models [3-6] to investigate the nonlinear relationship between ventilation rate and indoor humidity. However, certain factors, particularly the moisture buffering effects of building materials, can be challenging to account for in physical models [7]. Data-driven models face challenges in collecting the necessary data. To model ventilation performance using artificial neural networks, researchers collected data on IAQ, temperature, humidity, wind speed, and window and door characteristics in a residential building [8].

In our previous research, we introduced a novel hybrid model that utilizes only measured indoor and outdoor humidity data to effectively model the influence of outdoor humidity, ventilation rate, and internal moisture production rate on indoor humidity in mechanically ventilated buildings/spaces [9]. This approach hybridizes a novel analytical method with a simple linear regression model, making it suitable for all types of ventilation systems, including constant volume ventilation (CAV). In this study, we aim to compare the performance of the novel hybrid model [9] with the simplified calculation method proposed in EN ISO 13788 [10] for modeling the impact of ventilation on indoor humidity. This comparison was lacking in our original work [9] and is crucial from a literature perspective. This work is an extension of our previous research [9].

2. Methodology

The novel hybrid model developed in [9] aims to upgrade the following model to model the impact of outdoor humidity, ventilation rate ($\dot{V}$, m^3/h) and internal moisture production rate on indoor humidity:

$$v_i = av_e + b \tag{1}$$

where v_i and v_e are the indoor and outdoor humidity in [g/m^3]. The model coefficients, a and b, are determined based on the measured indoor and outdoor humidity. In this study, daily averaged values were used for the sampling interval, although shorter intervals may be possible depending on internal moisture production rates and other influential factors. While this linear model (Equation (1)) has been widely reported and studied in [6, 8-9, 11-12], it only has one input (i.e., v_e), and assumes a fixed ventilation rate, which is the averaged ventilation rate over the measurement duration. In this paper, we refer to this fixed ventilation rate as the reference ventilation rate ($\dot{V}_{reference}$). In order to quantify the internal moisture change (Δm) induced by varying the reference ventilation rate while keeping the outdoor humidity constant, a novel theory was developed in [9]. According to this theory, only the change in the outdoor absolute humidity (AH) contributes to Δm. Therefore, the change in the reference ventilation rate does not affect Δm, and the linear relationship between indoor and outdoor humidity given by Equation (1) holds [9]. To account for Δm, the true outdoor humidity (i.e., v_e) in Equation (1) is replaced by a fictitious outdoor humidity called "pseudo-outdoor humidity" in this paper, which includes both the true outdoor humidity and a fake humidity term accounting for Δm.

For a fixed reference ventilation rate $\dot{V}_{reference}$, increasing the reference ventilation rate *l* times is equivalent to drawing in outdoor humidity into the space *l-1* times, which also results in *l-1* times indoor humidity being drawn out of the space. Further details can be found in [9]. Based on mathematical calculations, the pseudo-outdoor humidity can be calculated as $v_e + (l-1)v_e - (l-1)v_i$. By substituting the pseudo-outdoor humidity for v_e in Equation (1), we obtain:

$$v_\mathrm{i} = \frac{la}{(1+a(l-1))}\, v_\mathrm{e} + \frac{b}{(1+a(l-1))} \tag{2}$$

where *l* can be less than 1. The adoption of pseudo-outdoor humidity is a novel concept introduced in our previous research [9], which can also be utilized to incorporate internal moisture production rate as an additional input to Equation (1). However, in this paper, we will solely focus on the case of ventilation rate as an additional input.

EN ISO 13788 [10] introduces a simplified steady-state model to evaluate the influence of outdoor humidity, ventilation rate, and internal moisture production rate on indoor humidity. The model is expressed as:

$$v_i = v_e + \frac{G}{1000\dot{V}} \tag{3}$$

where $\dot{V}$ is ventilation rate (m^3/h), and G is internal moisture production rate (kg/h). It should be noted that the EN ISO 13788 model, represented by Equation (3), does not take into account the hygroscopic moisture capacity of building materials, i.e., moisture buffering effects. In this work, we aim to compare the performance of two models, namely Equation (2) and Equation (3), in the case of varying ventilation rates.

3. Case studies

A bedroom in a single-story and single-family house (Figure 1) was selected as a case study for the two models, Equation (2) and Equation (3). Synthetic data, including indoor humidity, at 10-minute intervals were generated using the commercial software TRNSYS 18 and its effective capacitance humidity module [13]. Table 1 lists the important parameters for the TRNSYS model.

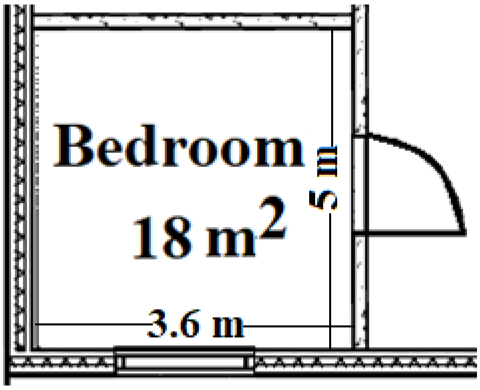

Figure 1. Bedroom with 2.6 m ceiling height.

Table 1. Information about the bedroom in the TRNSYS model

Element	Property	U-value (W/m^{2}K)
External wall	13 mm gypsum board + 540 mm mineral wool (wooden framed), 9 mm wind shield board	0.08
Roof	13 mm gypsum board + 650 mm mineral wool (wooden framed) + 10 mm waterproof sheet	0.07
Base floor	14 mm parquet + 80 mm concrete +365 mm EPS-insulation + 1000 mm ground layer	0.1
Internal wall	13mm gypsum board + 50 mm air gap (wooden framed) + 13 mm gypsum board	2.42
Windows	g-value: 0.26	0.80
Ventilation system		
Mechanical supply and exhaust ventilation system	Constant Air Volume system (100% outdoor air system)	
Operation schedule	Monday–Sunday 00:00–24:00	
Supply and exhaust air flow rate	25.92 m^3/h	
Setpoint		
21 ˚C for heating and 27 ˚C for cooling		
Internal moisture production rate		
0.162 kg/h for 22:00–7:00 (occupied period), Monday–Sunday		

One-year weather data from Changchun, a city in Northern China, were extracted from an open-source dataset as it is similar to the Nordic climate. Based on the generated indoor humidity data for the bedroom, values of a and b were obtained as 0.9897 and 2.1105, respectively, for Equation (2). Furthermore, we assumed an ideal situation for the EN ISO 13788 model (Equation (3)), where the true internal moisture production rate (i.e., 0.162 kg/h for 22:00–7:00, Monday–Sunday) and ventilation rate (i.e., 25.92 m^3/h) were known. Then, Equations (2) and (3) were used to estimate indoor humidity for two scenarios:

Scenario 1 (ventilation rate is increased by two times, i.e., *l*=2 in Equation (2))

Scenario 2 (ventilation rate is reduced by 50%, i.e., *l*=0.5 in Equation (2)).

We utilized commonly used measures, including root mean square error (RMSE), mean absolute percentage error (MAPE), and coefficient of determination (R2), to assess the performance of Equations (2) and (3) for model fit.

$$RMSE = \sqrt{\frac{\sum_{k=1}^{N}(\hat{y}(k)-y(k))^2}{N}} \tag{4}$$

$$MAPE(\%) = \frac{100\sum_{k=1}^{N}\frac{|\hat{y}(k)-y(k)|}{y(k)}}{N} \tag{5}$$

$$R^2 = 1 - \frac{\sum_{k=1}^{N}(\hat{y}(k)-y(k))^2}{\sum_{k=1}^{N}(\hat{y}(k)-\bar{y}(k))^2} \tag{6}$$

where $\hat{y}(k)$ is the simulations by Equation (2) or Equation (3), $y(k)$ is the TRNSYS generation, and $\bar{y}(k)$ presents the mean of $y(k)$

4. Results and discussion

Figure 2 shows the comparisons of the simulations by the commercial software TRNSYS and by Equations (2) and (3) in Scenario 1 and Scenario 2. Table 2 displays their performance.

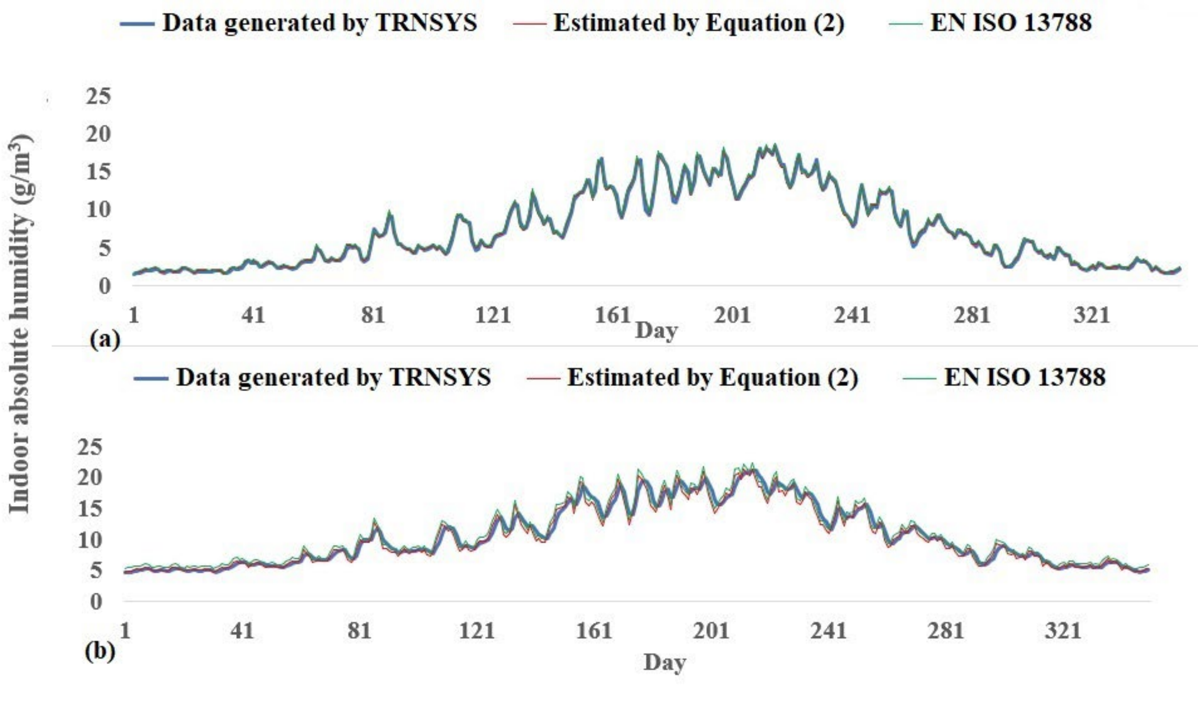

Figure 2. Comparison of simulations by TRNSYS and by Equation (2) and Equation (3) (i.e., EN ISO 13788). The time step is day: (a) Scenario 1 and (b) Scenario 2.

Table 2. The performance of the two models: Equation (2) (the hybrid model by the authors) and the EN ISO 13788 model (Equation (3) (the time step is day)

		RMSE	**MAPE (%)**	**R^2**
Equation (2)	Scenario 1	0.38	4.63	0.99
	Scenario 2	0.88	5.75	0.97
EN ISO 13788	Scenario 1	0.44	6.7	0.99
	Scenario 2	1	8.23	0.97

The results of both models were satisfactory. However, the hybrid model (Equation (2)) outperformed the EN ISO 13788 model (Equation (3)) for both scenarios, even though the true internal moisture production rate was assumed to be known for the EN ISO 13788 model. In practice, it is difficult to obtain the true internal moisture production rate due to moisture buffering effects. For the hybrid model, over 85% of the simulations have an MAPE of less than 10% (for both scenarios combined). This figure is 69% for the EN ISO 13788. There are two factors that contribute to the greater accuracy of the hybrid model. Firstly, the hybrid model is based on a data-driven model (Equation (1)) which generally yields more precise results than a physical model like the EN ISO 13788 model. Secondly, the hybrid model takes moisture buffering effects into consideration, whereas the EN ISO 13788 model neglects this aspect. Equation (1) includes two parameters with physical interpretations: av_e and b. Specifically, av_e represents the portion of indoor humidity that originates from outdoor humidity, while b represents the portion of indoor humidity that arises from internal moisture sources and sinks, such as occupants, furniture, and building materials. The moisture buffering effects of building materials, which involve the uptake and release of moisture, are also included in b. Both models showed reduced performance in Scenario 2 compared to Scenario 1, but the EN ISO 13788 model exhibited a greater decline. The hybrid model, for example, decreased by about 1.12% (=5.75%-4.53%) in terms of MAPE, whereas the EN ISO 13788 model decreased by 1.53% (=8.23%-6.7%). It is a well-established fact that moisture buffering effects are more pronounced at lower ventilation rates [6].

The EN ISO 13788 model is a physical model that operates under steady-state conditions. To model indoor humidity based on outdoor humidity and ventilation rate, internal moisture production rate information is required. Conversely, the hybrid model only requires the measurement of indoor and outdoor humidity to determine the two parameters, a and b in Equation (2). As previously discussed, the values of a and b implicitly incorporate information about internal moisture production rate and moisture buffering effects. This characteristic makes the hybrid model highly convenient for use, especially in big data analysis and field studies.

5. Conclusions

This study compared two simplified indoor humidity models, namely the hybrid model by the authors in [9] and the EN ISO 13788 model in [10], for modeling the influence of ventilation rate on indoor humidity in two scenarios: increased and decreased reference ventilation rate. The hybrid model outperformed the EN ISO 13788 model in terms of accuracy for both scenarios.

In section 4, we discussed the advantages and limitations of both models. The EN ISO 13788 model requires information about internal moisture production rate and ignores moisture buffering effects. On the other hand, the hybrid model does not have these limitations, but it is a regression model, meaning its accuracy is dependent on the quality of measurements. However, with the increasing use of IoT (Internet of Things) sensors, long-term measurements are readily available, making the proposed methodology more suitable for this trend and producing higher accuracy than the EN ISO 13788 model.

One area of focus for future work is enhancing the quality of the hybrid model. One potential avenue for improvement is to employ pseudo-outdoor humidity, rather than actual outdoor humidity, in the construction of Equation (2) in order to increase the R^2 value.

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