Assessment of in-situ aging and maintenance impact on Relative Humidity-Controlled Mechanical Extract Ventilation (RH-MEV) Systems: A Case study in multi-family social housing buildings

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ABSTRACT

This paper presents a comprehensive evaluation of Relative Humidity-Controlled Mechanical Extract Ventilation (RH-MEV) systems installed in multi-family social housing buildings, focusing on the assessment of in-situ aging and the impact of maintenance on the performance of the system. Building upon the Performance 2 project conducted from 2020 to 2024, which evaluated the durability and performance of RH-MEV systems over a 15-year period, this study delves deeper into the longevity and maintenance aspects of these systems. The research investigates the performance of provisory products, both inlet and extract units, after 1.25 years of operation under real conditions. Provisory units were installed and operate during the performance characterization in the lab after 13 years of in-situ operation of the real products between Performance 1 and Performance 2 projects. The performance of provisory products after 1.25 years of in-situ operation is compared to the manufacturer's specifications, highlighting the impact of factors such as aging and maintenance. Furthermore, the study examines the influence of maintenance on the performance of the system by comparing the results of the characterization of the provisory ventilation units as collected after 1.25 years of operation (dirty) and after cleaning (as could be done by the occupant), against the original manufacturer tolerances. The findings reveal significant variations in cleanliness among different types of ventilation units. Kitchen exhaust units were found to be the most heavily soiled, with oily residues, while some bathroom and shower room exhaust units appeared more encrusted with a mixture of dust and fibres. Despite these cleanliness challenges, the hygroscopic function of the units remains intact, allowing them to modulate ventilation rates based on humidity levels. However, airflow limitations were observed at low humidity levels in both kitchen and bathroom/shower room exhaust units. In contrast, air inlet units were generally cleaner and exhibited a positive response to changes in humidity levels, confirming their functionality in modulating airflow based on indoor conditions. Overall, most of the ventilation units met fabrication specifications, ensuring optimal operation despite the state of cleanliness, and guarantying the Indoor Air Quality (IAQ) in the housing buildings after 1.25 years. This analysis provides insights into the need of maintenance procedures in sustaining or enhancing the performance of RH-MEV systems over time. The paper discusses the implications of in-situ aging and maintenance on RH-MEV system performance, providing valuable insights for system designers, manufacturers, and building managers. By understanding how these factors affect long-term performance, stakeholders can make informed decisions regarding system design, maintenance schedules, and IAQ management strategies, ultimately enhancing IAQ and occupant comfort in multi-family social housing buildings.

KEYWORDS

Smart ventilation, residential ventilation, IAQ, energy efficiency, durability

1 INTRODUCTION

In recent years, the focus on Indoor Air Quality (IAQ) in multi-family social housing buildings has intensified, driven by a growing understanding of its impact on occupants' health and well-being. In Europe, regulatory directives have underscored the importance of eco-design requirements and energy labelling for residential ventilation units, including the widespread adoption of low-pressure systems, demand-controlled ventilation (DCV) systems, and balanced heat recovery systems to ensure both energy efficiency and IAQ optimization [1]. Smart ventilation, particularly Relative Humidity-Controlled Mechanical Extract Ventilation (RH-MEV) systems, has emerged as a promising solution to address the dual challenges of energy consumption and IAQ management in residential buildings. These systems employ sophisticated controls to adjust ventilation rates based on real-time indicators such as humidity levels, ensuring optimal IAQ while minimizing energy usage. The adoption of such systems is increasingly supported by regulatory frameworks in various European countries, reflecting a broader recognition of their potential benefits [2], [3], [4].

Smart ventilation, using RH-MEV, was studied during the "Performance 1" project which included a large-scale monitoring on thirty-one new occupied apartments in two buildings extended from 2007 to 2009, respectively situated in Paris and Villeurbanne (near Lyon) and equipped with RH-MEV [5]. In each dwelling of both buildings of this study, the Air Terminal Devices – ATD (exhaust air ATDs and air inlet) were installed during the construction of the buildings more than 15 years ago. In Performance 2 project, and to evaluate the functioning of these ATDs after aging, these units were collected to characterize their current hygroscopic performances in the laboratory [6], [7]. During this period, non-instrumented new products temporarily replaced the collected ATDs to maintain building ventilation during the laboratory tests.

The research investigates provisory units, both inlet and extract units, installed for 1.25 years in Paris under real conditions during the characterization of actual products characterized in the laboratory after 13 years of in-situ operation (Figure 1).

A. Relatively clean ATD B. Dirty ATD

Figure 1. Example of collected Kitchen extract units.

Comparisons are made between the performance of provisory products after 1.25 years of in-situ operation and the specifications of the manufacturer. Furthermore, the study compares the results of exhaust units and air inlets as collected (more or less dirty) and after cleaning (as it could be done by the occupant) to the original manufacturer tolerances. This analysis provides insights into the efficacy of maintenance procedures in sustaining or enhancing the performance of RH-MEV systems over time. The paper discusses the implications of in-situ aging and maintenance on RH-MEV system performance, providing valuable insights for system designers, manufacturers, and building managers. By understanding how these factors affect long-term performance, stakeholders can make informed decisions regarding system design, maintenance schedules, and IAQ management strategies, ultimately enhancing Indoor IAQ and occupant comfort in multi-family social housing buildings.

2 METHODOLOGY

Tests were conducted following the methodology used for the characterization of the instrumented ATDs [REF]. This characterization was made in two separate rooms for exhaust units and air inlets, each controlled for temperature and humidity by Air Handling Units (AHUs). Exhaust units were connected to a test bench comprising a fan, duct, and orifice flowmeter (Figure 2). Fan speed was regulated based on pressure measurements to maintain a constant pressure. Similarly, air inlets were positioned in test boxes connected to a fan and orifice flowmeter, with fan speed controlled based on pressure differentials. Airflow measurements were recorded for each humidity step (rise and decrease) to assess performance.

a. Air inlet.

b. Exhaust unit.

Figure 2. Example of the ATDs on the hygro-aeraulic test bench.

The characterization of air exhaust units was conducted under an operating pressure of 100 Pa. The airflow rate was continuously measured across various humidity levels, with the temperature maintained at a constant 21°C throughout the test. Similarly, the performance of air inlets was characterized using a comparable protocol. A pressure difference of 10 Pa was applied to the ATD terminal, and airflow rates were measured at different relative humidity steps. The temperature was maintained at 21°C for the duration of the test. Each point on the hygro-aeraulic curve represents measurements taken at stable humidity and airflow rate values.

3 RESULTS AND ANALYSIS

Data collected from laboratory tests were analysed to characterize the performance of ATDs after 1.25 years of in-situ operation. Most of the collected ATDs, both air inlet and air exhaust units, have shown a low level of maintenance (regarding cleaning by the occupants and/or the maintenance company). Based on the state of the ventilation units observed, it was observed that the kitchen exhaust units were the most heavily soiled, exhibiting a layer of dirt that was predominantly oily in nature (Figure 3a). Some bathroom and shower room exhaust units appeared to be more encrusted than others, with a mixture of dust, hair, and other fibres. In contrast (Figure 3b), the air inlet units were generally found to be cleaner.

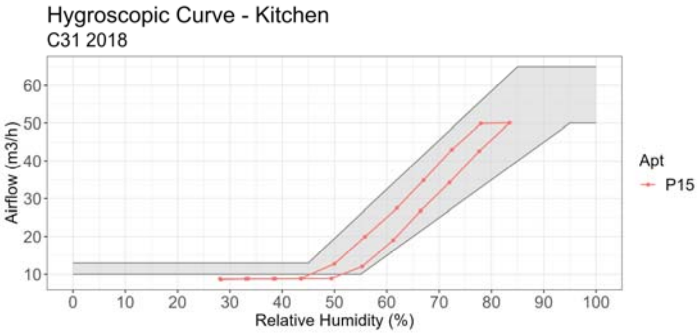
A. Kitchen B. Bathroom

Figure 3. Example of the state of the collected units depending on the room.

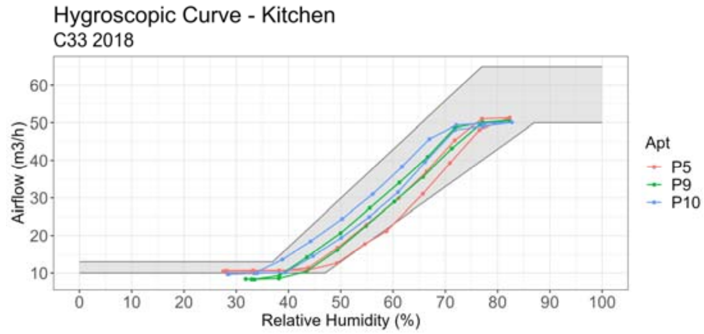
Comparisons were made with the performance characterization against the fabrication specifications:

- Kitchen Exhaust Units:

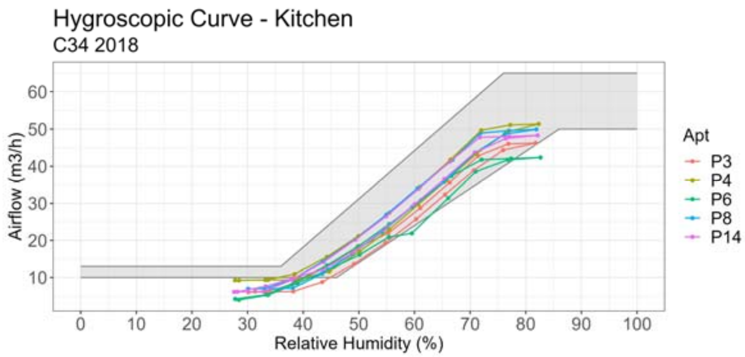
Figure 4 displays the results for all the kitchen ATDs. As mentioned earlier, during the all the kitchen units were evaluated with an insufficient level of maintenance (Figure1).



a. C31 2018



b. C33 2018



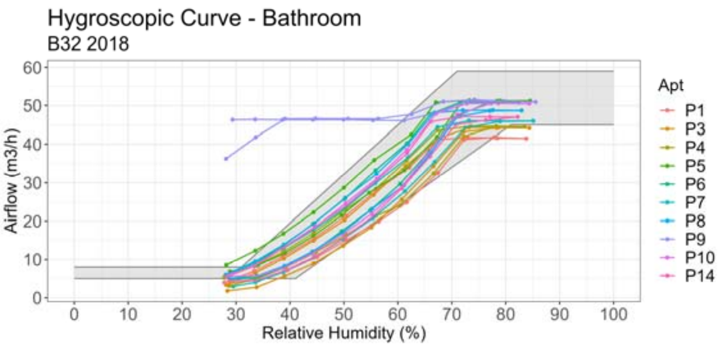
c. C34 2018

Figure 4. Results of the hygro-aeraulic curves – Kitchen.

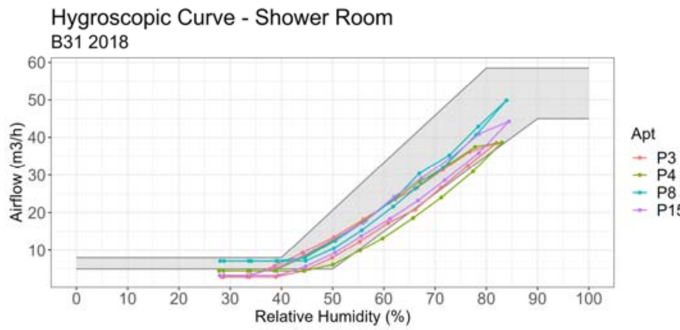
The results show that the curves generally fall within the expected envelopes, indicating a consistent response to changes in humidity levels. This responsiveness to humidity suggests that the hygroscopic functionality of the units remains intact, despite potential factors such as aging or environmental conditions. One interesting finding is the limitation of airflow at low humidity levels. This phenomenon raises questions regarding potential causes, with one possibility being the accumulation of debris or particulate matter on the shutter box over time. Such buildup could restrict airflow, resulting in reduced ventilation performance, particularly at lower humidity levels. However, it is noteworthy that despite the observed limitation in airflow at low humidity levels, the hygroscopic function of the units appears to remain effective. This suggests that while airflow may be restricted under certain conditions, the units continue to modulate ventilation rates based on humidity levels as intended. The robustness of the RH-MEV system (design and hygroscopic sensor) leads the exhaust units to deal well with obstruction or blocking over time.

- Bathroom Exhaust Units:

Bathroom exhaust units were characterized in the laboratory and their hygroscopic performance (airflow response to humidity) were compared to the tolerances of fabrication (Figure 5a). The curves depicting the performance of these units generally fall within the expected envelope, indicating a consistent response to changes in humidity levels. However, it is notable that all units except one exhibited a response to humidity, suggesting a high degree of functionality in modulating ventilation rates based on humidity levels.



a. Bathroom.



b. Shower Room

Figure 5. Results of the hygro-aeraulic curves.

A noteworthy trend observed in the bathroom exhaust units is the tendency towards a limitation of airflow at low humidity levels. This limitation could potentially be attributed to factors such as the accumulation of debris or particulate matter within the units, which may restrict airflow and impact overall ventilation performance, particularly in environments with lower humidity levels. This trend raises concerns regarding potential blockages and the need for periodic maintenance to address such issues. The one air exhaust unit that did not exhibit any response to changes in humidity levels presented a missing spring in the product.

- Shower Room Exhaust Units:

The laboratory characterization of exhaust units in the shower rooms yielded data from 4 tested units (Figure 5b). Similar to the bathroom units, the curves representing the performance of these units align well within the expected envelope. Additionally, all tested units exhibited a positive response to changes in humidity levels, confirming their functionality in modulating ventilation rates based on environmental conditions. However, a notable trend observed in the shower room exhaust units is the tendency towards a lower airflow at low humidity levels compared to the tolerances. This trend suggests a potential limitation in ventilation performance under specific humidity conditions. This could be indicative of factors such as blockages or obstructions within the units. While the units react well to humidity variations, the observed lower airflow at lower humidity levels warrants further investigation into potential causes.

While the units generally exhibit a consistent response to humidity and fall within expected performance envelopes, trends towards airflow limitation or suboptimal performance at low humidity levels raise concerns regarding potential maintenance issues. Addressing these concerns through regular maintenance protocols is crucial to ensure optimal performance and longevity of RH-MEV systems in multi-family social housing buildings.

- Bedroom and living room inlet units:

Hygroscopic performances of the air inlets were characterized in the laboratory and compared to the manufacturer specifications (Figure 6). The observations indicate that most of the characterized units exhibit performance within the expected envelope, with curves aligning well with the anticipated response to humidity variations.

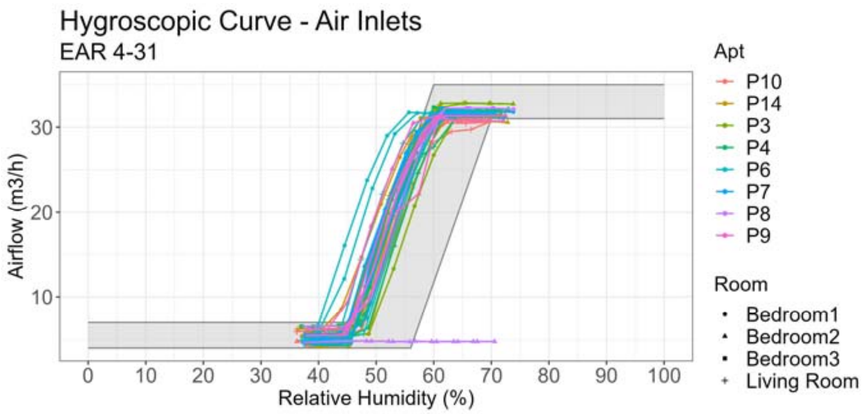


Figure 6. Results of the hygro-aeraulic curves – Bedrooms and living rooms.

One air inlet unit did not exhibit any response to changes in humidity levels. This anomaly is associated to a missing spring in the product. Another unit displayed a significant deviation from the expected performance specifications and only two others in the limit of this criteria, indicating potential irregularities or anomalies in its functionality. This deviation may warrant closer scrutiny to determine the root cause and assess the unit's overall effectiveness in modulating airflow based on humidity levels.

However, despite the particular case of the air inlet with a missing spring, all the air inlets units showed a positive response to changes in humidity levels, confirming their functionality in modulating airflow based on indoor conditions of the room. While this response aligns with the expected behaviour of hygroscopic air inlet units, most of the air inlets (16 out of 19) meet the specifications of fabrication to maintain optimal operation and therefore to ensure IAQ.

4 CONCLUSIONS

The comprehensive analysis conducted in this study provides valuable insights into the performance and effectiveness of RH-MEV provisory units installed during 1.25 years in multi-family social housing buildings.

This variation in cleanliness among different types of ventilation units highlights the importance of more adequate maintenance strategies. For instance, the presence of oily residues in kitchen exhaust units may necessitate more frequent and thorough cleaning to prevent airflow obstruction and maintain optimal performance of the RH-MEV system. In addition, the discovery of two ATDs lacking a response to humidity levels, attributed to a missing spring in the product, raises concerns regarding potential discrepancies in maintenance practices. Specifically, this observation may be associated with the interchanging of three WC and bathroom facades during maintenance procedures. Such a deviation from standard configuration could indicate an oversight and underlines the importance of meticulous attention to detail and adherence to established maintenance guidelines to prevent similar issues from arising in the future.

Overall, these observations highlight the importance of proactive maintenance efforts adapted to the specific needs of each ventilation product. By addressing cleanliness issues and implementing appropriate maintenance measures, occupants can ensure the continued effectiveness and longevity of ventilation systems in multi-family social housing buildings.

The findings reveal several key observations:

- Overall Performance: Most air inlets and exhaust units meet the original specifications after 1.25 years of aging in real life conditions. Their correct response to humidity ensures a good balance between IAQ and energy consumption.
- Maintenance Needs: Proactive maintenance, including regular cleaning and inspection of ventilation units, may mitigate issues like airflow limitation or irregular performance, ensuring optimal system functionality over time.
- Resilience: Despite potential challenges such as airflow limitation or suboptimal performance under certain conditions, the hygroscopic functionality of RH-MEV systems remains largely intact, indicating their resilience and suitability for long-term use in multi-family social housing buildings.

In conclusion, the findings of this study underscore the importance of ongoing monitoring, maintenance, and optimization efforts to maximize the performance and longevity of RH-MEV systems in multi-family social housing buildings. By addressing maintenance needs and implementing quality assurance measures, stakeholders can enhance IAQ, improve energy efficiency, and promote healthier living environments for occupants. Moreover, moving forward, continued research and collaboration are essential to further advancing the effectiveness and sustainability of RH-MEV systems in addressing the complex challenges of IAQ management in residential buildings.

Further investigation includes the characterization of the remaining units, air inlet and exhaust units, to provide a comprehensive assessment of the lasting ATDs. In addition, the next step of this study will focus on the ATDs characterization after cleaning by comparing the results of the provisory ventilation units as collected after 1.25 years of operation (dirty) and cleaned (as could be done by the occupant), against the optimal fabrication tolerances. This will allow to assess the impact of the lack of maintenance on the ventilation unit performance.

5 ACKNOWLEDGEMENTS

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