Examining the Impact of Improving the Airtightness of the Building Envelopes on Differential Pressures and Contaminant Dispersion in Temporary Negative Pressure Isolation Rooms

Jooyeon Roh[1], Shinhye Lee[1], Wonseok Lee[1], Sejin Lee[1], Myoung-souk Yeo[*2]

1 Department of Architecture and
Architectural Engineering,
Graduate School of Engineering,
Seoul National University
08826 Seoul, Korea

2 Department of Architecture and Architectural Engineering
/ Institute of Construction and Environmental Engineering,
Seoul National University
08826, Seoul, Korea
**Corresponding author: msyeo@snu.ac.kr*

SUMMARY

This study utilized a CONTAM simulation to assess the effects of airtightness improvements in TNPI rooms. Sobol sensitivity analysis was used to evaluate the impact of building envelope elements on pressure differentials and contaminant dispersion. Results showed that inter-room penetrations, ward doors, and ward ceilings significantly influenced differential pressure, while exterior walls and inter-room penetrations predominantly affected contaminant dispersion. These findings highlight the need for project-specific approaches in enhancing TNPI room airtightness, given that element impact varies by factors and does not correlate proportionally with their areas.

KEYWORDS

Airtightness, Contaminant dispersion, Pressure differentials, Temporary negative pressure isolation room

1 INTRODUCTION

Airborne infection isolation room (AIIR) are used to isolate patients with respiratory pathogens and limit transmissions in health care facilities. When its capacity is met due to the surging number of patients, the general hospital wards are converted into temporary negative pressure isolation (TNPI) rooms. This adaptation involves installing portable high-efficiency particulate air (HEPA) exhaust fan units. Their volume flow rate is controlled to comply with the negative pressure criteria and was generally maintained high due to low airtightness as confirmed in prior studies (Lee et al., 2023; Shin et al., 2023). This high-volume flow rate has been raising concerns including increased noise and energy usage (Lee et al., 2023). To deal with these issues, checking for leakage and sealing areas in the room during the makeshift is necessary (Saravia et al., 2007) and related guidelines recommend enhancing the air tightness of the ward. Yet, the standardisation of sealing protocols or prioritization of sealing parts is vague and challenging due to several reasons. The conditions of the wards vary as confirmed in (Geeslin et al., 2008; Shin et al., 2023), which determine the initial pressure differentials. Changes in these leakage areas affect the subsequent variations in pressure differentials and potential contamination risks. Therefore, modifications to the airtightness performance and the extent of these improvements should first be considered in project-specific approaches. Thus, this study investigated the impact of enhancing the air tightness in wards on pressure differentials and contaminant dispersion.

2 METHODOLOGY

This study leveraged a CONTAM simulation model to assess the effects of enhancing the airtightness of the building envelopes in TNPI rooms, considering the practical challenges of on-site experiments and comparative studies in real-world scenarios. As shown in Figure 1, the detailed methodology is outlined as follows:

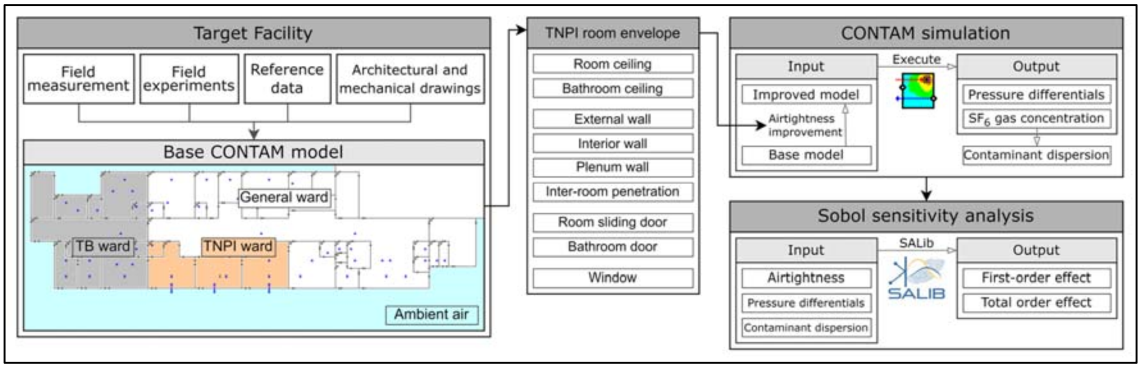

Figure 1: Schematic diagram depicting the methodology of the study

First, the target hospital ward was modeled using CONTAM. The initial airtightness was assumed based on reference datasets that can replicate the experimental data. Subsequently, it was hypothesized that the airtightness of the temporary negative pressure isolation (TNPI) rooms could be enhanced by up to 80%. These specific parameter ranges were employed in Sobol sensitivity analysis to quantitatively evaluate the impact of each building envelope on pressure differentials and contaminant dispersion. The elements considered for potential improvements included room ceilings, bathroom ceilings, windows, external walls, interior walls, inter-room penetrations, plenum walls, room sliding door, and bathroom doors.

3 RESULTS AND DISCUSSION

3.1 Effects of improving the airtightness on pressure differentials

The analysis, which included both first-order and total-order effects, indicated that inter-room penetrations (0.44), ward doors (0.28), and ward ceilings (0.19) exert the most substantial influence on differential pressure, in that sequence. In contrast to the typical makeshift enhancements of existing facilities, where the exterior wall was previously identified as the major influencer on differential pressure magnitudes (Roh et al., 2024), the exterior wall exhibited a less significant effect in scenarios where airtightness was enhanced. This trend contrasts markedly with that observed for inter-room penetration. In the case of ward ceilings and doors, they significantly impact differential pressure as factors contributing to the overall facility's airtightness and leakage area during improvements.

3.2 Effects of improving the airtightness on contaminant dispersion

Contaminant dispersion was evaluated based on the concentration of SF_6 gas detected in each zone, following its dispersion in the central room of three consecutive TNPI rooms. The analysis indicated negligible differences between the first-order and total-order effects on the potential infection risks by different elements. Contrary to the impact on differential pressure, the concentration of SF6 gas within the TNPI rooms was significantly influenced by the exterior walls (0.33), followed by windows (0.13), ward ceilings (0.10), and bathroom ceilings (0.04). This pattern suggests that airflows expelled through the TNPI rooms' exterior walls and windows and re-entering through the windows of the general wards and corridors in the same row exert the most significant influence. For elements impacting the concentration in the general ward and corridor adjacent to TNPI rooms, the influence was ranked in order of exterior wall, inter-room penetration, window, and ward door. However, it is notable that the absolute magnitudes of these effects were relatively small, approximately 0.3.

3.3 Overall results and discussion

Considering both pressure differentials and contaminant dispersion, during the makeshift in the target facility, it is necessary to improve the airtightness performance in the following order: inter-room penetration, exterior wall, room sliding door, and room ceiling. Each element within the converted TNPI rooms affects the differential pressure and potential infection risks to varying degrees, regardless of its total area. Moreover, the magnitude of each impact does not correlate proportionally with the areas of the respective elements, underscoring the necessity for a project-specific approach. Yet, the simulations in this study were conducted with ambient air treated as a single zone for re-entry and diffusion, which may have resulted in underestimations of contaminant dispersion compared to real-world situations.

4 CONCLUSION

This study responds to the urgent need to enhance airtightness in TNPI rooms, especially when general hospital wards are converted during high patient inflow. Utilizing CONTAM simulations, the improvements in airtightness by up to 80% and their effects on pressure differentials and potential infection risks were evaluated. Results indicate that inter-room penetrations and ward doors significantly influence differential pressures, while exterior walls and inter-room penetrations are the primary drivers of infection risks. Accordingly, enhancements in airtightness at inter-room penetrations, exterior walls, room sliding doors, and ward ceilings should be prioritized in such makeshift adaptations. The results underscore the necessity for tailored interventions, as the magnitude of impact is not proportional to the area of each modified element.

5 ACKNOWLEDGEMENTS

This research was supported by a grant of the project for Infectious Disease Medical Safety, funded by the Ministry of Health & Welfare, Republic of Korea (grant number : RS-2022-KH124613(HG22C0017)).

6 REFERENCES

Geeslin, A., Streifel, A., & Nelson, G. (2008). Air Leakage Analysis of Special Ventilation Hospital Rooms. ASHRAE Transactions, 114(2), 447–452.

Lee, S., Lee, W., Kim, E., & Yeo, M. (2023). Investigations on the emergency operation status of existing medical facilities to prepare for emerging infectious diseases in the post-COVID-19 era. Journal of The Korea Institute of Healthcare Architecture, 29(1), 43–51.

Roh, J., Lee, W., Lee, S., & Yeo, M. (2024). Analysis of Airtightness Performance and Differential Pressure Relationships in Rapidly Converted Temporary Negative Pressure Isolation Rooms. Korean Journal of Air-Conditioning and Refrigeration Engineering, 36(7), 325–331.

Saravia, S. A., Raynor, P. C., & Streifel, A. J. (2007). A performance assessment of airborne infection isolation rooms. American Journal of Infection Control, 35(5), 324–331.

Shin, H. W., Kim, D. W., Kim, J. M., Jung, H. B., & Kang, D. H. (2023). Analysis of Minimum Airflow Differences between Supply and Exhaust Air according to Airtightness of Rapidly Converted Temporary Negative Pressure Isolation Rooms. Journal of The Korea Institute of Healthcare Architecture, 29(4), 69–77.