Field investigation of indoor air quality in one Norwegian apartment building with burning candles





AZIMIL ALAM
Student – Norwegian University of Science and Technology

JULES NACINOVI
Student – Norwegian University of Science and Technology

KASPER OPPI
Student – Norwegian University of Science and Technology

THIBAULT LOSTE
Student – Norwegian University of Science and Technology

GUANGYU CAO
Dr. (Sc). Professor – Department of Energy and Process Engineering, Norwegian University of Science and Technology

Corresponding author email: Guangyu.cao@ntnu.no

This research aimed to quantify the effects of burning candles on Indoor Air Quality (IAQ) in Norwegian apartment building, and explored the relationship in between, since impacts of burning candles produces different serious contaminants spread along room. Multiple scenarios were investigated, and free-standing sensors were employed to measure various IAQ parameters. The findings revealed a significant increase of indoor pollutants when candles were burned indoors. Result shows application of air ventilation showed a slight improvement in IAQ level, although burning candles remained detrimental to indoor air quality. Turned out this work that refraining from lighting candles is the most effective way to maintain healthy IAQ in indoor environments. Air ventilations offered a modest improvement, but the most effective solution remains avoiding candle burning indoors. Further investigation may be needed with larger scales and quantity of experiments.

Keywords: Indoor Air Quality, indoor pollutant, burning candles, Norwegian apartment, ventilation strategy

Introduction

Indoor air quality (IAQ) is a crucial aspect of modern living, significantly influencing the health, comfort, and overall well-being of individuals. Among the numerous factors affecting IAQ, the presence of candle lights in indoor environments has become a topic of interest in recent years, especially in regions where candles are widely used, such as in some Scandinavian countries, including Norway for various purposes for creating a pleasant household indoor climate [**1,2**]. Candles, can release particulate matter and other pollutants into the indoor air, potentially compromising the IAQ. When a candle burns, it undergoes a chemical reaction of hydrocarbon-based molecules as a fuel with oxygen in the air, producing contaminants, heat, light, water vapour, and carbon dioxide concentration (CO_2) [**3**]. The calculated emission rate constants (ER) of the investigated gaseous compounds ranged between 92 and 4,910 µg/h[**4**]. Both acute and chronic exposures to indoor pollutants such as particle matters and organic compounds could induce adverse health effects such as damage to the nervous system, immune and reproductive diseases, respiratory system dysfunction, developmental problems, and cancers [**5**]. Numerous studies have been carried out to characterise the indoor emission and to quantify the emission induced by incense and candle combustion [**6,7,8**]. Addressing these concerns requires a comprehensive field investigation that considers multiple variables and scenarios.

Norwegian government issues a national guideline and regulation which also determines the required limits regarding the concentration of pollutants to achieve good indoor air quality of residential building, including particulate matters (PM), asbestos, formaldehyde, benzene, CO_2, CO, and ozone The indoor CO_2 concentration affect dissatisfaction of occupants at each certain level[**9**]. Indoor contaminant in Norway has maximum limits (requires daily concentration PM2.5 < 15ug/m³ and CO_2 level <1,000 ppm as recommendation)[**10**], besides, ventilation amount in Norway has its local standard which are 26m³/h for each person and extra 2.6 m³/h per square-meter of room area[**11**].

The primary objective of this research is to investigate the effect of burning candles on indoor air quality in a Norwegian apartment building. The study aims to understand how the ventilation strategy will affect indoor air quality in residential building with burning candles.

Method

Measurement setup

An apartment building named *Moholt-studentby* in Trondheim City, was used for the filed investigation. The apartment has four bedrooms, a bathroom, and a kitchen-dining room with a kitchen hood as an extract ventilation function (170m³/h equal with 3.0 ACH) in this study. In addition, there is a toilet next to the room we had investigated, it also has continuous exhaust ventilation centrally from the building on the rooftop. Experimental measurements with a few scenarios were conducted in the dining room at the end of October 2023. Free-standing sensors are applied during the experiment (CO_2, Relative Humidity, Temperature and PM2.5). Air hatch as air-open hole is located on the top level of the room, it can easily be closed or opened manually. Likewise, the air in the room has been changed between each scenario in order to reset the normal conditions of CO_2 and PM concentration at the beginning of each measurement. In the room there are four volunteer occupants with a light activity around the dinner table. Twelve candles were used in each scenario, dispatched between the dining table and the work station. Room layout scheme is shown in **Figure 1**.

Scenario Design

Few scenarios were developed and conducted in this work, in order to be able to compare the different scenarios, the four scenarios have the same initial state by opening the windows for twenty minutes before each measurement. The first two scenarios compare the influence of candles on indoor air quality while the ventilation is on, whereas the two last scenarios compare this influence while the ventilation is off. Fours scenarios are shown in **Figure 1**.

Scenario	Candles	Ventilation (ACH)
S1	No	3.0
S2	Yes	3.0
S3	Yes	0.5
S4	No	0.5

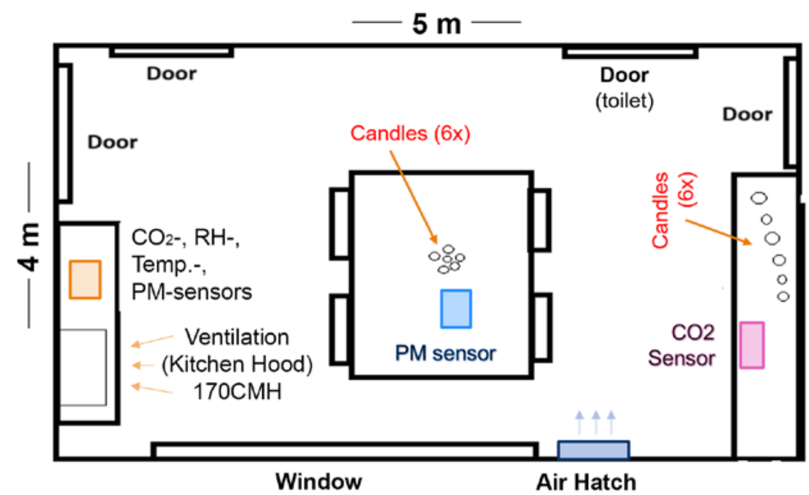


Figure 1. Design of scenarios, and room layout during experiments.

CONTAM as specialist in simulation program was used in this study to simulate indoor air quality. Some boundary conditions such as: room volume, occupants' number, duration, written capacity of mechanical ventilation (kitchen hood), opening holes are mentioned in simulation. By using simulation approaches, we will find out the emission rate and assume it is constant in each case.

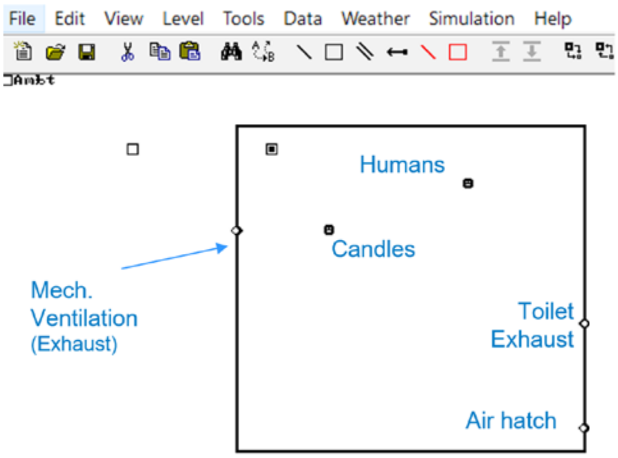


Figure 2. Configuration in CONTAM® Simulation.

Result & Discussions

Measured room air temperature, which increases in all scenarios due to external and internal heat gain in the room as shown in **Figure 3**. The heat gains due to the human body metabolism and indoor electronic was considered stable. While the extra internal heat gain may be caused by the candle burning. For all the scenarios the temperature is increasing due to these heat gains in the room. Noticing that for scenarios with the same state of ventilation, the one with candles will be warmer than the one without. In practice, S2 and S3 comparison between S2 and S3 shows us how mechanical ventilation application could extract the heat significantly.

Figure 4 show the CO_2 concentration and the particle concentration during each experiment. Not only human body metabolism, but candle lights also produce CO_2 contaminants into the room. There are similarities between the simulation with ventilation and without. While the CO_2 concentration increases a bit in the beginning it does reach a steady state when the ventilation is on, but when it is off the concentration is steadily increasing. The difference between the scenarios with ventilation is that the steady-state concentration of CO_2 is higher with the candles. Without the candles the concentration is around 1,000 ppm, while with the candles the

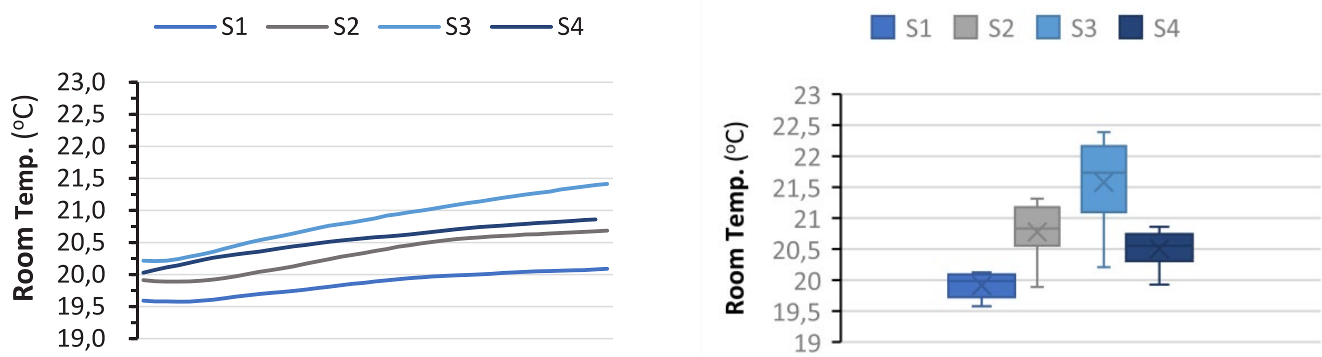


Figure 3. Temperature level: (left) in timestep (right) in descriptive statistic.

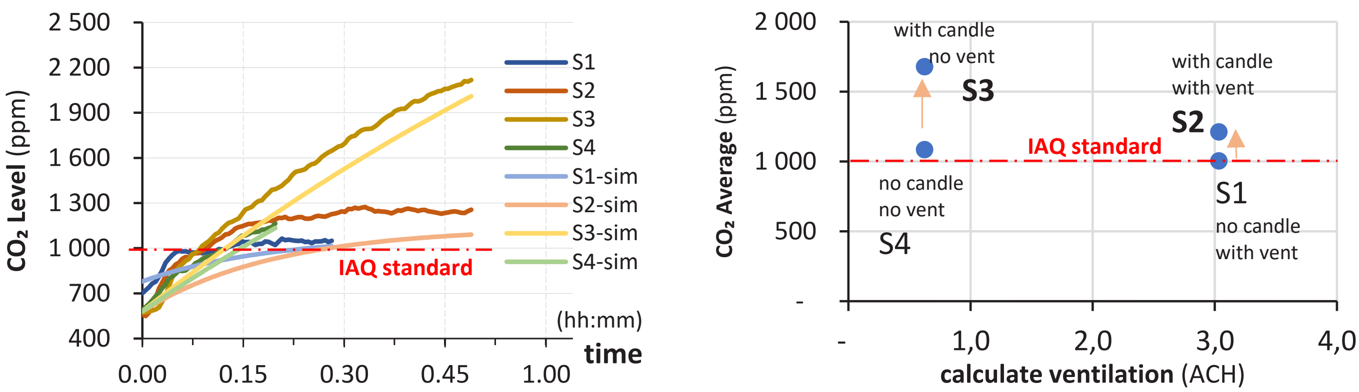


Figure 4. CO_2 concentration level: (up) in timestep (down) mean value vs. ventilation change each scenario.

concentration is around 1,200 ppm (S2) and even the ventilation of kitchen hood is off, the CO_2 increased but the scenario with the candles the CO_2 achieved significantly around 1,700 ppm-average (S3). It is therefore possible to say that burning candles can increase CO_2 concentration in a room much higher, where this is also confirmed by another study[**12**]. Also, measurement from experiments validated theoretical approach as shown in simulations and they performed similar results.

As candles produce soot and pollutants that can be spreading freely into the air through its thermal plume, the difference of PM concentration was analysed between scenarios. Results show That the particle concentration behaves a bit different from the CO_2 Concentration. In fact, the measured CO_2 concentration behaves like the simulated scenarios, the PM concentration in S2 does not behave as the simulated scenario. The simulated scenario assumes a uniform distribution of particles, while this is not the case when the ventilation is on. For S3 the PM concentration behaves somewhat the same as the simulated. The scenarios without mechanical ventilation of kitchen hood (S3) show how much particles the candles emitted extremely. The peak value of scenario-3 was almost 50 μg/m³ and is still increasing, while candles ran along with mechanical ventilation from kitchen hood together (S2) took around 10-15 μg/m³ below than applied local standard, as shown in **Figure 5**.

To indicate particle spread in room, comparison the concentration of particles on the table and at the exhaust point (mechanical ventilation / kitchen hood) has shown in **Figure 6**. This concentration was measured with a sensor on the table and with a sensor at the exhaust. Two different sections can be identified, during the first twenty minutes, the concentration of particles is very high on the table and quite low at the exhaust, that means that burning candles will directly harm the occupants. Then, after twenty minutes, the concentration on the table decreases and, if there is no ventilation system, the concentration at the exhaust could be higher, the particles spread around the room. **Figure 6 (right)** shows that the concentration on the table is on average higher than at the exhaust point. Therefore, even if there is a ventilation system, the occupants will be exposed to a higher concentration of particles than usual since the Particulate Matter (PM2.5) concentration at the table constantly exceeds that at the exhaust point within the indicated time range.

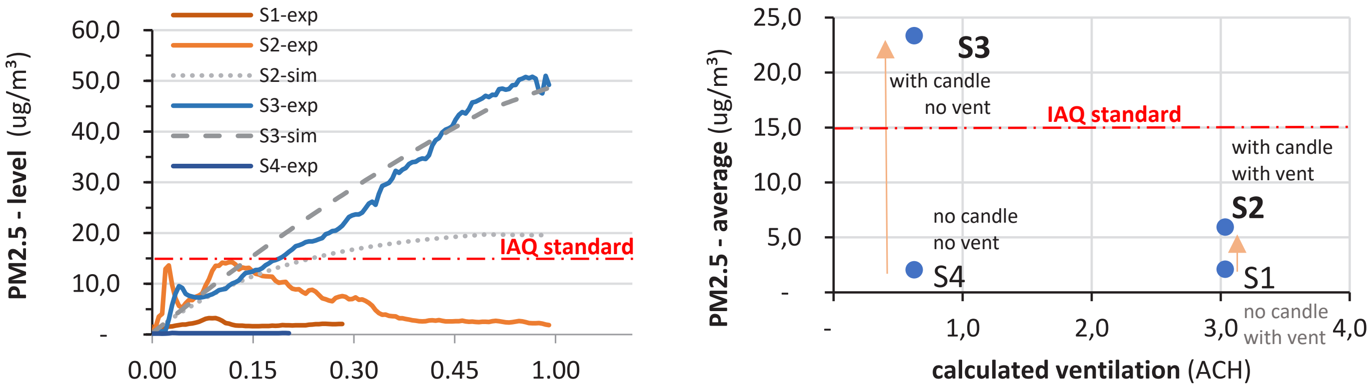
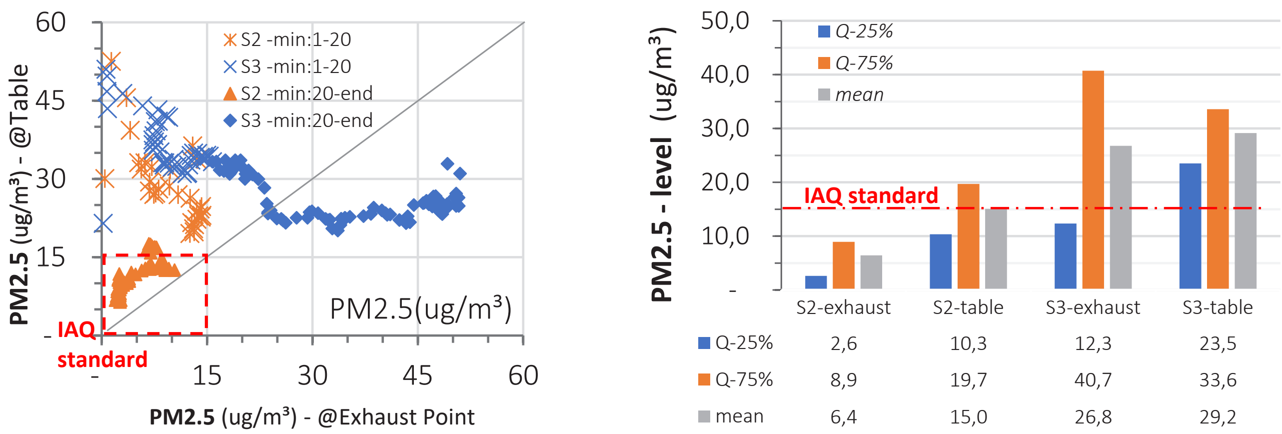


Figure 5. PM concentration level: (left) in timestep and; (right) mean value vs. ventilation change each scenario.



	S2-exhaust	S2-table	S3-exhaust	S3-table
Q-25%	2,6	10,3	12,3	23,5
Q-75%	8,9	19,7	40,7	33,6
mean	6,4	15,0	26,8	29,2

Figure 6. Comparison of PM2.5 concentration in different scenarios: (left) on table vs. (right) exhaust point.

This convergence suggests a change in the dynamics of pollutant dispersion over time, indicating the need for careful evaluation and potentially tailored interventions to protect occupants from increased particulate matter levels.

Conclusions

This study underscores the adverse impact of burning candles on indoor air quality in Norwegian apartment buildings. It is proven that burning candles increases indoor pollutants significantly if only supplying low amount of outdoor air. The increased contaminant concentration by burning candles may increase the risk of human exposure. Greater ventilation rate has been proven to be able to reduce indoor pollution concentrations to an acceptable level. While mechanical ventilation offered a significant improvement, the most effective solution remains avoiding candle burning or reduce the number of candles that are used at the same time indoors, regardless any kind of applied ventilation it has. If candles are used, placing candles close to extract or exhaust point may reduce the transmission of pollutants produced by the burning candles to the rest of the room and even to the occupants, thus reduce the risk of human exposure. Further comprehensive and larger scale of experiments may be performed to explore diverse factors that affect the spreading of pollutants from burning candles. ■

References

[1] Wyss, A. B., Jones, A. C., Bølling, A. K., Kissling, G. E., Chartier, R., Dahlman, H. J., . & London, S. J. (2016). Particulate matter 2.5 exposure and self-reported use of wood stoves and other indoor combustion sources in urban nonsmoking homes in Norway. PloS one, 11(11), e0166440.

[2] Stuhlmiller, C. M. (1998). Understanding seasonal affective disorder and experiences in Northern Norway. Image: The Journal of Nursing Scholarship, 30(2), 151-156.

[3] Raju, M. P., and J. S. T'ien. "Modelling of candle burning with a self-trimmed wick." *Combustion Theory and Modelling 12.2* (2008): 367-388.

[4] Derudi, M., Gelosa, S., Sliepcevich, A., Cattaneo, A., Rota, R., Cavallo, D., & Nano, G. (2012). Emissions of air pollutants from scented candles burning in a test chamber. *Atmospheric Environment*, 55, 257-262.

[5] WHO - World Health Organization (2005) Air quality guidelines – global update 2005. WHO Regional Publications, editor. European Series.

[6] Glytsos T, Ondracek J, Dzumbova L, Kopanakis I, Lazaridis M (2010) Characterization of particulate matter concentrations during controlled indoor activities. Atmos Environ 44:1539–1549.

[7] Pagels J, Wierzbicka A, Nilsson E, Isaxon C, Dahl A, Gudmundsson A et al (2009) Chemical composition and mass emission factors of candle smoke particles. J Aerosol Sci 40:193–208.

[8] Maupetit F, Squinazi F (2009) Characterization of benzene and formaldehyde emissions from burning incense and scented candles indoors: development of exposure scenarios and recommendations for use. Environ Risque Santé 8:109–118.

[9] Jokl, M. V. (2000). Evaluation of indoor air quality using the decibel concept based on carbon dioxide and TVOC. *Building and Environment*, 35(8), 677-697.

[10] Miljø-Direktoratet (2020). Grenseverdier for svevestøv, Forslag til reviderte grenseverdier for PM10 og PM2,5 https://www.miljodirektoratet.no/globalassets/publikasjoner/m1669/m1669.pdf.

[11] Direktoratet For Byggkvalitet (2017). Ventilasjon i byggverk for publikum og arbeidsbygning, Byggteknisk forskrift (TEK17) med veiledning § 13-3. https://www.dibk.no/regelverk/byggteknisk-forskrift-tek17/13/i/13-3.

[12] Kapalo, P., Kováč, M., Nagy, R., & Baka, Z. (2022, September). Indoor air quality assessment in the apartment–case study. *In IOP Conference Series: Materials Science and Engineering* (Vol. 1252, No. 1, p. 012061). IOP Publishing.