Original Article

Natural Ventilation in Iranian Bakeries: Identifying Gaps and Proposing Guidelines for Future Respiratory Pandemics Such as COVID-19

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Abstract

Aims: This study aimed to evaluate natural ventilation practices in traditional bakeries in Semnan Province, Iran, and assess their compliance with Iranian ventilation standards. It also desired to develop preliminary guidelines for improving ventilation to mitigate risks during potential respiratory pandemics such as COVID-19. **Methods:** This descriptive analytical study was conducted in the winter of 2023 in Semnan Province, located in northeastern Iran. The research evaluated 142 bakeries through observational surveys and measured key ventilation indicators, including airflow (L/s per m²), airflow per person (L/s per person), and air changes per hour (ACH). To develop preliminary guidelines, these ventilation indicators were reassessed across four scenarios, with openings set at 25%, 50%, 75%, and 100% of their maximum capacity. **Results:** The findings revealed that while 94.4% of the bakeries adhered to fundamental airflow guidelines, only 40.8% achieved the ACH standards, a key measure of indoor air quality (IAQ). Even with fully open ventilation openings, only 95.1% and 64.8% of the studied establishments met Iran's natural ventilation standards for airflow and ACH, respectively. **Conclusions:** The study highlights noncompliance with ACH standards in bakeries, underscoring the need for improved ventilation strategies. Proposed guidelines recommend maintaining a minimum ventilation opening area of 10% of the floor area and ensuring that mechanical ventilation systems operate continuously and optimally during activity hours. These measures are essential for enhancing IAQ and reducing the risk of potential respiratory pandemics such as COVID-19 in high-risk environments such as bakeries.

Keywords: Air changes per hour, food industry, indoor air pollution, respiratory tract infections, ventilation

INTRODUCTION

The COVID-19 pandemic has highlighted the ongoing threat of emerging infectious diseases, which pose significant health, economic, political, and social challenges worldwide.[1] Respiratory diseases, including SARS-CoV-2, primarily spread through airborne aerosols generated by breathing, coughing, and sneezing.[2] These aerosols can linger in the air for prolonged periods, increasing the risk of infection for nearby individuals.[3] Thus, effective ventilation is crucial for maintaining indoor air quality (IAQ), reducing airborne pathogen transmission, and protecting public health.[4]

To enhance IAQ and limit the spread of airborne pathogens, three key strategies can be employed: mechanical ventilation, natural ventilation (passive airflow systems), or a combination of both.[5] While mechanical systems are essential in many settings, passive airflow offers a cost-effective and accessible solution, particularly in resource-limited environments.[6] Research indicates that natural ventilation is highly effective

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in reducing SARS-CoV-2 transmission. For example, Firatoglu found that classrooms with adequate airflow experienced significantly lower transmission rates.[7] Li *et al*. (2021) attributed SARS-CoV-2 aerosol transmission in restaurants to poor ventilation.[8] Furthermore, other studies have confirmed that natural ventilation strategies can effectively mitigate COVID-19 transmission risks in various facilities.[9]

Given the probability of future respiratory disease outbreaks, including new COVID-19 variants and influenza, wariness and preparedness are essential.[10,11] Therefore, evaluating existing control measures such as natural ventilation is crucial, especially in high-risk, densely populated areas. Bakeries, for instance, often operate during respiratory pandemics and host large crowds, increasing the risk of disease transmission. Implementing effective ventilation strategies in these environments is vital for mitigating this risk.

This study aimed to evaluate natural ventilation practices in traditional bakeries in Semnan Province, Iran, and assess their compliance with national ventilation recommendations. By exploring the feasibility of meeting these requirements under various scenarios, we provide initial guidelines for optimizing natural ventilation in preparation for future respiratory pandemics, including COVID-19.

MATERIALS AND METHODS

Study population and sampling method

This study adopts a descriptive analytical approach, incorporating observational measurements conducted during the winter of 2023 in Semnan Province. Based on Shahmohammadi *et al*., we calculated the sample size using Equation 1:[12]

$$n = \frac{z^{2}{}_{1\text{-}\propto/2} \times p(1-p)}{d^{2}} \tag{1}$$

Here, $z^{2}{}_{1\text{-}\propto/2}$ is a constant value of 1.96 for a 95% confidence level, is the margin of error (set at 0.12), and is the estimated population proportion (0.76). With a design effect of 2 for stratified sampling and accounting for a potential 25% dropout rate, the minimum sample size was calculated to be 122. Ultimately, 142 bakeries were included in the study, randomly selected from each city based on their allocated sample size.

Study design and data collection

This study combined qualitative and quantitative methods to investigate natural ventilation in three phases.

Phase 1: Field observational survey

We conducted a field survey to evaluate bakeries' location, orientation, building dimensions (length, width, and height), opening area and configuration (shape, size, and position), type of natural ventilation, mechanical ventilation status, equipment layout, and raw material storage.

Phase 2: Natural ventilation practices

In the second phase, we assessed natural ventilation practices in traditional bakeries, evaluating their compliance with Iranian guidelines. We measured ventilation rate parameters, including airflow (L/s per m²), airflow per person (L/s per person), and air changes per hour (ACH).[13]

Phase 3: Feasibility of adhering to recommendations

In the third phase, we explored the feasibility of adhering to natural ventilation recommendations to establish preliminary guidelines for potential respiratory pandemics such as COVID-19. Ventilation rate parameters were measured across four scenarios with air inlet/outlet openings of 25%, 50%, 75%, and 100%.

Measurement instruments

We used the following instruments for measurements: a thermal anemometer (KIMO-AMI-301, France), a vane anemometer (PRO-AVM-07, Taiwan), a laser rangefinder (ATuMan LS-P, China), a tape measure, a mercury thermometer, and a digital thermometer (HTC-2, China). Measurements were conducted with precision-calibrated instruments, and a strict daily calibration protocol ensured accuracy and minimized potential errors.

Ventilation rate calculations

We used separate equations to calculate ventilation rate parameters based on the types of natural ventilation observed: cross ventilation (air enters through one opening and exits through another) and single-sided ventilation (openings on one side only). For bakeries with cross ventilation, we applied Equations 2-5.[14]

$$q = C_{d} \cdot A^{*}\sqrt{2gh\frac{T_{i}-T_{o}}{T_{o}} + 2\Delta P_{w}} \tag{2}$$

$$A^{*} = \frac{A_{t} \cdot A_{b}}{\sqrt{A_{t}{}^{2} + A_{b}{}^{2}}} \tag{3}$$

$$Cd = 0.4 + 0.0025(T_{i} - T_{o}) \tag{4}$$

$$\Delta P_{w} = \frac{1}{2}Cp_{1}v_{1}^{2} - \frac{1}{2}Cp_{2}v_{2}^{2} \tag{5}$$

Where, q: Airflow (m≥/s); A*: Effective opening area; A_t, A_b: Free-opening areas' C_d: Discharge coefficient; C_p: Pressure coefficient; g: Acceleration due to gravity; h: Inlet and outlet height difference (m); T_i: Inside temperature (Kelvin); T_o: Outside temperature (Kelvin);

P_w: Wind pressure coefficient; V: Wind speed;

For bakeries with single-sided ventilation, we used Equation 6.[15]

$$q_{v;arg} = 3600 \cdot \frac{\rho_{a;ref}}{\rho_{a;e}} \cdot \frac{A_{w.tot}}{2} \cdot max(C_{wind} \cdot u^{2}{}_{10.\ site} \cdot C_{st\,n} h_{w.st\,n} abs\ (T_{z} - T_{e})0.5 \tag{6}$$

Where, $q_{(v;\ arg)}$: Airflow (m³/h); $\rho_{a;\ ref}$: Reference air density (kg/m³); $\rho_{a;\ e}$: External air density (kg/m³); $A_{w.tot}$: Total opening area (m²); C_{wind}: Wind speed coefficient; $U_{10.site}$: Wind speed at 10 m height; C_{st}: Stack effect coefficient; $h_{w.st:}$ Useful stack effect height for airing (m); and $T_z - T_e$: Temperature difference between inside and outside (Kelvin);

Finally, we used Equation 7 to calculate ACH.[16]

$$ACH = \frac{Q}{V} \quad (7)$$

Where, ACH: Air changes per hour (ACH); Q: Airflow (m^3/h); V: Room volume (m^3)

Data analysis

All calculations and data analysis were performed using a computational tool developed in Excel 2019.

RESULTS

The study evaluated ventilation conditions in bakeries, comparing them to Iranian standards of 14.1 L/s per person and 3.5 L/s per m² of area. It found that 94.4% of the bakeries met these airflow standards. However, only 40.8% complied with Iran's recommended natural ventilation rate of 20 ACH. Table 1 provides a detailed breakdown of ACH compliance among the bakeries.

The study also analyzed natural ventilation parameters including airflow per person, airflow per area, and ACH under four scenarios: 25%, 50%, 75%, and 100% of ventilation openings open. Tables 2-5 summarize these findings.

When at least 50% of the openings were open, the airflow per person and per area met Iranian standards [Table 3]. However, even with all openings fully open, only 64.8% of the bakeries achieved the recommended ACH [Table 5].

Table 1: Classification of air changes per hour in bakeries

Number of bakeries	Classification of ACH	Percentage
28	<10	19.7
32	10–≤15	22.5
24	>15–<20	16.9
58	≥20	40.8
142	Total	100

ACH: Air changes per hour

DISCUSSION

This study evaluated natural ventilation practices in traditional bakeries in Semnan Province, Iran, assessing their compliance with national ventilation recommendations. We also investigated the feasibility of meeting these standards under various scenarios to provide primary guidelines for mitigating risks during future respiratory pandemics, such as COVID-19.

The findings revealed that 94.4% of bakeries met basic ventilation recommendations for airflow per person (L/s per person) and per square meter (L/s/m²). However, only 40.8% complied ACH standards. This discrepancy highlights a critical gap in dynamic airflow management, which is essential for minimizing the spread of airborne diseases.

Few studies have examined bakery ventilation in Iran. Lotfi Narani *et al*. found that only 60% of bakeries in Sanandaj City complied with health regulations, while Ghodsi and Mazloomi reported a 57.44% compliance rate in Malekshahi City.[17,18] These studies relied on questionnaires and subjective assessments, whereas our study used objective measures, including airflow per square meter, airflow per person, and ACH. These methodological differences likely explain the variations in results.

The primary issue identified was inadequate ACH. While most bakeries (94.4%) had sufficient static airflow, dynamic air changes necessary to reduce respiratory pandemic risks were often insufficient. Recent studies emphasize that airflow and air change rates alone are insufficient to prevent respiratory disease transmission.[19] To address this, interventions such as increasing the number and size of openings, redesigning their placement, altering their shape and angle, and installing wind deflectors are essential.[20]

Some research indicates that increasing social distancing can reduce disease transmission, even in poorly ventilated environments.[21] Despite this, practical challenges often arise in densely populated settings. For instance, our observations in bakeries revealed issues such as limited space, high customer density, inefficient equipment placement, and overstocking of

Table 2: Natural ventilation parameters with 25% of inlets/outlets open

Airflow (L/s per person)		Airflow (L/s per m² of area)		ACH	
≥ the recommended values, *n* (%)	≤ the recommended values, *n* (%)	≥ the recommended values, *n* (%)	≤ the recommended values, *n* (%)	≥ the recommended values, *n* (%)	≤ the recommended values, *n* (%)
131 (92.3)	11 (7.7)	115 (81)	27 (19)	4 (3.8)	138 (97.2)

ACH: Air changes per hour

Table 3: Natural ventilation parameters with 50% of inlets/outlets open

Airflow (L/s per person)		Airflow (L/s per m² of area)		ACH	
≥ the recommended values, *n* (%)	≤ the recommended values, *n* (%)	≥ the recommended values, *n* (%)	≤ the recommended values, *n* (%)	≥ the recommended values, *n* (%)	≤ the recommended values, *n* (%)
134 (94.4)	8 (5.6)	134 (94.4)	8 (5.6)	25 (17.6)	117 (82.4)

ACH: Air changes per hour

Table 4: Natural ventilation parameters with 75% of inlets/outlets open

Airflow (L/s per person)		Airflow (L/s per m^2 of area)		ACH	
≥ the recommended values, *n* (%)	≤ the recommended values, *n* (%)	≥ the recommended values, *n* (%)	≤ the recommended values, *n* (%)	≥ the recommended values, *n* (%)	≤ the recommended values, *n* (%)
135 (95.1)	7 (4.9)	134 (94.4)	8 (5.6)	59 (41.5)	83 (58.5)

ACH: Air changes per hour

Table 5: Natural ventilation parameters with 100% of inlets/outlets open

Airflow (L/s per person)		Airflow (L/s per m^2 of area)		ACH	
≥ the recommended values, *n* (%)	≤ the recommended values, *n* (%)	≥ the recommended values, *n* (%)	≤ the recommended values, *n* (%)	≥ the recommended value, *n* (%)	≤ the recommended values, *n* (%)
135 (95.1)	7 (4.9)	134 (94.4)	8 (5.6)	92 (64.8)	45 (35.2)

ACH: Air changes per hour

raw materials, all of which render social distancing measures ineffective. Furthermore, recent findings reveal that reducing ventilation alongside distancing measures may not sufficiently constrain airborne disease transmission.[22,23] To manage these challenges, practical solutions such as improving airflow through natural ventilation systems, in addition to mechanical ventilation, could mitigate respiratory disease transmission in environments such as bakeries, where space constraints and high occupancy are common.

We assessed the feasibility of meeting ventilation recommendations under four scenarios with varying air inlet/outlet openings: 25%, 50%, 75%, and 100%. Even with fully open openings (100%), only 95.1% and 64.8% of bakeries met the airflow and ACH recommendations, respectively [Table 5].

One key factor contributing to noncompliance with ACH is the outdated architecture of many bakeries. These structures typically have high ceilings, small inlet and outlet openings, and obstructions from equipment.[24] Similarly, Bennett *et al*. found that many small commercial buildings do not meet ventilation standards due to insufficient outdoor air supply.[25]

In this study, the average bakery had an area of 51.2 m^2 and a volume of 193.02 m^3. The average inlet opening measured 1.17 m^2, while the outlet opening was only 0.6 m^2. According to the findings of this study, complying with Iranian standards would require a minimum inlet opening of 1.6 m^2 and an outlet opening of 1.2 m^2. Thus, the inadequate size of these openings, particularly the outlets, is likely a primary reason for noncompliance.

It is important to note that effective natural ventilation relies on optimizing air inlet and outlet designs.[26] While some studies suggest an air intake size of 10%–25% of the floor area,[27] our findings indicated that an intake as low as 4% may be sufficient. However, local climate factors, such as wind patterns and temperature differentials, require a minimum air inlet size of 10% to meet compliance standards.[28]

The second reason some bakeries may not comply with ventilation standards is their reliance on single-sided natural ventilation. Existing evidence shows that single-sided ventilation, which depends on wind-induced airflow through a single opening, is less efficient compared to cross-ventilation.[29] Park *et al*. found that cross-ventilation, with 15%–30% window openings, can provide adequate airflow to reduce the risk of COVID-19 transmission in schools, whereas single-sided ventilation is significantly less effective.[24] In addition, another study indicated that cross-ventilation can achieve airflow efficiency up to 3.5 times greater than that of single-sided ventilation.[30]

The third reason for failing to meet ventilation standards in this study may stem from inadequate mechanical ventilation in the bakeries examined. The observational survey revealed that these bakeries lacked efficient mechanical systems. While natural ventilation can effectively mitigate the risks of infection transmission and enhance air quality in buildings,[31] some studies indicate that mechanical ventilation with filtration reduces indoor pollution more effectively than natural ventilation alone.[32,33] Furthermore, Montgomery *et al*. reported that although natural ventilation can keep pollutant levels below current standards, it is subject to airflow variability and offers less control over pollutant levels compared to mechanical systems.[33]

Therefore, integrating mechanical ventilation with natural ventilation, known as hybrid systems, appears to be an effective approach for reducing the risk of respiratory airborne diseases in bakeries. This method combines the strengths of both systems, optimizing air circulation and pathogen removal, particularly in high-density environments.[34,35] In addition, a hybrid system provides flexibility in meeting IAQ needs while enhancing energy efficiency and occupant health.[36,37] The usefulness of ventilation systems is impacted by the specific context of the building. Key factors include the layout, size, intended use, structural limitations, occupancy levels, and external environmental conditions, such as outdoor air quality and weather patterns.[5,38] Consequently, further studies are needed to determine the optimal ventilation system for bakeries.

This study proposes primary guidelines for natural ventilation in traditional bakeries to mitigate health risks during potential respiratory pandemics. For optimum natural ventilation, the total area of air inlets must equal at least 10% of the bakery's floor area. Outlet openings should also measure a minimum of 1.2 m². New bakery permits should restrict designs relying solely on single-sided natural ventilation while existing facilities should elevate their systems by adding outlet vents and incorporating mechanical ventilation.

In crowded places such as bakeries, natural ventilation is inadequate to lower infection risks. A hybrid system integrating natural and mechanical methods is essential for improving IAQ and minimizing the spread of respiratory diseases. Mechanical systems should operate continuously during business hours to maintain consistent airflow, dilute airborne contaminants, and supply fresh air. Regular maintenance ensures these systems remain effective. In addition, mechanical ventilation is vital to control heat, smoke, and dust, ensuring a safe working environment in bakeries.

The study reveals that many bakeries lack efficient mechanical ventilation systems, and Iran lacks government guidelines to address this issue. To address this issue, detailed specifications for mechanical ventilation must be created, covering airflow rates, fan types, filtration systems, ductwork design, and control mechanisms. These standards will enable bakeries to manage air quality effectively, reduce health risks, and comply with future regulatory requirements.

Similar to prior studies, this research has specific limitations. The efficacy of natural ventilation depends on local climate factors, such as wind speed, wind patterns, air pressure, and temperature variations, as well as architectural design.[39] Conducted in Semnan Province, located in northeastern Iran, this study's conclusions may not be universally applicable due to climatic differences. Hence, additional studies across diverse regions are needed to document comprehensive guidelines for bakery ventilation. Furthermore, since this investigation was conducted during the winter, seasonal studies are required to address climate variations throughout the year and their impact on natural ventilation efficiency.

Conclusions

This study evaluated natural ventilation practices in traditional bakeries in Semnan Province, Iran, revealing that while 94.4% met basic airflow recommendations, only 40.8% complied with ACH standards. This indicates significant gaps in ventilation compliance, which is crucial for enhancing air quality and reducing airborne respiratory disease risks. The study recommends that the air inlet/outlet area be at least 10% of the floor space. In addition, it suggests integrating mechanical ventilation with natural airflow and maintaining continuous mechanical ventilation during operating hours. These measures could improve IAQ and enhance public health preparedness for respiratory pandemics. However, the present investigation focuses on Semnan Province, which may limit the findings' applicability due to regional climate and architectural differences. Further research across diverse geographical regions is necessary to develop adaptable ventilation strategies for global public health.

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Ethics code

The authors approved this study with Ethical Number: IR.SEMUMS.REC.1401.262.

Conflicts of interest

There are no conflicts of interest.

Authors' contributions

Zeinab Rasouli Divkolaei: Conceptualization; Investigation; Writing – original draft, review, and editing; Khalilollah Moeinian: Conceptualization; Methodology; Project administration; Writing – review and editing; Hamidreza Nassehinia: Methodology; Visualization; Writing – review and editing; Elahe Saleh: Data analysis, validation; Software; Writing – review and editing; Taleb Askaripoor: Conceptualization; Supervision; Data curation; Writing – original draft, review, and editing.

AI was used for writing assistance

ChatGPT and Grammarly were used for grammar and spelling corrections, while the authors reviewed, edited, and approved the final version.

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