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Abstract	This study examines the evolution of the ‘wet markets’ in Hong Kong and Singapore, focusing on some of their recent retrofits in Hong Kong, in which traditional and hybrid-ventilation methods with open facades are upgraded to mechanically ventilated systems with sealed and closed facades. The upgrades from open air to air-tight impacts not only the architectural expression and tectonic representation of these markets buildings, the façade’s openness expressing architectural tenets for civic provisions in the modern city. The upgrades also increases the energy consumption for air exchange and cooling, while challenging the balance of hygiene maintenance, thermal and olfactory comfort in a multiphysics environment. By measuring the particulate concentration in the newly-retrofitted wet markets in Hong Kong that have recently transitioned to mechanical ventilation within sealed facades, and comparing them with the hybrid-ventilated wet markets with open facades, still prevalent in Hong Kong in Singapore, this analysis quantitatively assesses the impacts of different ventilation strategies on the indoor environmental quality of these markets. A significant aspect of our study is the development of a framework to evaluate the benefits and drawbacks of the retrofit strategies for aging wet markets, which were designed with open air, in both cities. Our goal is to offer evidence-based insights and recommendations that can guide future retrofits, as well as shape regulatory policies, ensuring that these vital urban public spaces continue to thrive while adapting to modern standards of health, comfort, and sustainability. The findings will contribute to the still little-studied discussion on urban market renovations.
Keywords (separated by '-')	Indoor air quality - ventilation rate - wet market - air velocity - CO2

From Open Air to Air-Tight: Analyzing the Ventilation Overhaul in Hong Kong's Wet Markets and Its Implications

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Abstract. This study examines the evolution of the 'wet markets' in Hong Kong and Singapore, focusing on some of their recent retrofits in Hong Kong, in which traditional and hybrid-ventilation methods with open facades are upgraded to mechanically ventilated systems with sealed and closed facades. The upgrades from open air to air-tight impacts not only the architectural expression and tectonic representation of these markets buildings, the façade's openness expressing architectural tenets for civic provisions in the modern city. The upgrades also increases the energy consumption for air exchange and cooling, while challenging the balance of hygiene maintenance, thermal and olfactory comfort in a multiphysics environment. By measuring the particulate concentration in the newly-retrofitted wet markets in Hong Kong that have recently transitioned to mechanical ventilation within sealed facades, and comparing them with the hybrid-ventilated wet markets with open facades, still prevalent in Hong Kong in Singapore, this analysis quantitatively assesses the impacts of different ventilation strategies on the indoor environmental quality of these markets. A significant aspect of our study is the development of a framework to evaluate the benefits and drawbacks of the retrofit strategies for aging wet markets, which were designed with open air, in both cities. Our goal is to offer evidence-based insights and recommendations that can guide future retrofits, as well as shape regulatory policies, ensuring that these vital urban public spaces continue to thrive while adapting to modern standards of health, comfort, and sustainability. The findings will contribute to the still little-studied discussion on urban market renovations.

AQ1 AQ2

Keywords: Indoor air quality · ventilation rate · wet market · air velocity · CO2

1 Introduction

The spotlight on wet markets' hygiene during the COVID-19 outbreak highlighted their complex role in public health and ecology, with some studies linking them to the virus's emergence [2]. The resultant ban on wildlife trade aimed to cut zoonotic transmission risks but also spotlighted the socio-economic and conservation challenges [9]. Amidst these discussions, the critical issue of wet markets' ventilation and indoor air quality has remained largely unexplored [8]. Given the aging infrastructure of their prevalent open or

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hybrid-ventilation systems, it is imperative to intensify research and update regulations concerning air quality in these markets, not only to ensure their immediate safety and sustainability but also to inform robust retrofitting strategies for the future.

Pre-COVID research on wet markets primarily concentrated on hygiene, analyzing pathogens on surfaces like cutting boards [3] and in air samples. However, such studies seldom dig further into ventilation, offering limited insight into overall air quality or the effectiveness of airflow systems. This gap is notable particularly in sealed markets, where air sampling reveals little about continuous ventilation dynamics. Existing standards, including ASHRAE 62.1, offer broad guidelines but fall short of addressing the specific needs of wet markets since they are seldomly considered 'indoor', unlike their counter parties such as the supermarkets. Furthermore, the CDC's emphasis on increased ventilation for health [1] reflecting on challenges from COVID-19, but lacks detailed implementation strategies for these unique spaces which arguably were the theoretical source of the disease. This study aims to bridge this gap by evaluating the efficacy of forced ventilation in retrofitted wet markets, particularly within Hong Kong's municipal services buildings, multi-functional and typically built 1980 s–2000 s, to understand its impact on energy usage and indoor air quality in light of the recent sealing of such spaces.

To do so, we leverage micro-controllers and sensors through IoT solutions for high-sample-rate measurements at various sites (mix-mode ventilated markets, air-conditioned markets and shopping centers) as was done in prior studies [4]. Their precisions and accuracies may be lower comparing to commercial sensors, but can nonetheless offer performance aligning with EN-ISO-7726 and EN-16242 standards [7], making them suitable for assessing air flow rates and moist air properties. This data is crucial for evaluating the effectiveness of current ventilation systems and informing necessary improvements. In addition, we will put heavy emphasis on CO2 concentration as proxy for assessing ventilation adequacy and the risk of airborne disease transmission. Emerging studies suggest a direct correlation between lower CO2 levels and reduced transmission risks, challenging the traditional 1000 PPM threshold setaber by ASHRAE [5]. By correlating CO2 data with ventilation metrics, we aim to quantify the ventilation efficiency in sealed and mixed-mode ventilated markets, thereby contributing to the development of more effective ventilation strategies.

2 Methodology

2.1 Site and Instrumentation

Established in 1983 and recently upgraded with sealed envelop and reopened in 2023 with significant local government funding, the Aberdeen Market and Cooked Food Centre (CFC) stands as a typical and representative example among Hong Kong's 39 markets and cooked food centres—87\% of which were constructed before 2000. As the first of its kind to undergo such retrofitting, the Aberdeen CFC showcases a transition from mixed-mode ventilation, which previously linked it directly to the external heat of Hong Kong streets, to a modernized centrally air-conditioned system with sealed envelope.

In our study, we utilized a set of affordable sensors from an Arduino kit, chosen for their wide use in environmental monitoring [4]. We measured temperature and humidity

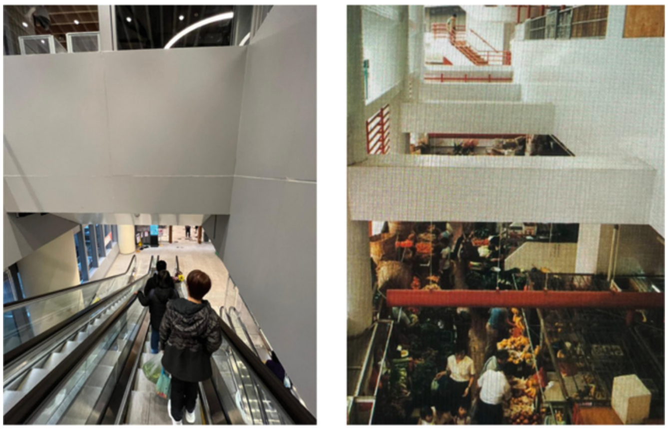

Fig. 1. Same location on escalator during after (left, 2023) and before (right, 1992) the modernization effort at Aberdeen market.

with DHT22 sensors, known for their reliable performance, and used the BME280 sensor for precise air pressure readings (± 0.1 kPa). Initially, we employed an anemometer for air velocity measurements but later opted for the more compact FS3000–1005 to reduce market disruption and improve data accuracy. Each sensor was calibrated with high-end equipment to ensure consistent and accurate data collection [6].

2.2 Experimental Setup and Data Collection

To examine the differences resulting from the modernization by comparing open and enclosed wet markets, we analyzed environmental data from the renovated Aberdeen Market, now supported by central air-conditioning, against the mechanically ventilated Kwun Chung Market CFC, alongside two adjacent shopping malls as references. This selection was aimed at contrasting market ventilation with that of nearby commercial spaces under similar outdoor environmental conditions.

Sensors were placed at 1.2 m high to record air temperature (T_a), humidity (RH), velocity (v_a), and CO2 levels. Our focus areas within these markets were: a) beneath air diffusers/fans, b) the farthest point from these ventilation sources, and c) areas with high foot traffic, like escalators, depicted in Fig. 1. Data was collected bi-seconds from 2 to 4 PM on March 27th, 2024, coinciding with the day's peak temperature of 28 °C, as reported by the HK observatory. Each sensor setup was stabilized for 2 min before measurements to ensure accuracy, especially when transitioning between outdoor and indoor environments.

3 Results and Discussions

Our measurements reveal distinct indoor environmental qualities across the four buildings. Figure 2 highlights these differences, particularly in air temperature and CO2 levels, between open markets (L1-L7) and enclosed spaces (L8 onwards). Our analysis easily delineates the environments: spaces with lower CO2 levels (below 500 ppm) generally exhibit higher air temperatures (above 28 °C), whereas areas with higher CO2 (above

500 ppm) tend to have cooler air (below 23 °C). Our analysis on the measured data revealed significant differences in indoor environmental quality between open (Building 1, L1-L7) and closed (Building 14–17) market configurations. Notably, CO2 levels and air temperatures varied significantly across the studied locations, with the closed market showing close resemblence to that of central-air-conditioned shopping centers, suggesting that the modernization of wet markets has a profound impact on their indoor climates.

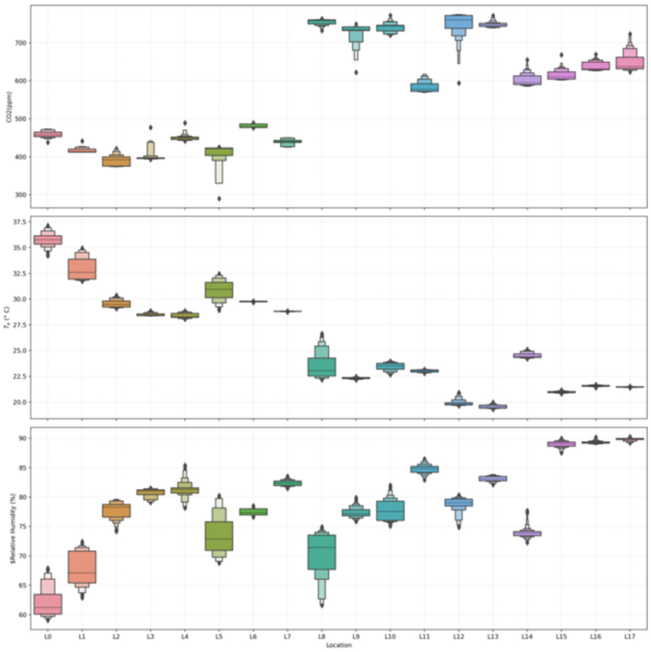

Fig. 2. CO2 level, air temperature and relative humidity measured at various characteristic locations across all four buildings.

Figure 2 illustrates this contrast between CO2 levels and air temperatures between the open and close buildings, i.e. L1-L7 and L8 onwards, respectively. Open markets exhibited higher air temperatures and lower CO2 levels, indicating more natural ventilation and a less controlled environment. Close markets, on the contrary showed lower air temperatures and higher CO2 levels, yet a further increased relative humidity as a result from mechanical ventilation and compressor-driven cooling. In particular, this means a pre-renovation CFC having CO2 leveling around 450 PPM, whereas the closed spaces consistently registered numbers above 600 PPM. This coincides with the relative humidity of the outdoor air got pushed up from roughly 75\% inside the open CFC to above 90\% inside the renovated CFC.

We believe these findings highlight an interesting problem in the indoor air quality in retrofitted markets, where the push for increased ventilation to mitigate virus transmission post-COVID-19 often leads to excessive cooling and energy use. Notably, observed CO2 levels in modernized markets were consistently below the 1000 PPM threshold recommended by ASHRAE, suggesting acceptable (albeit per earlier regulative guidelines) ventilation but raising questions about energy efficiency [1]. This balance between air quality and energy consumption highlights a crucial area for future research, particularly in the context of sustainable urban development and post-pandemic public health strategies.

4 Conclusions and Future Works

Our study serves as a preliminary investigation into the environmental shifts occurring in wet markets as they transition from open-air to fully enclosed formats. Given its exploratory nature, our analysis is constrained by a narrow dataset—observations from a two-hour span on a typical spring day. The limited duration of our data collection, confined to a brief window on a spring day, restricts our ability to encompass the full spectrum of environmental fluctuations, especially the extreme conditions prevalent during the hotter months of August and September, i.e. typical hot days seen in August and September. Future studies should consider a broader temporal scope, including days with higher temperatures and/or higher indoor-outdoor pressure differentials, to understand the impact of the sealing up on indoor air quality and the need for de-humidification.

Our observation suggest that the modernized wet markets may be operating with higher-than-necessary energy usage to maintain air quality, possibly due to an overemphasis on supplying fresh air. Validating our hypothesis regarding the potential for excessive energy consumption in modernized markets necessitates in-depth collaboration with mechanical engineers and facility managers. Such interdisciplinary dialogues are crucial for demystifying the operational logic and efficiency of current ventilation strategies.

Subsequent inquiries should focus on uncovering ventilation strategies that not only optimize energy efficiency but also maintain a delicate equilibrium between air quality, thermal comfort, and humidity management, particularly in the challenging context of hot and humid climates. Such advancements are pivotal for the sustainable evolution and resilience of urban markets in a progressively carbon-neutral era.

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Chapter 9

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