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A study on evaluation of indoor air quality at residential houses in Hanoi (Viet Nam)

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Abstract: Indoor air quality significantly impacts human health and is a major contributor to respiratory and cardiovascular diseases. This study aimed to assess and analyze indoor pollution by measuring environmental parameters inside homes in Hanoi, the capital city of Vietnam, in conjunction with homeowner surveys. The findings indicate that indoor air quality is influenced by the flow and quality of the clean air supply and is further compromised by pollutants generated from human activities. Key pollutants identified include fine particulate matter (PM2.5), carbon dioxide (CO2), total volatile organic compounds (TVOC), and mold, which tend to accumulate in high concentrations within indoor environments, leading to air quality degradation. Based on the results, heat recovery ventilation (HRV) is recommended to use for improving indoor air quality and occupant comfort as well as significantly reducing the energy consumption of air conditioning systems during the summer months.

Keywords: CO2 concentration; Indoor air quality; Heat recovery, PM2.5 particulate matter; TVOC concentration

1. Introduction

Air quality, particularly indoor air quality (IAQ)[1)], has emerged as a significant topic of discussion in recent years. Studies indicate that people spend more than 90% of their time indoors[2)]. According to the World Health Organization (WHO), indoor air pollution leads to approximately 3.2 million deaths annually, including 237,000 deaths among children under five years of age[3)]. In 2022, Hanoi was identified as the most polluted city in the country, with winter average Air Quality Index (AQI) levels[4)] ranging from 150 to 200, exceeding WHO guidelines[5)]. These findings underscore a lack of public awareness regarding IAQ issues[6)]. In Vietnam, standards such as TCVN 13521:2022[7)] and TCVN 5687:2010[8)] have been established for residential and public buildings to define IAQ parameters[9)], although inconsistencies persist[10)] due to various factors. To comprehensively assess urban residential environments[11)] in Hanoi, a research team conducted measurements and surveys in homes. The study aims to evaluate IAQ parameters[12)] and gather homeowner feedback on air quality. The research outcomes are expected to provide detailed assessments of indoor environments[13)], offering practical solutions to improve current residential conditions[14)].

2. Tables and Figures

2.1. Tables

The selected structures for evaluation must be representative of the typical urban residential buildings[15)] in Hanoi, Vietnam. The criteria for selecting these survey structures are as follows:

- Located within the city of Hanoi
- Positioned in the city center or adjacent to major thoroughfares

Based on these criteria, the research team has chosen two residential buildings in Hanoi mentioned in Table 1. Additionally, the selection of these two structures aims to facilitate a comparative analysis of indoor and outdoor air quality.

2.2. Measurement equipment

The indoor air quality (IAQ) parameters will be assessed using the IAQ Monitoring Sensor set and a power consumption meter supplied by the Daikin Group with data collected at five-minute intervals mentioned in Table 2 [16)]. For mold and bacteria sampling, measurement will be

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conducted using filtration methods[17], cultivation techniques[18], or impact methods[19] and will be evaluated based on the following standards: TCVN 10736-16:2017, TCVN 10736-17:2017, TCVN 10736-18:2017.

IAQ Monitoring Sensor will measure the following indicators: CO2 concentration, Fine Dust Concentration PM2.5, TVOC concentration, Temperature, Humidity. Power Meter[20] will measure Thermal Ventilation Consumption Electronics. Timer will measure Air Conditioning Consumer Electronics.

In addition to the measuring devices mentioned above, this research group also utilized a heat recovery ventilation system to help improve air quality in residential spaces[21]. Below are the specifications of the heat recovery ventilation system used by the research group[22].

Table 1: Characteristics of the selected construction project object

	Type of construction	Location	Room volume
1	Collective apartment	Downtown Hanoi	Kid room: 14x3 = 42m3 Master bedroom: 15x3=45m3 Office room: 14x3=42m3 Living room: 32x3=96m3
2	Apartment building	Suburban area of Hanoi City	Bedroom 1: 13,5x3=40.5m3 Bedroom 2: 15.5x3=46.5m3 Bedroom 3: 16.7x3=50.1m3 Living room: 46x3=138m3

Table 2: Parameters to be measured in the research project

	Specifications		Unit	Value		
1	Flow		m^3/h	80	100	120
2	Dehumidification mode		g/kg	Low 13.7	Standard 11.5	High 9.4
3	Air processing efficiency	Cooling efficiency	W	-	-	800
		Cooling power consumption	W	-	-	350
		Heating efficiency	W	-	-	1000
		Heating power consumption	W	-	-	400
4	Device dimensions	Condenser	mm	800×580×250		
		Evaporator	mm	675×284×550		
5	Refrigerant		-	R32		

3. Results and discussion

3.1. Journals and proceedings

- Evaluate the CO2 concentration in the room

The standard TCVN 13521:2022 standard specifies that the permissible CO2 concentration in an indoor environment must be below 1000 ppm. This threshold aligns with common regulations established by many countries worldwide.

Indoor stuffiness can be attributed to various factors, primarily the number of occupants and the architectural design of the house[23]. Figure 1 illustrates the daily variation in CO2 concentration in a bedroom. CO2 levels typically peak between 9:00 PM and 6:30 AM when the room is occupied for sleeping. With the ventilation system operating at level 1, the CO2 concentration remains three times higher than the permissible standard, reaching 3000 ppm from 11 PM to 6 AM. At level 2, CO2 levels decrease to a range of 1500 ppm to 2000 ppm during occupancy, which is an improvement over level 1 but still exceeds the standard (approximately 1000 ppm). Operating the system at level 3 significantly reduces CO2 levels, with fluctuations between 1100 ppm and 1300 ppm, markedly lower than levels 1 and 2. According to the survey, homeowners report a slight improvement in air quality at levels 1 and 2, though they still experience stuffiness, particularly on humid days. However, at level 3, homeowners feel truly comfortable and relaxed.

- Assessing the concentration of TVOC indoors

In the case of the centrally located apartment in Hanoi, which is an older building, the concentration of Total Volatile Organic Compounds (TVOCs) is not attributed to furniture or wall paint but primarily to the homeowner's lifestyle habits[24]. Activities that typically elevate TVOC levels include the use of fragrances (such as perfume, scented candles, and cleaning products), burning incense, and cooking. Figure 2 depicts the TVOC concentration in

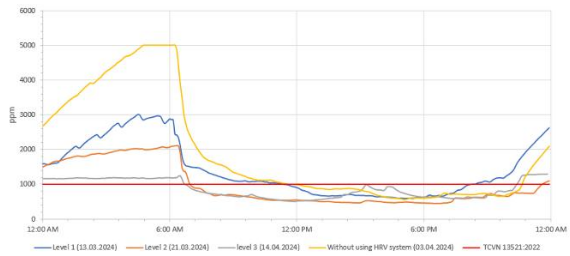

Fig. 1: CO2 concentration chart in bedroom 1

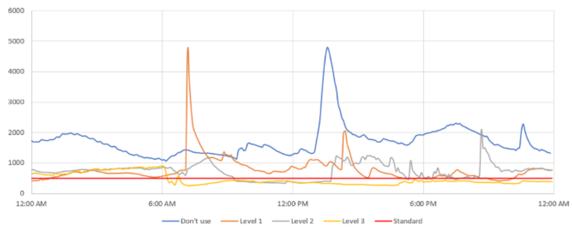

Fig. 2: Chart of TVOC concentration in the living room

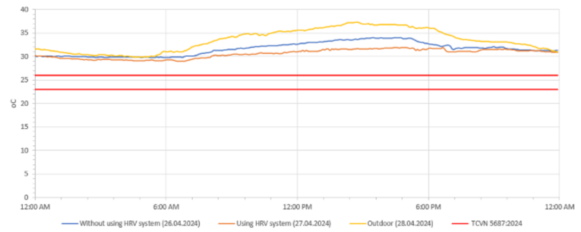

Fig. 3: Temperature chart in the living room

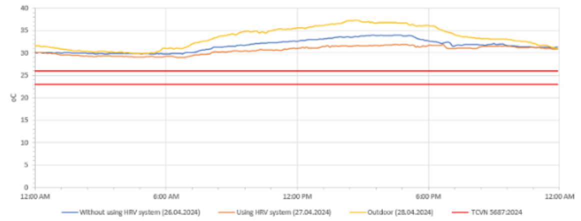

Fig. 4: Chart of humidity in the living room

the living room of the Chua Lang apartment on the first day and the full moon of the lunar calendar. Incense burning generally occurs in the morning between 7-9 AM. It is evident that during these times, TVOC concentration in the room increases substantially, reaching 12000 µg/m3, which is 24 times above the permissible standard. Exposure to such high TVOC levels can lead to breathing difficulties, dizziness, and significant adverse health effects for the homeowner[25].

- Evaluating indoor temperature

Figure 3 demonstrates the effect of ventilation equipment[26] on room temperature during summer when operating in combined heat recovery and cooling mode. In the Northern region during summer, outdoor temperatures can soar to 35-38°C, bringing substantial heat into the room via fresh air, resulting in increased electricity consumption. When the equipment operates in ventilation combined with cooling mode (Allmighty)[27], the low temperature and humidity of the supply air are used to exchange heat with the outdoor fresh air through a heat exchange unit, reducing a portion of the heat and moisture[28]. The fresh air then passes through a cold coil for further cooling and dehumidification. Measurement results indicate that the heat recovery and cooling function of the ventilation equipment lowers room temperature by approximately 2-3°C compared to the outdoor temperature and by 2°C compared to not using the equipment, thereby conserving energy consumption for air conditioning units.

- Evaluating indoor humidity level

The dehumidifying function (Almighty ERV) of the device is designed to control indoor humidity levels. Northern Vietnam experiences a humid season, with outdoor humidity reaching up to 90-100%[29]. Figure 4 illustrates that on humid days, opening windows for natural ventilation (without using a heat recovery ventilation device) will increase indoor humidity, maintaining it at a high level of 85-90% when outdoor humidity is 90-100%. The dehumidifying ventilation mode[30] of the device

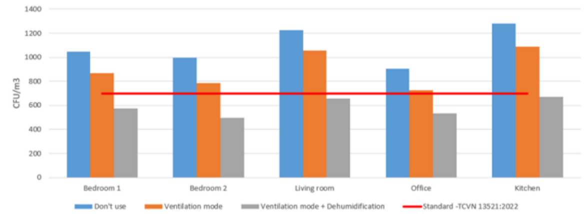

Fig. 5: Chart of indoor mold concentration

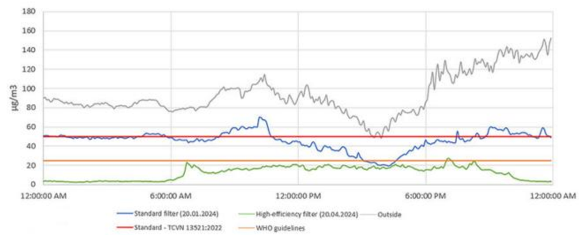

Fig. 6: Compares the dust filtration effectiveness of standard filters and high-efficiency filters

processes the humidity of the incoming fresh air before it enters the room. Consequently, indoor humidity is maintained around 70-80%, approximately 10% lower than with natural ventilation. However, there are still instances when indoor humidity exceeds permissible standards due to high outdoor humidity[31].

- Evaluate the total amount of mold and bacteria in the house

According to the survey, homeowners experience significant discomfort[32] during humid weather. High humidity levels in the room facilitate mold growth, and the toxins produced by mold can enter the body, leading to health issues[33]. Figure 5 shows the results of mold sampling at the surveyed location in March (during the humid period), with mold concentrations in rooms without using heat recovery ventilation equipment ranging from 1000 to 1300 CFU/m3, exceeding the standard of 300 to 600 CFU/m3. By using the dehumidifying ventilation mode of the heat recovery ventilation unit to treat the humidity of fresh air before supplying it to the room, mold concentrations decreased significantly. Indoor mold levels ranged from 500 to 670 CFU/m3, which is lower by about 500 to 630 CFU/m3 compared to not using the equipment[34]. Figure 6 compares the dust filtration efficiency of a standard filter and a high-efficiency filter, showing that the high-efficiency filter significantly increases filtration capacity and brings the indicators below the permissible limits.

3.1.1. Evaluate the concentration of fine dust PM2.5

Standard filters maintain indoor dust concentrations at 25-50 µg/m3, meeting the TCVN 13521:2022 standard but still exceeding WHO guidelines. When homeowners open windows, external dust infiltrates, causing indoor dust levels to surpass permissible standards, indicating that homeowner habits significantly impact the dust filtration

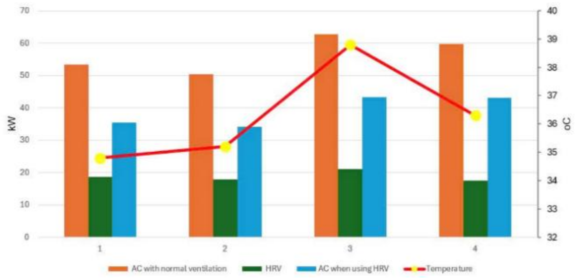

Fig. 7: Energy consumption chart of air conditioner

efficiency of the device[35]. With high-efficiency filters, indoor PM2.5 concentrations range from 4 to 5 µg/m3 when outdoor dust levels are 75 to 90 µg/m3. As outdoor dust levels increase to 100-150 µg/m3, indoor concentration rises to 20-25 µg/m3.

3.2. Evaluating the performance of air conditioner cooling support

Figure 7 shows a significant difference was identified in evaluating the impact of heat recovery ventilators on reducing air conditioning energy consumption. During the study period, outdoor temperatures consistently ranged from 34 to over 38 degrees Celsius. Findings showed that with standard ventilation, the air conditioner consumed 224.35 kWh per month. However, when the heat recovery ventilator was employed, this consumption dropped to 158.05 kWh. The combined energy usage of both the air conditioner and the heat recovery ventilator was only marginally higher than that of the air conditioner alone, by approximately 0.8 to 1 kW. These results indicate that heat recovery ventilation technology not only substantially lowers air conditioning energy use but also improves indoor air quality.

4. Conclusions

From an objective analysis and evaluation of the data collected by the measuring devices, combined with subjective opinions and comments from homeowners, it is evident that the air quality in Hanoi's residential areas is often significantly worse than the external environment, failing to meet life needs and directly affecting human health. This poor air quality is largely influenced by living habits and activities.

The thermal ventilation device provided by Daikin Japan for the experiment has shown effectiveness both in measured parameters and user perception. Ventilation devices have demonstrated significant improvements in indoor air treatment: CO2 levels dropped from over 5000 ppm to near the standard 1000 ppm during nighttime sleep; reductions in PM2.5 and TVOC concentrations occurred much faster compared to without the device. Furthermore, in extreme weather conditions, such as high temperatures (>30°C) or high humidity, thermal ventilation devices can improve indoor temperature and humidity to meet national standards (TCVN 5687-2010).

It is expected that the research and future studies will contribute to developing national standards for indoor air quality, integrating air quality standards into mandatory building codes to enhance human physical and mental health.

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