Aerosol and Air Quality Research

ORIGINAL RESEARCH
https://doi.org/10.4209/aaqr.230225

Survey of Indoor Air Pollution Health Literacy among Community-dwelling Adults in Taiwan

Jia-Ling Wu[1], Yu-Han Huang[1], Yi-Chin Huang[1], Chien-Cheng Jung[2], Pei-Chen Lee[1], Ming-Yeng Lin[3], Wen-Hsuan Hou[1,5,6,7†], Chung-Yi Li[1,2,4*†]

[1] Department of Public Health, College of Medicine, National Cheng Kung University, Tainan, Taiwan
[2] Department of Public Health, College of Public Health, China Medical University, Taichung, Taiwan
[3] Department of Environmental and Occupational Health, College of Medicine, National Cheng Kung University, Tainan, Taiwan
[4] Department of Healthcare Administration, College of Medical and Health Science, Asia University, Taichung, Taiwan
[5] Department of Physical Medicine and Rehabilitation, School of Medicine, College of Medicine, Taipei Medical University, Taipei, Taiwan
[6] Cochrane Taiwan, Taipei Medical University, Taipei, Taiwan
[7] Department of Physical Medicine and Rehabilitation, Taipei Medical University Hospital, Taipei, Taiwan

OPEN ACCESS

Received: October 28, 2023
Revised: March 11, 2024
Accepted: March 13, 2024

*** Corresponding Author:**
cyli99@mail.ncku.edu.tw

† These authors contributed equally to this work

Publisher:
Taiwan Association for Aerosol Research
ISSN: 1680-8584 print
ISSN: 2071-1409 online

ABSTRACT

This study aimed to investigate the level of indoor air pollution health literacy (IAPHL) among adult residents of Taiwan and the associated covariates. A cross-sectional web-based online survey of 647 adults in Taiwan was conducted from May to October 2021 using a reliable and valid IAPHL instrument. We used weighted multiple linear regression models to identify covariates significantly associated with overall and four matric-specific IAPHL scores. The weighted sample size was 616 subjects aged between 20 and 88 years old (mean: 45.8 years, standard deviation: 18.1). Generally, adult residents of Taiwan showed only a moderate level of overall IAPHL, with the highest and lowest matric-specific score for "understanding" and "appraising," respectively. The key factors associated with adults' IAPHL included sex, age, work related to indoor air pollution, smoking status, exposure to second-hand smoke, budget for improving indoor air quality, and number of beneficial goods used. The community-dwelling adults in Taiwan had only moderate levels of IAPHL. Adults with certain characteristics associated with low IAPHL should be the objects of further educational interventions or public health policy-making aiming to improve IAPHL. To improve the IAPHL level of adults, we might need to focus on characteristics such as indoor air pollution information provision and health risk perceptions.

Keywords: Indoor air pollution, Environmental health literacy, Health competency, Cross-sectional study, Community health

1 INTRODUCTION

The National Human Activity Pattern Survey reported that humans spend over 85% of their time in indoor environments, including homes, schools, offices, or other buildings, during the day (Klepeis *et al.*, 2001). Therefore, indoor air quality (IAQ), which is defined as the quality of the air in and around buildings, may strongly affect the health, productivity, and comfort of individuals living and working in buildings (U.S. EPA, 2023). Very fine droplets, particles, and microbiomes may accumulate in and spread through the air in indoor environments. In developed countries, including Taiwan, indoor air pollutants include total volatile organic compounds (Chen *et al.*, 2016), CO, particulate matter with an aerosol diameter of 2.5 ($PM_{2.5}$), particulate matter with an aerosol diameter of 10 (PM_{10}), and microbiological load (Chen *et al.*, 2016; Fonseca *et al.*, 2022; Jung *et al.*, 2015), all of which play significant roles in determining IAQ, along with the influence of outdoor air quality. According to the U.S. Environmental Protection Agency, air pollutant concentration levels may be 2–5 times higher indoors than outdoors (U.S. EPA, 2023). The number of deaths attributed to indoor air pollution is large, at 3.8 million per year (WHO, 2023). In consideration of the influence of high temperatures and humidity in indoor spaces, particularly in Taiwan's humid subtropical climate, the health risks associated with exposure to indoor air pollution are pronounced (Fang *et al.*, 1998).

Health literacy and awareness are growing in the public health domain. Health literacy can support the promotion of health equity by improving people's access to health information and capacity to use it effectively (Van den Broucke, 2014). Environmental health literacy (EHL), defined as the ability to seek, understand, evaluate, and apply environmental health information to promote the adoption of informed choices, reduction of health risks, improvement of the quality of life, and protection of the environment, has gained emphasis owing to the recent increase in public awareness of environmental pollution (Lindsey *et al.*, 2021). Accordingly, enhancing EHL specifically related to indoor air pollution is evidently needed.

While previous studies have primarily focused on risk assessment and monitoring of IAQ, limited information exists regarding population-level IAPHL (Jung *et al.*, 2022; Kishi *et al.*, 2018; Sun *et al.*, 2019). Some studies have illustrated the influence of sociodemographic characteristics and health behaviors, such as age, education level, race/ethnicity, socioeconomic status, smoking, drinking, physical activities, and self-consumption, on an individual's health literacy (Garcia-Codina *et al.*, 2019; Sørensen *et al.*, 2012). These covariates have been predominantly associated with general health literacy rather than specifically with indoor air pollution health literacy (IAPHL). Scant information exists regarding IAPHL at the population level.

To this end, we utilize a previously developed and validated IAPHL instrument based on the European Health Literacy Survey Questionnaire (HLS-EU-Q) conceptual model. This model comprises 12 constructs, covering 4 health literacy competencies (access, understanding, appraisal, and application) across 3 health domains (healthcare, disease prevention, and health promotion) (Wu *et al.*, 2022). We conducted a cross-sectional survey using a national sample of adult community dwellers to investigate the level of overall and four matric-specific (i.e., accessing, understanding, appraising, and applying) IAPHL scores and to identify the factors related to IAPHL scores, providing insights for targeted interventions to minimize health risks associated with indoor air pollutants.

2 METHODS

2.1 Study Design and Participants

A cross-sectional study was conducted between May 2021 and October 2021 through an online video survey owing to the COVID-19 pandemic. The sample size required for this survey was calculated through multiple linear regression (Jan and Shieh, 2019). The sample size of 478 achieved 90% power to detect an effect size (f^2) of 0.050 attributable to 8 independent variable(s) using an F-test with a significance level (alpha) of 0.050. The variables tested were adjusted for 13 additional independent variable(s). The calculations assumed an unconditional (random X's) model. The study sample finally consisted of 647 participants from Taiwan, aged 20 years and above, who completed the survey, with a higher-than-expected response rate of 89.6%. The participants were selected via convenience quota sampling. While a convenient sample through the snowball sampling of the study participants was included in this study, quota sampling was also performed to assure the representativeness of the sample concerning the region (north, central, south, and east/remote island), gender, and age group (20–39 years, 40–65 years, and over 65 years) distribution of Taiwan's population in 2020. For additional information on the sample, see the previous study (Wu *et al.*, 2022). Ethical approval for this study was obtained from the Institutional Review Board of the National Cheng Kung University (No. 110–213).

2.2 IAPHL Instrument and Measurements

Information on reliability and validity was published in our previous study (Wu *et al.*, 2022). The IAPHL instrument was developed on the basis of the integrated health literacy conceptual model proposed by HLS-EU-Q, and the psychometric properties of the IAPHL instrument were validated. A 38-item instrument was established, covering 12 constructs, including 4 information competencies, namely, access, understanding, appraisal, and application, in 3 health domains, that is, healthcare, disease prevention, and health promotion, from individuals to communities to assess IAPHL. The 38-item IAPHL instrument was rated on a 4-point Likert-type scale ranging from 1 (very difficult) to 4 (very easy) and used to indicate the participants' IAPHL level. If the response of a participant was "*I do not know*" or "*I have no experience*," then it was coded as a missing value. The overall IAPHL score was calculated as the mean of the scores of all the relevant items. Thus, the score ranged from 1 to 4, and the higher the score, the better the health literacy. In addition to the overall IAPHL score, four matric-specific scores, that is, accessing, understanding, appraising, and applying, were calculated to indicate the information competencies.

2.3 Covariates

Studies showed that a number of factors, including personal, sociodemographic, socioenvironmental, and situational determinants, might influence an individual's health literacy (Sørensen *et al.*, 2012). Sociodemographic characteristics include gender, age, education level (middle school or lower, high school, college, postgraduate studies), current occupation (10 occupational categories), living arrangement (living alone, living with children, living with older students, or living with elderly individuals), and region of residence (north, central, south, or east). The occupational classification was based on the Standard Occupational Classification System of Taiwan, in which the inter-rater reliability was substantial (Li *et al.*, 2000).

The questionnaire was administered to collect IAPHL-related information, specifically work related to indoor air pollution (i.e., "*Is your or your household members' work related to indoor air pollution, or may you and your co-inhabitants obtain indoor air pollution information at work*?" Yes or No), smoking status ("Nonsmoker," "Former smoker," or "Current smoker"), exposure to second-hand smoke (No or Yes), budget for improving IAQ (e.g., "*How much are you willing to spend on products that can improve indoor air quality*?" with four spending categories: not willing to spend on such products, less than 10%, 11%–20%, or more than 21% of my income), factors affecting IAQ (e.g., "*Which of the following situations do you think will affect indoor air quality?*"—using air freshener or perfume, using insecticide or disinfectant, using curtains, using detergent, using carpet, cooking without a range hood, turning on a window- or split-type air conditioner in an interior space, keeping a furry animal, efflorescence on walls, worshipping with an incense stick, smoking, some of the situations, or all the situations), use of beneficial products in your residence (e.g., "*Which of the following do you have or use in your residence*?"—air purifier, air freshener, dehumidifier, wallpaper, incense burner/candles/and so on, eco-friendly paint, curtains, potted plants, carpet, any, or none), and hours per day spent indoors.

2.4 Statistical Analysis

In this study, weighted analysis was conducted using stratification weights based on the region (north, central, south, and east/remote island), gender, and age group (20–39 years, 40–65 years, or over 65 years) distribution of Taiwan's population in 2020 to mitigate the effect of any sample imbalances.

Continuous variables were expressed as means (standard deviation [SD]), and categorical variables were expressed as numbers (percentage) to describe the demographics and quantitative parameters of the study participants. The IAPHL score was presented as means (± SD) and medians (interquartile range), and a comparison of the differences between the four matric-specific IAPHL scores was conducted with a linear regression model with generalized estimating equations (GEEs), which considered the within-subject correlations of the matric-specific scores from the same subject.

After the descriptive analysis, a multivariate linear regression model was employed with the stepwise method to identify the covariates significantly associated with the overall and matric-specific IAPHL scores. The linear relationships were verified through scatterplots, which were visually inspected for linearity. The assumptions of normality, homoscedasticity, independence, and multicollinearity were also validated for the linear regression model by examining the residual plots and calculating the variance inflation factor, and no violation of the above assumptions was found. The robustness for handling missing data was assessed through sensitivity analysis, with a single imputation as "1." We employed quantitative bias analysis to assess the potential impact of unmeasured confounding. To quantify this impact, we calculated E-values (VanderWeele and Ding, 2017), measuring the minimum effect needed for an unmeasured confounder on both exposure and outcome to nullify observed exposure-outcome associations. All the statistical analyses and graphing were performed using R version 4.1.3 or SAS version 9.4 (SAS Institute, Cary, NC). All the tests were two sided, and statistical significance was defined as a p-value of less than 0.05.

3 RESULTS AND DISCUSSION

3.1 Results

After the unequal probability of sample selection was accounted for in terms of age, sex, and geographical stratifications, a total of 616 participants were included in the weighted analyses. The analyzed sample comprised 304 males (49%) and 312 females (51%). Table 1 shows that the participants had a mean age ± SD of 45.8 ± 18.1 years, were highly educated (71% completed college or higher), and lived with co-inhabitants (n = 528, 86%). The majority (71%) of the participants did not obtain additional information about indoor air pollution from work.

The mean ± SD score of the four matrices (i.e., accessing, understanding, appraising, and applying) was 2.37 ± 0.74, 2.58 ± 0.72, 2.36 ± 0.64, and 2.51 ± 0.69, respectively. The weighted regression model with GEEs indicated statistical significance ($p < 0.0001$) for comparing differences among the four matric-specific scores, with the highest and lowest matric-specific score noted for "understanding" and "appraising" competencies, respectively (Table 2).

Table 3 presents the results of the weighted multiple linear regression models, which indicated the variables significantly associated with the overall and four matric-specific IAPHL scores. The covariates significantly associated with the overall IAPHL score included gender, age, work related to indoor air pollution, smoking status, exposure to second-hand smoke, budget for

Table 1. Demographic characteristics of participants (N = 616).

Variable	n (%)
Sex	
Male	304 (49.35)
Female	312 (50.65)
Age (years)	
Mean ± SD	45.78 ± 18.07
20–34	203 (32.92)
35–44	78 (12.58)
45–54	139 (22.60)
55–64	69 (11.26)
≥ 65	127 (20.64)
Education level	
Middle school or lower	75 (12.10)
High school	105 (17.04)
College/undergraduate	323 (52.44)
Graduate	113 (18.42)
Occupation	
Finance, banking, insurance, real estate	64 (10.43)
Industrial production, commercial manufacturing, retail, buy and sell	105 (17.01)
Information technology, automation	29 (4.67)

Table 1. (*continued*).

Variable	n (%)
Construction, fittings, housing	27 (4.30)
Accommodations, food preparation and servicing	33 (5.37)
Transport, logistics, port, airport, telecommunication	22 (3.57)
Culture, design, sports, tourism, leisure, education, research, training	116 (18.79)
Healthcare, care, welfare, social work	32 (5.23)
Government administration, policy adviser, military affairs, nonprofit organization	47 (7.59)
Student	108 (17.58)
Others (e.g., retiree, housekeeper)	34 (5.45)
Living arrangement	
Living alone	88 (14.32)
Living with someone [1]	528 (85.68)
Children under 12 years of age	115 (18.65)
Student over 12 years of age	489 (79.35)
Individual above 65 years of age	179 (29.08)
Residence in Taiwan	
North	252 (40.91)
Central	142 (23.05)
South	181 (29.38)
East	41 (6.66)
Work related to indoor air pollution	
Yes	180 (29.21)
No	436 (70.79)
Smoking status	
Nonsmoker	498 (80.85)
Former smoker	83 (13.52)
Current smoker	35 (5.62)
Exposure to second-hand smoke	
Yes	228 (37.09)
No	388 (62.91)
Budget for improving IAQ	
Not willing to spend on specific products	77 (12.43)
Less than 10%	335 (54.33)
11%–20%	153 (24.91)
More than 21%	51 (8.32)
Factors affecting IAQ	
Number of correct answers	4.53 ± 3.52
Number of wrong answers	6.47 ± 3.52
Use of IAQ-benefiting products in residence	
Number of beneficial products used	1.83 ± 1.08
Number of harmful products used	1.48 ± 1.19
Hours spent indoors per day	
Mean ± SD	16.14 ± 5.35
0–5 hours	19 (3.02)
6–10 hours	124 (20.20)
11–15 hours	95 (15.46)
16–19 hours	96 (15.57)
More than 20 hours	282 (45.74)

Note: IAQ—indoor air quality.

[1] Living with someone is a multiple-choice question, that is, an interviewee may be living with a child under the age of 12 years and a person above the age of 65 years. Thus, the total for children under 12 years of age, a student over 12 years of age, and individual over 65 years of age (n = 783) is greater than the total number of the respondents living with someone (n = 528).

Table 2. Descriptive statistics of overall and matric-specific scores for IAPHL.

Matrix	Mean ± SD	Median (Q1, Q3)	Min.	Max.
Overall	2.46 ± 0.62	2.50 (2.11, 2.87)	0.08	4.00
Accessing	2.37 ± 0.74	2.40 (2.00, 2.80)	0.00	4.00
Understanding	2.58 ± 0.72	2.64 (2.09, 3.09)	0.00	4.00
Appraising	2.36 ± 0.64	2.33 (2.00, 2.78)	0.00	4.00
Applying	2.51 ± 0.69	2.63 (2.13, 3.00)	0.00	4.00
p-value	< 0.0001[1]			

Note: SD—standard deviation; Q1—25th percentile; Q3—75th percentile; Min.—minimum; Max.—maximum.
[1] *p*-values for comparison between the four matric-specific IAPHL scores by using a linear regression model with generalized estimating equations.

improving IAQ, and number of IAQ-benefiting products used. In contrast to people whose work related to indoor air pollution had significantly higher overall IAPHL score (adjusted $\beta = 0.26$), those who were former smokers (adjusted $\beta = -0.27$) and current smokers (adjusted $\beta = -0.46$) had lower IAPHL scores. The participants willing to spend on products that can improve IAQ had significantly high IAPHL scores. The results of the four matric-specific IAPHL scores were similar to the results of the overall score.

To explore potential interactions, we conducted analyses examining the correlation between demographic characteristics and occupations associated with indoor air pollution. Across all analyses, the consistent findings indicated the absence of a statistically significant interaction between the selected variables. For quantitative bias analysis, we prioritized factors influencing the level of IAPHL, namely work content related to indoor air pollution. As the exposure effect of work content is presented as an additive effect rather than multiplicative effect, i.e., a risk ratio scale, we converted the naive point estimate to an approximate risk ratio (VanderWeele and Ding, 2017), which is estimated at 1.02. Based on the risk ratio of 1.02 and its corresponding confidence limits, the E-value was computed at 2.54, with a lower confidence interval limit of 2.05. An E-value of 2.54 means that there could be unmeasured confounders associated with both the exposure and the outcome, and its strength of association would need to be at least 2.54 to explain away the observed association. For nullifying the association, an unmeasured confounder must be linked to both work content related to indoor air pollution and the level of IAPHL, with a risk ratio of at least 2.54. Given that we have included most of the known factors associated with indoor air pollution health literacy including personal sociodemographic, socioenvironmental and situational determinants, unmeasured confounders were less likely to surpass the corresponding E-values in associations with exposure and the level of IAPHL. It suggests that the association between work content and indoor air health literacy is less likely to be completely explained by unmeasured confounding.

3.2 Discussion

People spend a considerable amount of time in enclosed buildings (Klepeis *et al.*, 2001), so the resolution of indoor air-related health problems and the improvement of people's indoor health literacy are essential. Nonetheless, research on the degree of IAPHL and its contributors is scarce. This paper is believed to be the first one that presents the community-dwelling adults' overall and four matric-specific IAPHL scores, as well as their correlates.

The community-dwelling adults in Taiwan had only a moderate (2.36–2.58 out of 4) level of IAPHL, with the lowest and highest matric-specific scores for "appraising" and "understanding" competencies, respectively. In Taiwan, people had high competency of understanding and applying/using the information available to them to avoid overexposure to indoor air pollution but had low competency in the access to indoor air pollution information that they needed. They also had low ability in interpreting and evaluating (i.e., appraising) the information regarding indoor air pollution. This finding is similar to the result of a previous general health literacy survey conducted in eight European countries, which suggested that the ability to "appraise" health information is perceived as more difficult than "understanding" it (Pelikan and Ganahl, 2017).

Table 3. Multiple linear regression models of overall and matric-specific scores for IAPHL.

Covariates	Overall	Accessing	Understanding	Appraising	Applying
	Adjusted β (95% CI)	Adjusted β (95% CI)	Adjusted β (95% CI)	Adjusted β (95% CI)	Adjusted β (95% CI)
Sex (Ref. = female)	0.14 (0.04, 0.24)**	0.15 (0.02, 0.27)*	0.12 (0.00, 0.23)	0.15 (0.04, 0.26)**	0.13 (0.02, 0.25)*
Age	–0.005 (–0.008, –0.002)**	–0.006 (–0.01, –0.002)**	–0.007 (–0.01, –0.003)***	–	–0.004 (–0.01, –0.0001)*
Education level					
Middle school or lower	Ref.	Ref.	Ref.	Ref.	Ref.
High school	0.17 (–0.01, 0.35)	0.28 (0.06, 0.49)*	0.13 (–0.08, 0.34)	0.22 (0.04, 0.40)*	0.18 (–0.03, 0.38)
College/undergraduate	0.03 (–0.15, 0.21)	0.15 (–0.07, 0.37)	–0.04 (–0.26, 0.17)	0.16 (–0.002, 0.33)	0.004 (–0.20, 0.21)
Graduate	0.14 (–0.06, 0.35)	0.24 (–0.01, 0.48)	0.12 (–0.12, 0.36)	0.26 (0.07, 0.45)**	0.11 (–0.12, 0.34)
Work related to indoor air pollution					
No	Ref.	Ref.	Ref.	Ref.	Ref.
Yes	0.26 (0.17, 0.36)***	0.26 (0.14, 0.38)***	0.29 (0.17, 0.41)***	0.25 (0.15, 0.36)***	0.24 (0.13, 0.35)***
Smoking status					
Non-smoker	Ref.	Ref.	Ref.	Ref.	Ref.
Former smoker	–0.27 (–0.41, –0.12)***	–0.25 (–0.43, –0.08)**	–0.28 (–0.45, –0.11)**	–0.29 (–0.44, –0.14)***	–0.27 (–0.43, –0.11)**
Current smoker	–0.46 (–0.67, –0.26)***	–0.37 (–0.62, –0.12)**	–0.48 (–0.72, –0.24)***	–0.50 (–0.72, –0.28)***	–0.54 (–0.77, –0.31)***
Exposure to second-hand smoke					
No	Ref.	Ref.	Ref.	Ref.	Ref.
Yes	–0.12 (–0.21, –0.02)*	–0.11 (–0.22, 0.003)	–0.17 (–0.28, –0.06)**	–	–
Budget for improving IAQ					
Not willing to spend	Ref.	Ref.	Ref.	Ref.	Ref.
Less than 10%	0.29 (0.14, 0.45)***	0.34 (0.15, 0.52)***	0.24 (0.06, 0.42)**	0.24 (0.08, 0.40)**	0.42 (0.25, 0.59)***
11%–20%	0.40 (0.23, 0.57)***	0.43 (0.22, 0.63)***	0.38 (0.18, 0.58)**	0.36 (0.18, 0.53)***	0.51 (0.32, 0.70)***
More than 21%	0.41 (0.20, 0.62)***	0.47 (0.21, 0.72)***	0.36 (0.11, 0.61)*	0.33 (0.11, 0.58)**	0.57 (0.33, 0.81)***
Number of beneficial products used	0.05 (0.01, 0.09)*	–	0.07 (0.02, 0.12)*	–	0.07 (0.02, 0.12)**
Hours per day spent indoors	–	–	–	–	0.01 (0.004, 0.02)**

Note: IAQ—indoor air quality, CI—confidence interval.
*p-value < 0.05; **p-value < 0.01; ***p-value < 0.001.

Our study results confirmed another health literacy survey in Germany, in which the lowest percentage of respondents (47.7%) indicated that they had difficulties understanding health information (Schaeffer *et al.*, 2021).

A systematic review has highlighted critical problems with regard to health-related fake news shared on social media platforms, either by mistake or on purpose. Such fake news could markedly threaten an individual's health quality (Melchior and Oliveira, 2022), especially when one lacks the competence to appraise adequate and applicable indoor air pollution-related information. The barrier in appraising health literacy was associated with lack of careful consideration and relevant knowledge and familiarity with fake news, whose dissemination has increased substantially in recent years (Pennycook and Rand, 2021). One study demonstrated that the public has a limited health risk perception of indoor air pollutants. Nonetheless, the public perceives universities and research institutes as the most credible sources of health-related information, even though the media are considered the most important source of information on the health risks of indoor air pollutants (Dingle and Lalla, 2002). The overall and matric-specific IAPHL scores from the present study's survey are similar to the results of a previous survey on ambient air pollution health literacy (AAPHL), which reported that understanding information related to air pollution is easier than appraising it (Hou *et al.*, 2021). Among the four matric-specific competencies of IAPHL and AAPHL, the "appraising" matrix was the most difficult, which is similar to that in chronic disease health literacy research, where the lowest-scoring domain was the appraisal of health information (Dinh *et al.*, 2020). Elevating civil awareness and increasing the public's appraisal ability to distinguish between correct information, erroneous information, and "fake news" through the dissemination of health information are important. This outcome implied that evidence-based risk communication can help translate evidence into risk messages and provide accurate, understandable, and meaningful information to individuals with varying levels of basic and scientific literacy (Finn and O'Fallon, 2017).

Among the potential determinants of health literacy proposed by the European Commission, the distinct factors impacting health literacy include personal (e.g., age, education, gender, race, socioeconomic status, occupation, and income literacy), societal and environmental (e.g., culture, social systems, and political forces), and situational (e.g., social support, family and peer influence, media use, and the physical environment) determinants (Sørensen *et al.*, 2012). The present study indicated that the determinants of IAPHL include gender, age, educational attainment (personal determinants), smoking status (situational determinants), and work related to indoor air pollution (socioenvironmental determinants), which are generally consistent with what the European Commission proposed.

Apart from the European Commission proposal, our study findings are also consistent with those of a previous systematic review, reporting that old age and low education level are independent predictors of low health literacy among patients with heart failure and breast cancer (Cajita *et al.*, 2016; Shen *et al.*, 2019). Similarly, a cross-sectional study on community-dwelling elderly individuals identified old age and low educational attainment as significant predictors of low health literacy (Baker *et al.*, 2000; Hou *et al.*, 2021). The present study demonstrated that residents with work related to indoor air pollution or nonsmoking status were associated with a high level of IAPHL. Quick *et al.* (2009) found that nonsmokers exhibited a significantly strong awareness of tobacco-associated risks, a preventive attitude toward the dangers of environmental tobacco smoke, and support for clean indoor air policies. This finding corresponds to understanding, appraising, and applying health literacy compared to smokers (Quick *et al.*, 2009).

Although most smokers do not care about IAQ and tend to neglect the related diseases caused by indoor air pollutants, a Korean study reported no significant association between smokers' IAQ perceptions and smoking status (Kim *et al.*, 2019). On the contrary, a study supports the notion that the perception of IAQ is mainly related to smoking status (Langer *et al.*, 2017). Smokers usually fail to accomplish the four domains of the indoor air pollution health information processing because they have insufficient awareness of indoor air pollution and its impact on health and do not perceive smoke-free indoor environments as important. Consequently, they typically do not actively seek information or knowledge about indoor air pollution, and their ability to mitigate excessive exposure to indoor air pollution is compromised. A previous study noted that an individual's knowledge, attitude, subjective norms, favorable support, and awareness of the risks associated with environmental exposure, such as to tobacco smoke, may be increased if his/her family members and/or coworkers encourage preventive behavioral intention and support clean indoor air policies (Quick *et al.*, 2009). The more individuals believe that overexposure to indoor air pollution is risky, the more likely that they will remind their co-inhabitants to support clean indoor air environmental conditions (Badland and Duncan, 2009).

To the best of our knowledge, this study is the first nationwide survey of community dwellers on IAPHL levels, which also identified potential determinants of IAPHL. Unlike most prior studies that emphasized perceived health symptoms related to IAQ (Raufman *et al.*, 2020) or aimed to capture participants' perceptions of IAQ and to explore the factors that influence participants' behavior (Tomsho *et al.*, 2022), our study assessed an individual's comprehensive domain of health literacy on indoor air pollution among inhabitants. The IAPHL based on the HLS-EU-Q conceptual model not only assessed an individual's knowledge and behaviors toward IAPHL but also emphasized an individual's competence of obtaining and evaluating health information related to indoor air pollution (Wu *et al.*, 2022). Several studies reported the global burden of indoor air pollution-induced cardiorespiratory, pediatric, and maternal diseases, especially in low-income countries (Badland and Duncan, 2009; Lee *et al.*, 2020; Pandey *et al.*, 2021; Yin *et al.*, 2020). Most previous studies indicated a positive association between air pollution exposure and risk perception through the influence of behavior, experience, socioeconomic factors, and information/communication (Cho *et al.*, 2020; Dong *et al.*, 2019; Pu *et al.*, 2019). A study indicated that increased levels of EHL may contribute to the improvement of health outcomes related to household air pollution (Finn and O'Fallon, 2017). Improved EHL levels, through enhancing individuals' knowledge and understanding of the risks and mitigation strategies associated with indoor air pollution, can empower individuals to make informed decisions and adopt healthy practices within their households (Mendell *et al.*, 2011). The current study contributes to the understanding of IAPHL, emphasizing the importance of targeted risk communication and awareness campaigns.

This study has several important limitations that need mentioning. First, the participants recruited via convenience sampling might not be representative of the whole adult population in Taiwan. Nonetheless, we managed to weigh our sample with the region of residence, gender, and age group of Taiwan's population to increase the representativeness of the study sample. Second, potential selection bias was a challenge in this study because data were collected through an online video survey, resulting in the study sample being composed disproportionally of adults with considerable capability in operating communication devices and access to the Internet (Andrade, 2020; Wright, 2005). This matter was particularly true for some elderly individuals willing to participate in an online survey only when they live with someone who has relatively good health and high education level and can help them (Dodge *et al.*, 2014). Such a limitation was unavoidable in research conducted during the COVID-19 pandemic period, in which an on-site face-to-face interview was almost impossible. Third, one potential selection bias was related to the voluntariness. People who choose not to participate in the study tend to have low interest in the research topic. Fourth, the presence of two potential sources of information bias in our study was noted. The first potential source of information bias from health literacy depends on cognitive and communicative skills (Nutbeam, 2000), but the cognitive and communicative functions of the participants were not assessed in this study. Nevertheless, additional response categories (i.e., "*I do not know*" or "*I have no experience*") were recorded to preserve the participants' comprehension of the questionnaire items. The second source of potential information bias was related to the questionnaire length. A lengthy questionnaire can potentially introduce response burden and affect the quality of responses. Participants may experience fatigue or lose interest as the questionnaire progresses, leading to incomplete or inaccurate answers. A good questionnaire should aim for an optimal length, typically consisting of 25–30 questions within 30 min (Sharma, 2022). Lastly, the findings from a study with cross-sectional designs like ours preclude the causal inference.

4 CONCLUSIONS

The adult residents in Taiwan had only a moderate level of IAPHL, with the highest and lowest matric-specific scores for "understanding" and "appraising" competencies, respectively. In addition, attendance to a job related to indoor air pollution and nonsmoking status were significantly associated with enhanced IAPHL. From a public health perspective, the study results may provide insights into the development of tailored educational intervention programs considering personal, situational, and socioenvironmental determinants to improve the IAPHL of community dwellers. Identification of people who do not have adequate IAPHL may help determine who should be prioritized. Exploring the effectiveness of diverse intervention measures on health literacy or conducting in-depth studies on specific populations, such as the elderly, women, and occupational exposure groups, to understand their health literacy status may provide insights for future research directions. Understanding the subjective health-literate decision-making process regarding perceptions of health risks from indoor air pollution is crucial. Thus, reinforcing health gains by providing effective health communication strategies for improving IAQ may encourage healthy behaviors through accessing, understanding, assessing, and applying IAPHL across communities. Moreover, IAQ can benefit not only from educational interventions but also from strategic public policy enhancements. Recommendations for policy improvements should be formulated to address pollution sources and reduce fake news, aligning with efforts to improve overall indoor environmental quality. Integrating public health literacy considerations into these policies can contribute to fostering awareness and understanding among the general population. A comprehensive approach can be established by combining educational initiatives with targeted policy measures to create healthy indoor environments and raise public health literacy levels.

LIST OF ABBREVIATIONS

AAPHL	ambient air pollution health literacy
CI	confidence interval
EHL	environmental health literacy
GEEs	generalized estimating equations
HLS-EU-Q	European Health Literacy Survey Questionnaire
IAPHL	indoor air pollution health literacy
IAQ	indoor air quality
Min.	minimum
Max.	maximum
$PM_{2.5}$	particulate matter with an aerosol diameter of 2.5
PM_{10}	particulate matter with an aerosol diameter of 10
SD	standard deviation

ADDITIONAL INFORMATION AND DECLARATIONS

Authors' Contributions

JLW, YHH, YCH, WHH, CCJ, PCL, MYL, and CYL designed the study and contributed to the interpretation of the results. JLW, YHH, WHH, and PCL drafted the initial manuscript. WHH, CCJ, PCL, MYL, and CYL developed the questionnaire and conducted the survey. JLW, YHH, and YCH performed the statistical analyses. PCL, WHH, and CYL revised the manuscript. All the authors reviewed the manuscript and read and approved the final manuscript.

Funding

This work was funded by the Health Promotion Administration, Ministry of Health and Welfare (110-0331-02-23-01) and by the Ministry of Science and Technology (109-2314-B-006-044-MY3). The content of this research may not represent the opinion of the Health Promotion Administration, Ministry of Health and Welfare.

Availability of Data and Materials

The datasets used and/or analyzed in the current study are available from the corresponding authors upon reasonable request.

Conflict of Interest Statement

The authors declare that they have no competing interests.

Ethics Approval

This study was approved by the Institutional Review Board of the National Chung Kung University (No. 110-213).

Consent to Participate

A video consent script, including the following information, was read to the study participants before the video interview: purpose of the study; duration of participation; description of the procedures; description of potential risks/discomfort; description of the benefits; confidentiality; contact person and procedure in case of questions regarding the study (researcher); the rights of the participant, including the voluntary nature of participation and right to withdraw anytime without penalty; the approximate number of participants. The informed verbal consent process was considered to be complete when the study participant asked no additional questions and agreed to the initiation of the video interview.

REFERENCES

Andrade, C. (2020). The limitations of online surveys. Indian J. Psychol. Med. 42, 575–576. https://doi.org/10.1177/0253717620957496

Badland, H.M., Duncan, M.J. (2009). Perceptions of air pollution during the work-related commute by adults in Queensland, Australia. Atmos. Environ. 43, 5791–5795. https://doi.org/10.1016/j.atmosenv.2009.07.050

Baker, D.W., Gazmararian, J.A., Sudano, J., Patterson, M. (2000). The association between age and health literacy among elderly persons. J. Gerontol. Ser. B 55, S368–S374. https://doi.org/10.1093/geronb/55.6.S368

Cajita, M.I., Cajita, T.R., Han, H.R. (2016). Health literacy and heart failure: a systematic review. J. Cardiovasc. Nurs. 31, 121–130. https://doi.org/10.1097/JCN.0000000000000229

Chen, Y.Y., Sung, F.C., Chen, M.L., Mao, I.F., Lu, C.Y. (2016). Indoor air quality in the metro system in North Taiwan. J. Environ. Res. Public Health 13, 1200. https://doi.org/10.3390/ijerph13121200

Cho, M., Lee, Y.M., Lim, S.J., Lee, H. (2020). Factors associated with the health literacy on social determinants of health: a focus on socioeconomic position and work environment. Int. J. Environ. Res. Publ. Health, 17, 6663. https://doi.org/10.3390/ijerph17186663

Dingle, P., Lalla, F. (2002). Indoor air health risk perceptions in Australia. Indoor Built Environ. 11, 275–284. https://doi.org/10.1177/1420326X0201100504

Dinh, H.T.T., Nguyen, N.T., Bonner, A. (2020). Health literacy profiles of adults with multiple chronic diseases: A cross-sectional study using the Health Literacy Questionnaire. Nurs. Health Sci. 22, 1153–1160. https://doi.org/10.1111/nhs.12785

Dodge, H.H., Katsumata, Y., Zhu, J., Mattek, N., Bowman, M., Gregor, M., Wild, K., Kaye, J.A. (2014). Characteristics associated with willingness to participate in a randomized controlled behavioral clinical trial using home-based personal computers and a webcam. Trials 15, 508. https://doi.org/10.1186/1745-6215-15-508

Dong, D., Xu, X., Xu, W., Xie, J. (2019). The relationship between the actual level of air pollution and residents' concern about air pollution: evidence from Shanghai, China. Int. J. Environ. Res. Publ. Health 16, 4784. https://doi.org/10.3390/ijerph16234784

Fang, L., Clausen, G., Fanger, P.O. (1998). Impact of temperature and humidity on the perception of indoor air quality. Indoor Air 8, 80–90. https://doi.org/10.1111/j.1600-0668.1998.t01-2-00003.x

Finn, S., O'Fallon, L. (2017). The emergence of environmental health literacy—From its roots to its future potential. Environ. Health Perspect. 125, 495-501. https://doi.org/10.1289/ehp.1409337

Fonseca, A., Abreu, I., Guerreiro, M.J., Barros, N. (2022). Indoor air quality in healthcare units—

A systematic literature review focusing recent research. Sustainability 14, 967. https://doi.org/10.3390/su14020967

Garcia-Codina, O., Juvinyà-Canal, D., Amil-Bujan, P., Bertran-Noguer, C., González-Mestre, M.A., Masachs-Fatjo, E., Santaeugènia, S.J., Magrinyà-Rull, P., Saltó-Cerezuela, E. (2019). Determinants of health literacy in the general population: results of the Catalan health survey. BMC Public Health 19, 1122. https://doi.org/10.1186/s12889-019-7381-1

Hou, W.H., Huang, Y.C., Lu, C.Y., Chen, I. C., Lee, P.C., Lin, M.Y., Wang, Y.C., Sulistyorini, L., Li, C.Y. (2021). A national survey of ambient air pollution health literacy among adult residents of Taiwan. BMC Public Health 21, 1604. https://doi.org/10.1186/s12889-021-11658-z

Jan, S.L., Shieh, G. (2019). Sample size calculations for model validation in linear regression analysis. BMC Med. Res. Methodol. 19, 54. https://doi.org/10.1186/s12874-019-0697-9

Jung, C.C., Wu, P.C., Tseng, C.H., Su, H.J. (2015). Indoor air quality varies with ventilation types and working areas in hospitals. Build. Environ. 85, 190–195. https://doi.org/10.1016/j.buildenv.2014.11.026

Jung, D., Choe, Y., Shin, J., Kim, E., Min, G., Kim, D., Cho, M., Lee, C., Choi, K., Woo, B.L., Yang, W. (2022). Risk assessment of indoor air quality and its association with subjective symptoms among office workers in Korea. Int. J. Environ. Res. Public Health 19, 2446. https://doi.org/10.3390/ijerph19042446

Kim, J., Jang, M., Choi, K., Kim, K. (2019). Perception of indoor air quality (IAQ) by workers in underground shopping centers in relation to sick-building syndrome (SBS) and store type: a cross-sectional study in Korea. BMC Public Health 19, 632. https://doi.org/10.1186/s12889-019-6988-6

Kishi, R., Ketema, R.M., Ait Bamai, Y., Araki, A., Kawai, T., Tsuboi, T., Saito, I., Yoshioka, E., Saito, T. (2018). Indoor environmental pollutants and their association with sick house syndrome among adults and children in elementary school. Build. Environ. 136, 293–301. https://doi.org/10.1016/j.buildenv.2018.03.056

Klepeis, N.E., Nelson, W.C., Ott, W.R., Robinson, J.P., Tsang, A.M., Switzer, P., Behar, J.V., Hern, S.C., Engelmann, W.H. (2001). The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. J. Exposure Sci. Environ. Epidemiol. 11, 231–252. https://doi.org/10.1038/sj.jea.7500165

Langer, S., Ramalho, O., Le Ponner, E., Derbez, M., Kirchner, S., Mandin, C. (2017). Perceived indoor air quality and its relationship to air pollutants in French dwellings. Indoor Air 27, 1168–1176. https://doi.org/10.1111/ina.12393

Lee, K.K., Bing, R., Kiang, J., Bashir, S., Spath, N., Stelzle, D., Mortimer, K., Bularga, A., Doudesis, D., Joshi, S.S., Strachan, F., Gumy, S., Adair-Rohani, H., Attia, E.F., Chung, M.H., Miller, M.R., Newby, D.E., Mills, N.L., McAllister, D.A., Shah, A.S.V. (2020). Adverse health effects associated with household air pollution: a systematic review, meta-analysis, and burden estimation study. Lancet Global Health 8, e1427–e1434. https://doi.org/10.1016/S2214-109X(20)30343-0

Li, C.Y., Wu, S.C., Wen, S.W. (2000). Longest held occupation in a lifetime and risk of disability in activities of daily living. Occup. Environ. Med. 57, 550–554. http://www.jstor.org/stable/27731369

Lindsey, M., Chen, S.R., Ben, R., Manoogian, M., Spradlin, J. (2021). Defining environmental health literacy. Int. J. Environ. Res. Public Health 18, 11626. https://doi.org/10.3390/ijerph182111626

Melchior, C., Oliveira, M. (2022). Health-related fake news on social media platforms: A systematic literature review. New Media Soc. 24, 1500–1522. https://doi.org/10.1177/14614448211038762

Mendell, M.J., Mirer, A.G., Cheung, K., Tong, M., Douwes, J. (2011). Respiratory and allergic health effects of dampness, mold, and dampness-related agents: a review of the epidemiologic evidence. Environ. Health Perspect. 119, 748–756. https://doi.org/doi:10.1289/ehp.1002410

Nutbeam, D. (2000). Health literacy as a public health goal: a challenge for contemporary health education and communication strategies into the 21st century. Health Promot. Int. 15, 259–267. https://doi.org/10.1093/heapro/15.3.259

Pandey, A., Brauer, M., Cropper, M.L., Balakrishnan, K., Mathur, P., Dey, S., Turkgulu, B., Kumar, G.A., Khare, M., Beig, G., Gupta, T., Krishnankutty, R.P., Causey, K., Cohen, A.J., Bhargava, S., Aggarwal, A.N., Agrawal, A., Awasthi, S., Bennitt, F., Bhagwat, S., *et al.* (2021). Health and economic impact of air pollution in the states of India: the Global Burden of Disease Study 2019. Lancet Planet. Heath 5, e25–e38. https://doi.org/10.1016/S2542-5196(20)30298-9

Pelikan, J.M., Ganahl, K. (2017). Measuring health literacy in general populations: Primary findings from the HLS-EU consortium's health literacy assessment effort. Stud. Health Technol. Inf. 240, 34–59. https://doi.org/10.3233/978-1-61499-790-0-34

Pennycook, G., Rand, D.G. (2021). The psychology of fake news. Trends Cognit. Sci. 25, 388–402. https://doi.org/10.1016/j.tics.2021.02.007

Pu, S., Shao, Z., Fang, M., Yang, L., Liu, R., Bi, J., Ma, Z. (2019). Spatial distribution of the public's risk perception for air pollution: A nationwide study in China. Sci. Total Environ. 655, 454–462. https://doi.org/10.1016/j.scitotenv.2018.11.232

Quick, B.L., Bates, B.R., Romina, S. (2009). Examining antecedents of clean indoor air policy support: Implications for campaigns promoting clean indoor air. Health Commun. 24, 50–59. https://doi.org/10.1080/10410230802606992

Raufman, J., Blansky, D., Lounsbury, D.W., Mwangi, E.W., Lan, Q., Olloquequi, J., Hosgood, H.D. (2020). Environmental health literacy and household air pollution-associated symptoms in Kenya: a cross-sectional study. Environ. Health 19, 89. https://doi.org/10.1186/s12940-020-00643-5

Schaeffer, D., Berens, E.M., Vogt, D., Gille, S., Griese, L., Klinger, J., Hurrelmann, K. (2021). Health literacy in Germany—Findings of a representative follow-up survey. Dtsch. Arztebl. Int. 118, 723–729. https://doi.org/10.3238/arztebl.m2021.0310

Sharma, H. (2022). How short or long should be a questionnaire for any research? Researchers dilemma in deciding the appropriate questionnaire length. Saudi J. Anaesth. 16, 65–68. https://doi.org/10.4103/sja.sja_163_21

Shen, H.N., Lin, C.C., Hoffmann, T., Tsai, C.Y., Hou, W.H., Kuo, K.N. (2019). The relationship between health literacy and perceived shared decision making in patients with breast cancer. Patient Educ. Couns. 102, 360–366. https://doi.org/10.1016/j.pec.2018.09.017

Sørensen, K., Van Den Broucke, S., Fullam, J., Doyle, G., Pelikan, J., Slonska, Z., Brand, H., (HLS-EU) Consortium Health Literacy Project European (2012). Health literacy and public health: A systematic review and integration of definitions and models. BMC Public Health 12, 80. https://doi.org/10.1186/1471-2458-12-80

Sun, Y., Hou, J., Cheng, R., Sheng, Y., Zhang, X., Sundell, J. (2019). Indoor air quality, ventilation and their associations with sick building syndrome in Chinese homes. Energy Build. 197, 112–119. https://doi.org/10.1016/j.enbuild.2019.05.046

Tomsho, K.S., Polka, E., Chacker, S., Queeley, D., Alvarez, M., Scammell, M.K., Emmons, K.M., Rudd, R.E., Adamkiewicz, G. (2022). Characterizing the environmental health literacy and sensemaking of indoor air quality of research participants. Int. J. Environ. Res. Public Health 19, 2227. https://doi.org/10.3390/ijerph19042227

U.S. Environmental Protection Agency (U.S. EPA) (2023). Indoor Air Quality (IAQ). https://www.epa.gov/indoor-air-quality-iaq (accessed 30 June 2023).

Van den Broucke, S. (2014). Health literacy: a critical concept for public health. Arch. Public Health 72, 10. https://doi.org/10.1186/2049-3258-72-10

VanderWeele, T.J., Ding, P. (2017). Sensitivity analysis in observational research: introducing the e-value. Ann. Intern. Med. 167, 268–274. https://doi.org/10.7326/M16-2607

World Health Organization (WHO) (2023) Air Pollution. https://www.who.int/health-topics/air-pollution#tab=tab_1 (accessed 30 June 2023).

Wright, K.B. (2005). Researching internet-based populations: advantages and disadvantages of online survey research, online questionnaire authoring software packages, and web survey services. J. Comput.-Mediated Commun. 10, JCMC1034. https://doi.org/10.1111/j.1083-6101.2005.tb00259.x

Wu, J.L., Huang, Y.H., Huang, Y.C., Hou, W.H., Jung, C.C., Lee, P.C., Lin, M.Y., Li, C.Y. (2022). Psychometric properties of a novel instrument for evaluating indoor air pollution health literacy in adults. Indoor Air 32, e13155. https://doi.org/10.1111/ina.13155

Yin, P., Brauer, M., Cohen, A.J., Wang, H., Li, J., Burnett, R.T., Stanaway, J.D., Causey, K., Larson, S., Godwin, W., Frostad, J., Marks, A., Wang, L., Zhou, M., Murray, C.J.L. (2020). The effect of air pollution on deaths, disease burden, and life expectancy across China and its provinces, 1990–2017: an analysis for the Global Burden of Disease Study 2017. Lancet Planet. Heath 4, e386–e398. https://doi.org/10.1016/S2542-5196(20)30161-3